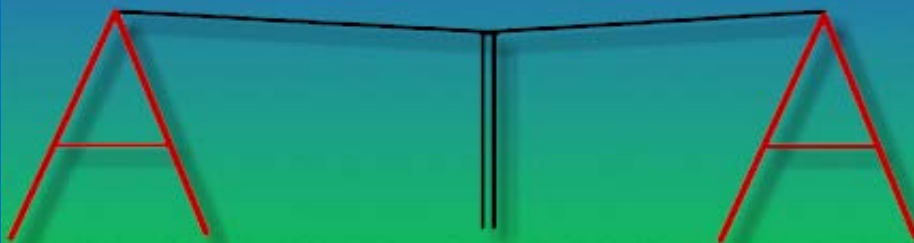


# **Antennas Made of Wires Volume 1**

***Simple & Effective***



**A Collection from the Works  
of L.B. Cebik, W4RNL**

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# **Antennas**

## **Made of Wires**

### **Volume 1:**

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## About the Author

L. B. Cebik, W4RNL, passed away in April 2008. He had written extensively about antennas and antenna modeling (as well as other electronics subjects) in most of the U.S. ham journals, including QST, CQ, Communications Quarterly, QEX, Ham Radio, 73, QRP Quarterly, Radio-Electronics, and QRPP. Besides the continuing series of antenna modeling columns he does for *antenneX* (continues through 2010), he also wrote a column for 10-10 News (An-Ten-Ten-nas) and another for Low Down (Antennas from the Ground Up). A life member of ARRL, he served as both Technical and Educational Advisor. Several years ago, LB joined the position as Technical Editor for *antenneX*.



L. B. has published over two dozen books, with works on antennas for both the beginner and the advanced student. Among his books are a basic and intermediate tutorial in the use of NEC antenna modeling software and compilations of his many shorter pieces. Some 30 of these books have been published by *antenneX* and listed in the BookShelf at our website.

He was a ham since 1954 and also a life member of QCWA and of 10-10 International. He also maintained a web site ( <http://www.cebik.com> ) on which he has placed a large collection of entries from his notebooks and publications sponsored by *antenneX*. A PhD and a teacher for over 30 years, he retired as professor emeritus of philosophy at the University of Tennessee, Knoxville. *antenneX* is/was very fortunate, indeed, to have had LB as a member of its writing team and Tech Editor for some 12 years.

I for one, lament daily at the tragic loss of one of my closest friends.

— Jack L. Stone, Publisher



## PREFACE

*it's not just wires anymore, it's an antenna!*

**W**hile numerous articles and books have described various wire antenna designs, but here is a series of new books from the works of antenna master, L.B. Cebik, W4RNL (SK). He is known the world over for his unique ideas about new ways to "bend wires" to get the most out of them. With LB's guidance, your success is practically guaranteed. It would be a rare occasion indeed that any design recommended by this author will not work as described. One can proceed with that confidence in mind.

This book is dedicated to the design, construction and use of antennas of various types of wire. The reader can save a lot of time and effort by reading these books. Then, experiment to your heart's content with an aim toward the goal of achieving the best signal for your unique environment.

With wire, antennas are very simple and easy to build at a very lowest of cost to achieve one's goal. This book will demonstrate a number of designs from conventional antenna wisdom. How satisfying is it to twist and bend wires together and make connections only to suddenly discover, ***it's not just wires anymore, it's an antenna!***

One book is not enough to describe all of the best-known designs, but we shall begin with this Volume 1 starting with some of the most simple and popular designs and gradually progress toward the more complex.

Along with some recommended wires, a pair of gloves and simple hand tools, wonders will sprout from your efforts quickly. And, with wires, such designs can be made to fit within the closest of environments. Many tips are suggested about how to make cramped spaces an asset rather than a liability—and keep your neighbors friendly as well.

We know the reader, newbie or advanced, will enjoy this book by one of the masters and have fun in the process!

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## Chapter 1: A Brief Note on Wires

**W**hile the following chapters and the various designs will usually contain the recommended types and sizes of wires, this is just a brief comment more as a caveat than anything else.

Using wires and other materials can be a matter of preference from experience, budget and the particular operating environment. Therefore, it is suggested that while the designs in this book may display recommendations, feel free to deviate, in other words: ***experiment***.

### Some things to consider:

- wire to be left on the ground should be an insulated wire
- wire isolated from anything conductive, you may use bare wire
- wire *not* isolated from anything conductive, use insulated wire
- environments subject to extreme weather, such as high winds or ice storms, heavier gauge wire may be a better choice
- use a good silicone seal on all connections
- beware of any surrounding dangers of electrical shock

### Wire measurement conversion table

Wire gauge -----	Dia. mm. -----	Dia. in. -----
0	8.251	0.3249
1	7.348	0.2893
2	6.544	0.2576
3	5.827	0.2294
4	5.189	0.2043
5	4.621	0.1819
6	4.116	0.1620
7	3.665	0.1443
8	3.264	0.1288

9	2.906	0.1144
10	2.588	0.1019
11	2.305	0.0907
12	2.053	0.0808
13	1.828	0.0720
14	1.628	0.0641
15	1.450	0.0571
16	1.291	0.0508
17	1.150	0.0543
18	1.024	0.0403
19	0.9116	0.0359
20	0.8118	0.0320

## Chapter 2: Wire Sizes and Other Materials

**R**ecent discussions about the use of various materials in antennas posed some interesting questions about the advisability of using such materials as stainless steel and phosphor bronze in different types of antennas.

Initial models that I used to explore the question all used wire diameters that were relatively large for the wavelength involved. For example, I used 0.1" (3 mm) elements for a VHF (225 MHz) antenna. For a 3-element beam showed only about 0.17 dB less gain for a stainless steel model relative to an aluminum model.

Material	Gain dBi	F-B dB	Source Z R ± jX Ohms
6061-T6 Aluminum	8.25	24.80	24.4 - j 0.8
Stainless Steel Type 302	8.08	23.65	25.0 + j 0.1

If we use only such large wire diameters relative to wavelength, the large surface area can mislead us into thinking that perhaps phosphor bronze and stainless steel are satisfactory for all antenna applications.

Of course, the question here is the electrical properties of the material, not the physical and chemical properties. Weight, corrosion, and other such factors must be considered in addition to these notes on the electrical properties of certain kinds of wire in antenna applications.

Proper tests of antenna wire types should press them toward levels of thinness relative to a wavelength that begin to show their limitations. Hence, the low HF wire dipole become a better test vehicle. It can show to some degree at what point one is better off leaving some materials alone, even if they offer some good physical and chemical properties. Materials that offer good performance when fat often reach their limits of application when thinned down.

All runs were made with a software version of NEC-2. Exact numbers may vary in the last decimal place with other programs--or if you simply choose a different

level of segmentation. 21 segments per dipole was the segmentation density used for these simple tests.

### Test 1: #14 wire dipole for 7.0 MHz

In this test, I took a resonant dipole model using lossless wire and then changed materials (from the usual list of materials) to see what the effect might be. Here is data on free space gain, source impedance, and efficiency for a number of materials. 6063-T843 and 6061-T6 are common aluminum alloys used mostly in tubing that we find in HF and VHF beam antennas. The "E<sub>y</sub>" notation is common computerese for "x 10 to the y power." Note where the list changes from E7 to E6.

Conductivity S/m	Material	Gain dBi	Source Z R ± jX Ohms	Eff'y %
Perfect	(lossless)	2.13	72.2 + j 0.1	100.00
6.2893E7	Silver	2.04	73.7 + j 1.4	98.09
5.8001E7	Copper	2.04	73.7 + j 1.5	98.01
3.7665E7	Pure Al.	2.02	74.1 + j 1.8	97.54
3.0769E7	6063-T832	2.01	74.3 + j 1.9	97.28
2.4938E7	6061-T6	2.00	74.6 + j 2.2	96.98
1.5625E7	Brass	1.96	75.2 + j 2.7	96.19
9.0909E6	Phosphor Bronze	1.91	76.2 + j 3.6	95.02
1.3889E6	Stainless Steel 302	1.55	83.0 + j 8.8	87.53

Note that even silver (untarnished) shows a 2% efficiency loss and a 0.1 dB gain loss relative to perfection. Even if silver were cheap, I would not waste it on a wire antenna of this kind, given the performance of copper. Also note the larger step drops as you move below pure aluminum on the list.

### Test 2. 4 MHz Wire dipole

The second modeling test took a different approach. With a 4 MHz wire dipole, what is the minimum AWG wire size necessary to achieve 1.75 dBi free space gain? Each change of material brought about a re-resonating of the antenna. I chose 1.75 dBi as the threshold of acceptability because this value resulted in wire sizes on the available list of automated selections in the program used.

Material Wire	Source Z R ± jX Ohms	Eff'y %	Gain dBi	Length Meters	AWG Size
Stls. Steel	78.3 + j 0.1	91.64	1.75	36.36	# 8
Ph. Bronze	78.3 - j 0.4	91.75	1.75	36.46	#16
Brass	78.1 + j 0.1	92.06	1.77	36.50	#18
6061-T6	78.1 - j 0.0	92.08	1.77	36.52	#20
6063-T832	77.5 - j 0.6	92.85	1.81	36.52	#20
Pure Alum.	78.3 - j 0.5	91.88	1.76	36.53	#22
Copper	78.4 - j 0.5	91.76	1.75	36.55	#24
Silver	78.2 + j 0.4	92.08	1.77	36.57	#24

First, the gain numbers are not exactly 1.75 dBi, but the value closest to it on the high side yielded by the smallest wire size that would yield at least 1.75 dBi. Second, within those limits, notice that there is an equality of source impedance and efficiency for a specific gain level. What differs among the antennas is the length necessary for resonance and the wire size.

Third, notice the wide range of antenna sizes in the list. As the wire grows thin for a given wavelength, the material losses play an increasing role in performance. If we use a conservative minimum gain of 1.75 dBi free space as the limit of acceptability, stainless steel--the strongest of the wires--would require a #8 AWG size to meet the standard. The electrical performance is at odds with its physical advantages.

Phosphor bronze is marginal under this test, requiring a minimum size of #16 AWG. If we set the gain standard higher, perhaps at 2.0 dBi free space, then phosphor bronze might fail to meet the electrical standard at an acceptable diameter.

Whether phosphor bronze will meet a given standard or whether the gain level obtainable with an available diameter of phosphor bronze wire is acceptable to a user is not a decision that can be made here. Instead, this note and the tests reported in it yield the advice not to misapply test results, not even these. The selection of wire material requires that you set standards of performance for a given application. Then, model (or build) your antenna using the range of

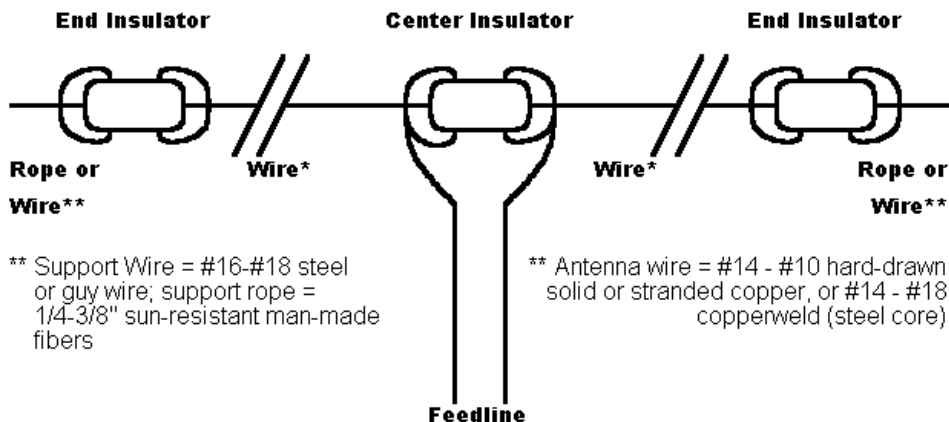
possible materials to see if each material meets the standard. When the diameter of the wire becomes thin enough relative to a wavelength, you may encounter a threshold situation in which some materials simply fail the electrical test.



## Chapter 3: Why Use Wires?

**F**or lower HF-band antennas, the reason for using wire antennas is simple: they work; they are cheap; and there is nothing better for most of our wallets. Understanding the dollar and work economy of wire antennas only requires that we look at Figure 1, a simplified sketch of typical wire antenna construction. There is not a lot of mechanical complexity in a wire antenna of the sorts we use on 80, 40, and 30 meters.

Fig. 1. Basic Wire Antenna Construction



The more difficult answer to our question involves understanding what wire antennas do and why and how they do it. In fact, most hams have very little idea of how wire antennas work. Of course, once we master wire antennas, we have also mastered the hardest part of all antennas, so perhaps it pays to go back to basics and take a closer look at these marvels of simplicity.

After getting a few terms squared away, we shall look at three types of linear (straight-line) wire antennas: a. the center-fed wire; b. the off-center-fed wire, and c. the end-fed wire. It would be nice to add some loops, fans, fractals, and wire beams to our agenda, but there is so much to say about these three simple antennas, that the fancy wires will have to await another day.

I am always amazed by how many wrong things we teach new hams to believe about antennas. Hence, I have no choice but to begin all over again. Inevitably, I shall repeat things you already know, but that is necessary to provide a framework for a few things you may not yet have encountered. For example, antennas do not radiate, at least not in the sense most folks think about radiating. For example, that 80-meter dipole you are using on 40 meters is no longer a dipole. For example, no matter what shape you make a horizontal antenna, the elevation angle of maximum radiation will change hardly at all. For example, as I lower a resonant half-wavelength dipole below a height of a half wavelength, the feedpoint impedance will exceed 75 ohms part way down and be lower than 75 ohm part of the way. If these teasers have not attracted your attention, then you just do not like wire.

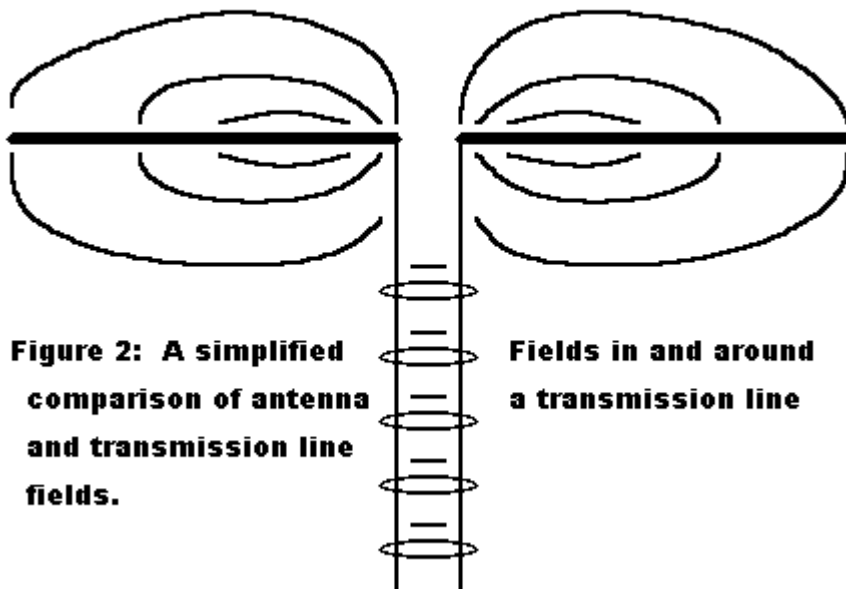
### **The 1/2 Wavelength Resonant Center-Fed Dipole Wire Antenna**

We are often taught that antennas are special devices, transducers that convert radio frequency alternating current energy into radiating electromagnetic fields. This teaching is only relatively true: antennas do the job better than most other electronic devices, but they all try. In fact, "conversion" is not really a precise word at all. Every instance of electrical energy has a field, and every field has associated electrical energy.

Moreover, antennas do not radiate outward in that sparky sense which we find in cartoons. Rather, they permit fields to expand from the wire without limit. A transmission line can be thought equally 1. as a waveguide confining electromagnetic fields or 2. as a conveyor of electrical energy from the source to the load. Figure 2 takes a field perspective on the transmission line and antenna

situation. And if you do not believe electronic components radiate, think about why iron and ferrite toroidal cores are all the rage in RF circuitry.

### **Fields (power flow) of a half-wave dipole**



**Figure 2: A simplified comparison of antenna and transmission line fields.**

**Fields in and around a transmission line**

All of this preamble brings us to the  $1/2$  wavelength resonant center-fed dipole antenna. By shortening the name of the antenna to "dipole," we can make most new hams believe that it is the most basic antenna of all. When we give the antenna's full pedigree, its true nature appears: it is a rather sophisticated and complex device. To be certain we are all on the same wavelength, let's review what each part of the name means (see Figure 3).

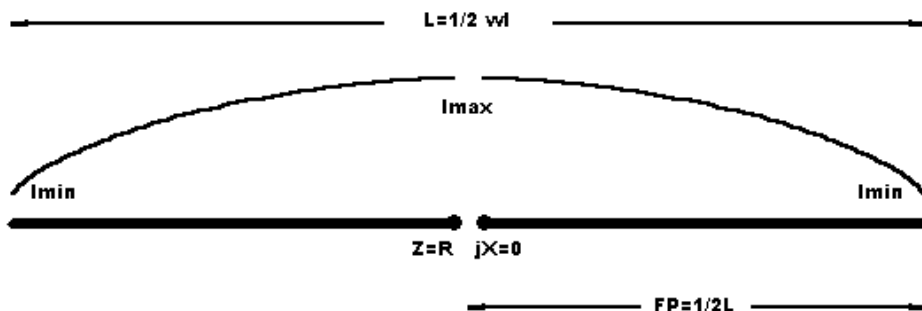


Fig. 3

### The Half-Wavelength Resonant Center-Fed Dipole Antenna

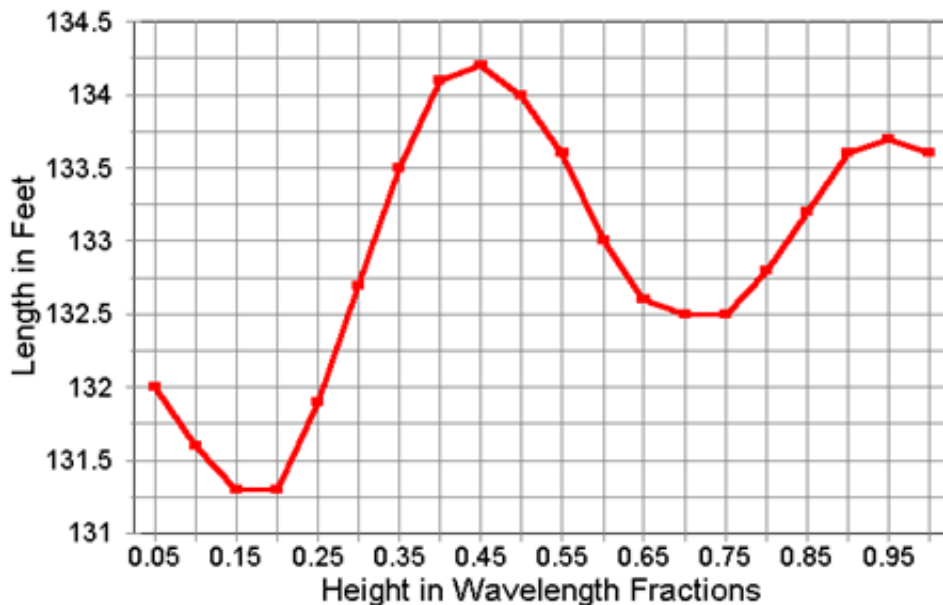
1. Dipole: the antenna is a dipole because it has two "poles," that is, regions of the antenna where the current goes from maximum to minimum.
2. Center fed: The antenna is fed at its exact center.
3. Half-wavelength: the antenna is approximately 1/2 wavelength long.
4. Resonant: the feedpoint impedance,  $Z$ , which is ordinarily composed of resistive and reactive components ( $R \pm jX$ ), is purely resistive.

What we think we know about dipoles is not much, but then we seem not to think we need to know much. The proper length in feet of a half-wavelength resonant wire dipole is  $468/F$  in MHz, and the feedpoint impedance is close to 70 ohms, with some decrease as we lower the antenna height. If you are content to live in the clouds, these old saws are fine; if you require more precision in your understanding, these bits of tradition do not live up to a half truth.

The following information is predicated on NEC-2/4 models, which means that they do not account for the terrain slopes in your area or the ground clutter in your yard. However, they are relatively accurate, even when translated to other frequencies, since antenna heights above ground are given as fractions of a wavelength. My examples will use #14 copper wire, so adjust longer for thinner wire and shorter for fatter wire.

## Dipole Length vs. Antenna Height

3.6 MHz Dipole: #14 Copper



## Dipole Length vs Antenna Height

3.6 MHz Dipole: #14 Copper

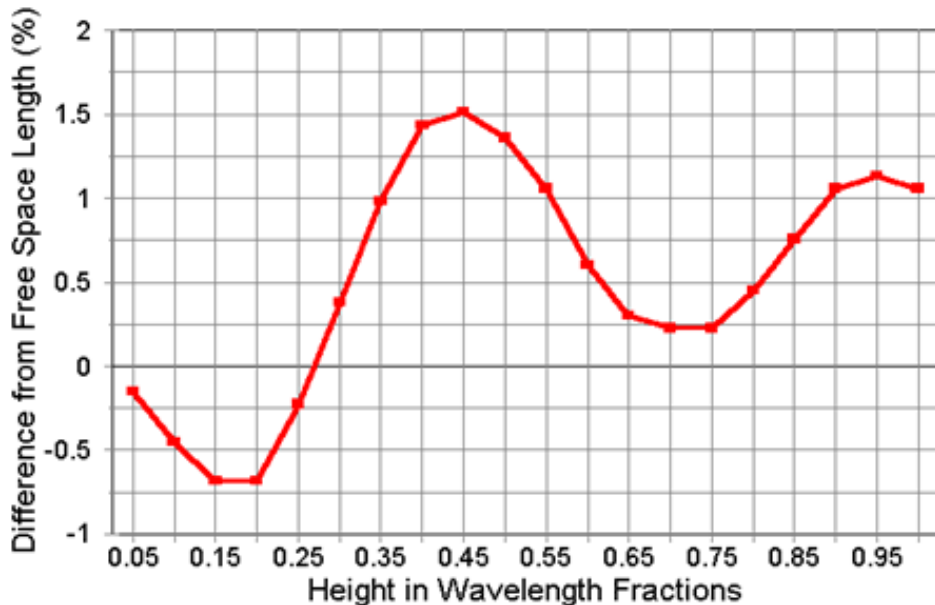
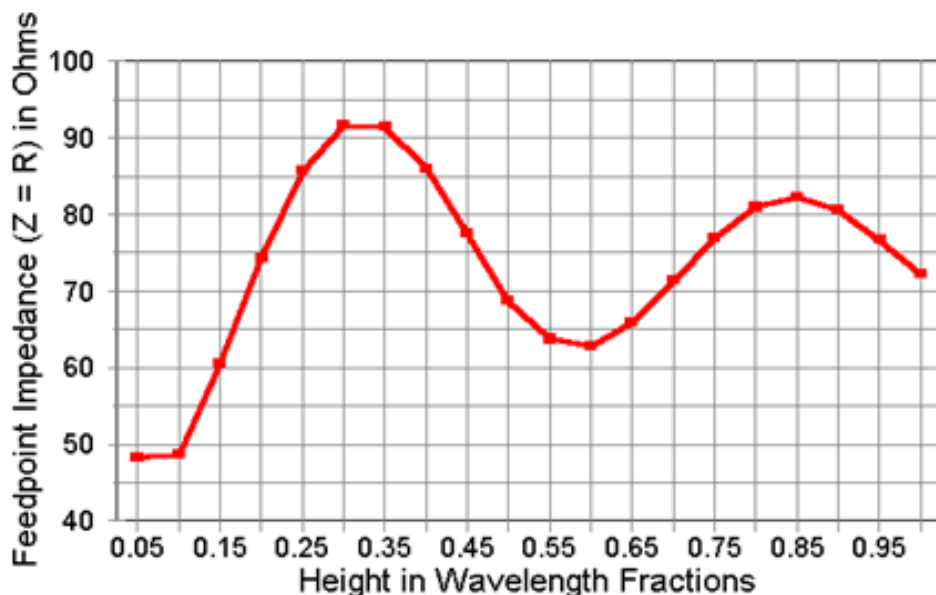


Fig.4

1. The length of a resonant half-wavelength dipole never gets down to the formula. See Figure 4. But it does vary by a total of about 3' at 3.6 MHz as you change height above ground from 1/20th of a wavelength to a full wavelength. Precise resonance is not significant to the wire's performance as a radiator, but it is nice to know where resonance really is.

## Feedpoint Impedance vs. Antenna Height

3.6 MHz Dipole: #14 Copper



## Feedpoint Impedance vs. Antenna Height

3.6 MHz Dipole: #14 Copper

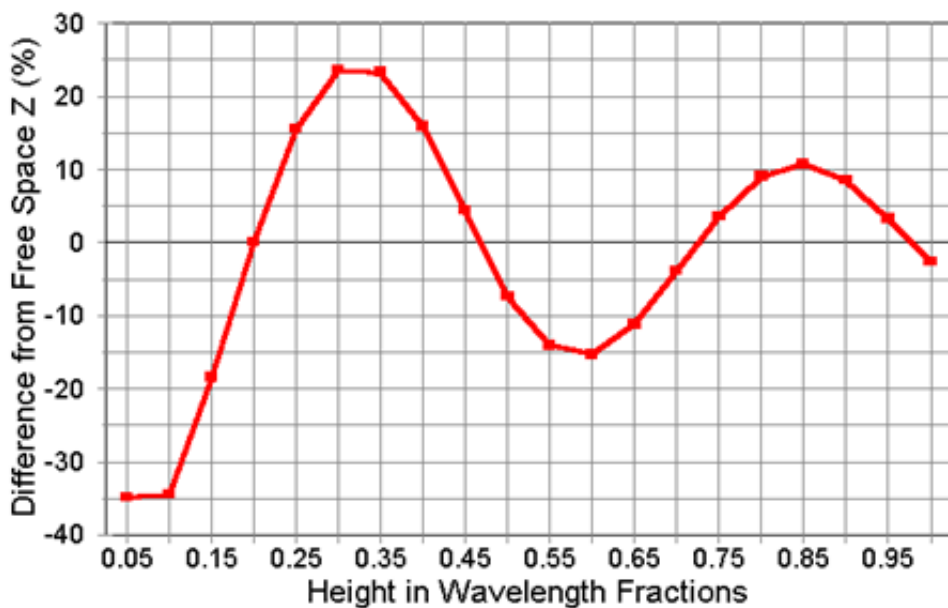


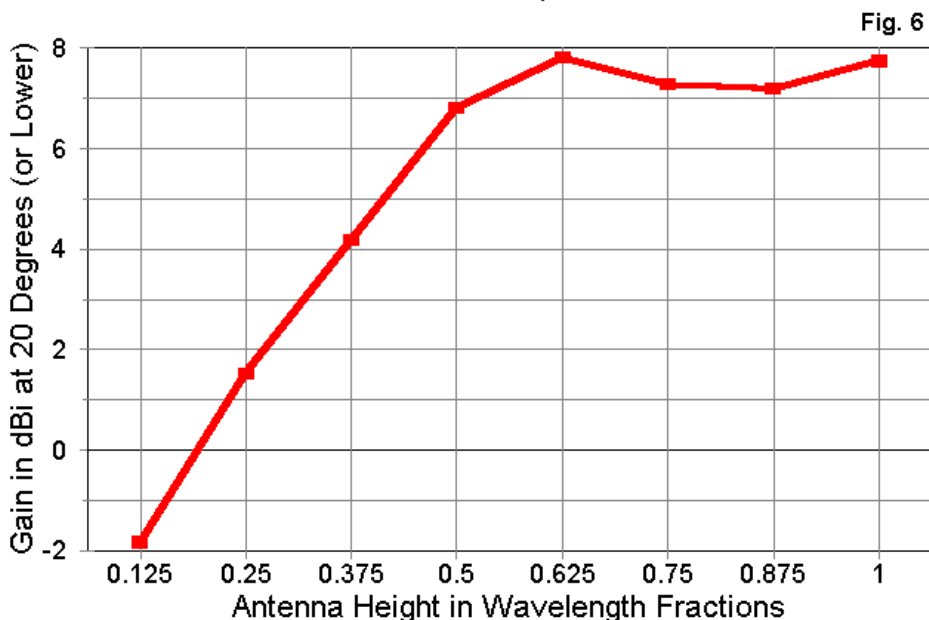
Fig.5

2. The feedpoint impedance at resonance also varies with height, going well above and well below the standard 70-ohm value as we move from 1 wavelength downward. See Figure 5. Again, your ground clutter may obscure this curve, but you can now see how the progression goes.

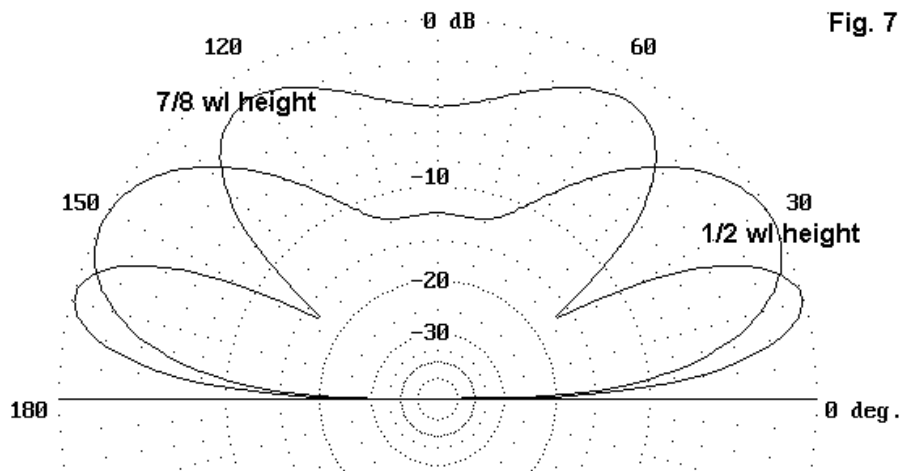


## Gain @ 20-Degree TO vs. Antenna Height

### 40-meter Dipole



3. We all believe that low-angle radiation is important to making contact with distant stations. How well does a low dipole do? See Figure 6, a 40-meter dipole. (Remember, we can translate the numbers to other frequencies, since heights are in units of a fraction of a wavelength.) The resonant half-wavelength dipole begins to do quite well as we increase its height from  $3/8$  wavelength to  $1/2$  wavelength. (Higher-angle radiation continues to dominate, which is why some folks prefer certain kinds of loops or beams for quieter DXing.) Note the dip in gain around the  $3/4$  wavelength height point. As we move an antenna upward, the lobe structure changes, and new lobes appear, often straight up.

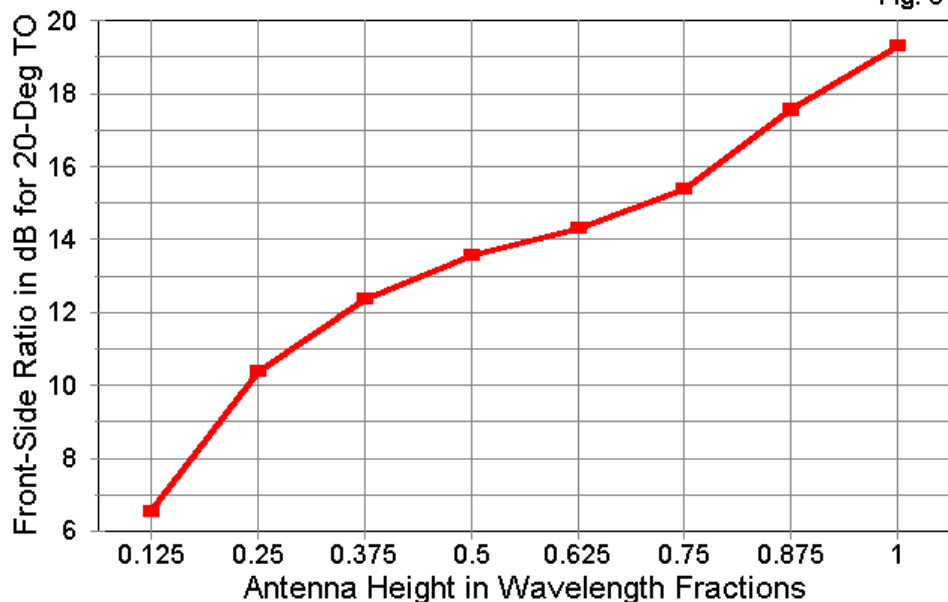


See Figure 7, which compares the elevation pattern of a dipole at 1/2 and at 7/8 wl. Much of the wire's energy at 7/8 wl is aimed at higher angles, nice for locals, but less helpful for DX.

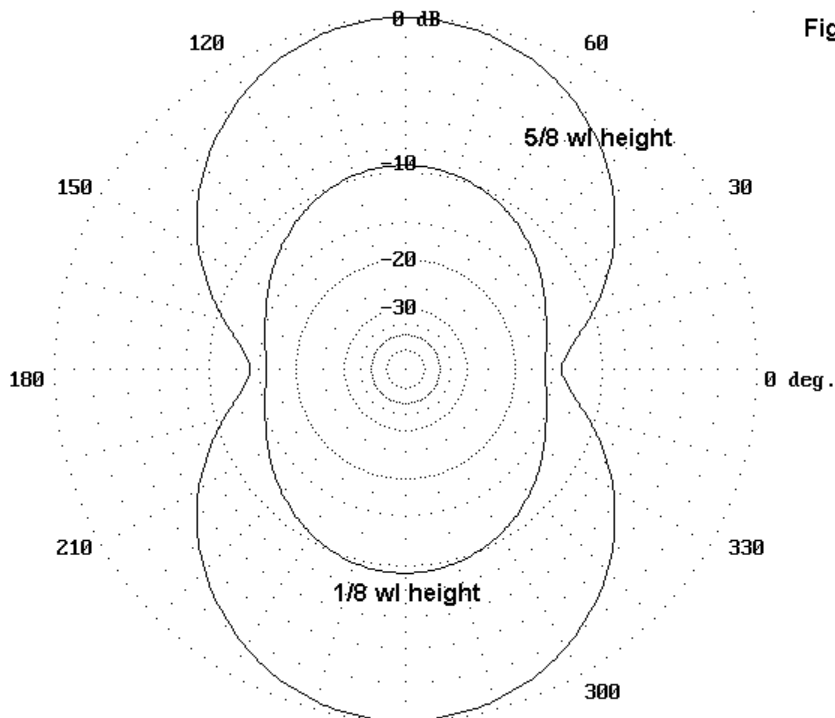
## Front-side Ratio vs. Antenna Height

### 40-meter Dipole

Fig. 8



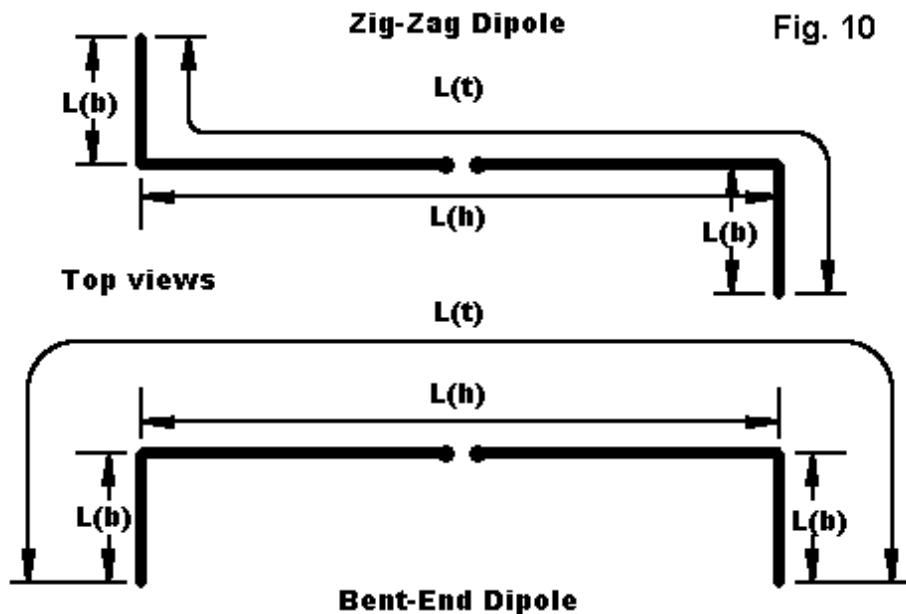
4. The traditional figure-8 pattern we associate with dipoles is mostly an illusion at low antenna heights. Figure 8 provides a graph of the front- to-side ratio of dipoles as we increase antenna height. Only above about 1/2 wavelength does the peanut shape of good side rejection appear. You do not need an inverted Vee at low heights on the low HF bands to have omnidirectional radiation; the dipole will do just fine. See Figure 9 for paired azimuth patterns at 22 degrees elevation for a graphic display of this fact.



All this must mean that the dipole is a pretty bad antenna, right? **WRONG!** The resonant half-wavelength dipole, even at relatively low antenna heights competes very well with everything folks have invented to compete with it. And usually at a fraction of the cost. Let's look at only two examples of the antenna's competitiveness.

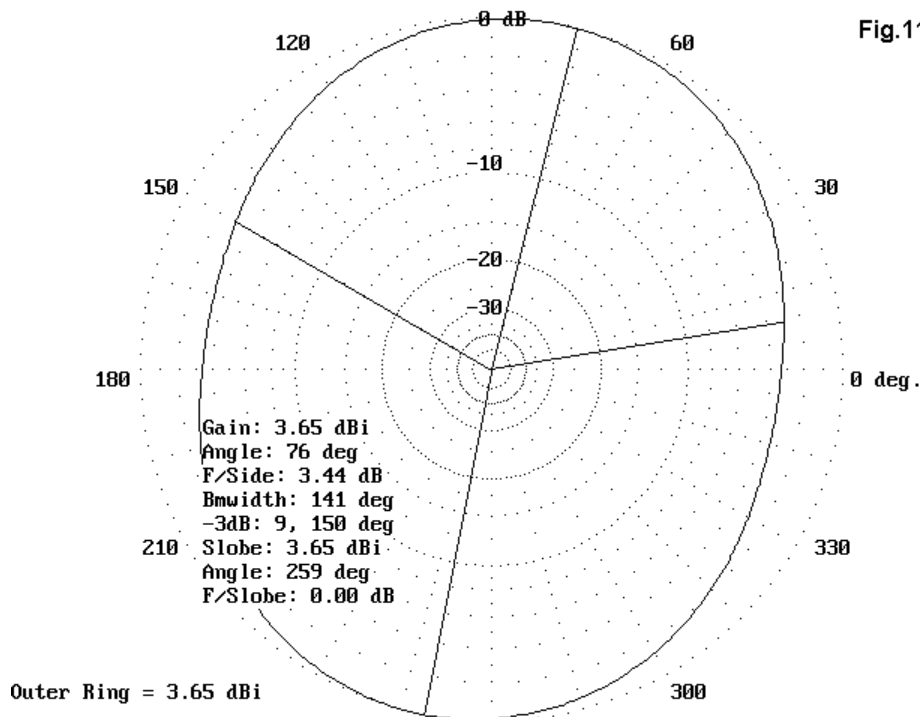
Most dipole competitors demand that you place their antennas just so or the maker will not be responsible for the performance. Already I am suspicious, because with an ordinary dipole, you can twist and turn as necessary and still have almost all of the dipole's performance. There are two ways of bending a

dipole, one a bit better than the other. See Figure 10. We can bend both elements in the same direction, whether down or to the same side. However, we lose a little of the antenna's radiation this way due to cancellation. The problem is insignificant until the horizontal main part of the element approaches 70% or less of the full length of the dipole.



Zig-zagging the wire horizontally maintains most of the antenna's radiation more efficiently, but at a cost, as shown in Figure 11. The antenna pattern tilts toward the outside corners of the wire. Remember, though, that one person's cost is another person's profit. Suppose you can almost but not quite get the main lobe of your dipole broadside to Europe. Perhaps you can create a zig-zag that will move the pattern without requiring that you move the trees in your yard.

Fig.11



Of course, you can Vee the dipole in any direction, or slope the whole wire down a hill. In estimating the probability that the antenna will still act like a dipole, just be very honest with yourself. Ask yourself, "Does the antenna still look like a dipole?" If the answer is an honest, "Yes," then your likelihood of good dipole performance is high.

And, do **NOT** sell the performance of a dipole short. Top-wire-height for top-wire-height, among competitive wire antennas, the dipole can make a case for itself as top dog. Figure 12 displays the outlines of 5 antennas. One is our old friend the half-wavelength resonant center-fed dipole. Three are loop antennas often

proposed as alternatives to the dipole. All four are shown as side views, face-on to the antenna wire. The last is a simple wire Yagi, thrown in because it makes use of about 1 wl of wire, the same as the loops. (Incidentally, my model of this #14 copper wire antenna for 40 meters has a driven element 66' long, a reflector 70' long, and a spacing of 20', with a feedpoint impedance close to 50 ohms.)

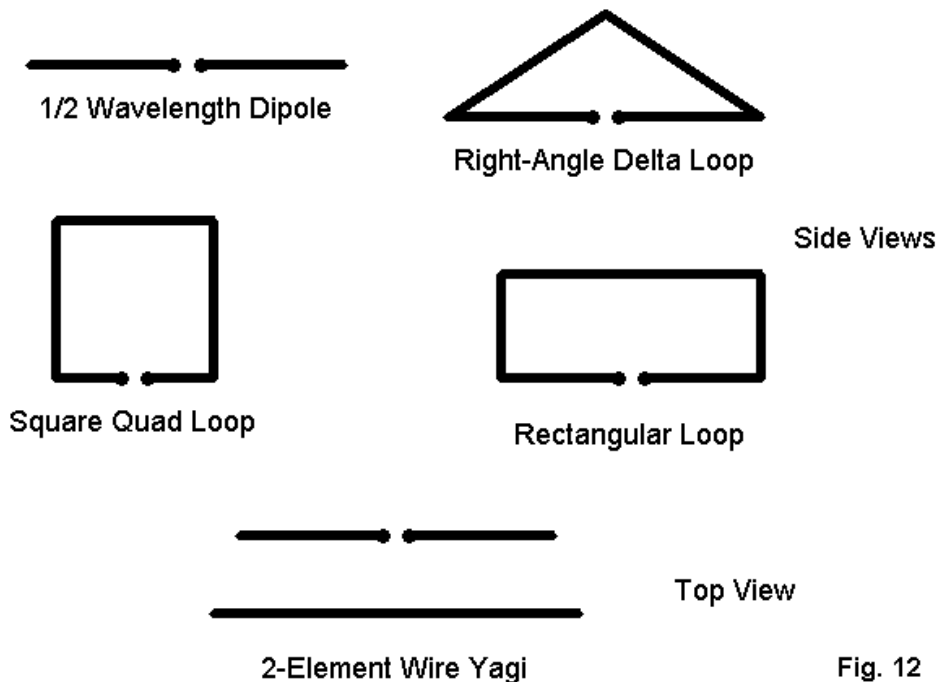


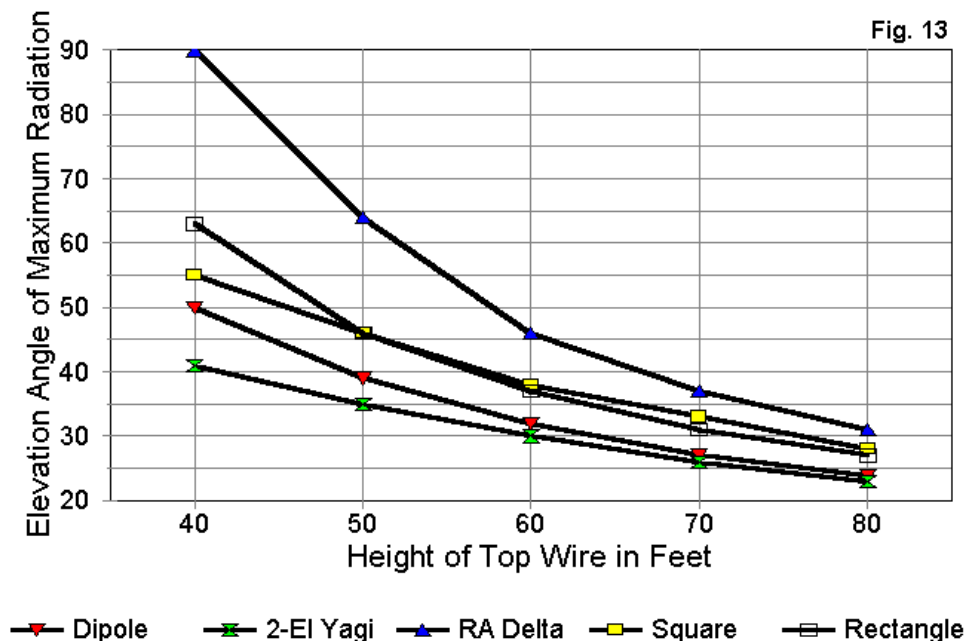
Fig. 12

The rules of the following exercise are simple: all the antennas have their top wires (or the apex of the triangle) at the same height. This is based on the premise that with low wire antennas on the lower HF bands, we put them just as high as we can get them, not at some theoretical height.

## 40-Meter Wire Antenna Take-Off Angles

### Dipole & Loop Angles of Max. Radiation

Fig. 13



On these terms, Figure 13 tells an interesting story. The elevation angle of maximum radiation of the right-angle delta is highest because so much of the high-current high-radiation part of the antenna is so low compared to the top height. The square and rectangular loops have comparable performance, better than the triangle, but worse than the dipole. In fact, the only antenna of the group with a consistently lower elevation angle of maximum radiation is the wire Yagi. Of course, the Yagi maintains a special parasitical relationship between elements that tends to hold the elevation angle of maximum radiation lower.



In the end, then, the only good reason for choosing one of the loops, vertically oriented, but fed as horizontally polarized antennas, is because one lacks the full length needed for a dipole at the top height available. (Feeding the loops as vertically polarized antennas is another matter calling for another full session or a chapter in ON4UN's book on low band DXing.) The dipole holds its own and surpasses many of its competitors.

## **The Center-Fed "Dipole" on All Bands**

Dipoles as resonant antennas are monoband affairs. To convert an 80-meter dipole to an all-band antenna (sometimes called a "doublet," but no longer a dipole except on one band), throw away the coax (or do not buy it in the first place). Run 450 ohm parallel feedline (or 300 ohm line, if that is more convenient) to an antenna tuning unit (ATU) and work all bands. This is an old and very successful tradition among hams.

What you can expect for performance at heights between 35' and 50' is shown in Chapter 7. See that Chapter for the contents of Figure 14. The higher the band, the higher the antenna in terms of fractions of a wavelength at the operating frequency--and hence, the lower the take-off angle. The 80-meter oval breaks up into an increasing number of lobes, and the gain in the strongest lobes increases. On 10-meters, it exceeds 10.5 dBi, but not broadside to the antenna wire. Patterns for 35' and 50' are shown, with the higher wire height being better, but only marginally so above 30 meters.

Installing an all-band doublet requires one of two things: either careful planning to set the main lobes where you want them on the bands of special interest, OR a willingness to take what you get based on the fact that you have only two tall supports. (If you have three supports, put up two or three of these antennas facing different directions and use an antenna switch for the strongest signal. They are cheap antennas!)

The exact length of the antenna no longer matters within broad limits, since the ATU will match to the parallel feedline with quite decent efficiency. I recommend a balanced ATU, using either a Z-match (for low power) or one of the pre-SSB inductively coupled units once so popular in handbooks. With a basic antenna like this, get back in touch with coupling basics as well.

Suppose you do not have 135' of space between supports but still want to work 80 meters and up. Try the 102' doublet. Again, exact length is unimportant, since we shall use parallel feedline and a balanced coupler. (That is why we do not call it a 'G5RV' here; 100' was a popular length long before Gil put his head on the chopping block trying to help some coax users effect an easier match on pre-WARC bands.) The 102' doublet is at least 3/8 wl long on 80, which makes it a reasonably efficient radiator there--and a very good one on all bands above 80.

See Chapter 8 for the contents of Figure 15, which tells the story, again at 35' and 50' heights. Note that compared to the longer 135' doublet, the 102' doublet expands its lobes more slowly, since it is shorter in terms of number of wavelengths long at each frequency. However, the gain is comparable on the upper bands. Ignore any differences under a dB. Once again, you can preplan the lobes by where you set your supports or you can accept what you get, or you can build more than one facing this-a-way and that-a-way and switch to the stronger signal.

In Figures 14 and 15 you have a compendium of patterns to establish your baseline expectations of these two popular multiband antenna arrangements. Your terrain and ground clutter will, of course, modify the reality you experience, but not so much in most cases, that the patterns are invalidated. Keep them as a reference file for future antenna thoughts. Thoughts like: "Gee. 10+ dBi gain on 10 meters with a hunk of wire no more than 3 or 4 wavelengths long. Wire is not such a bad option after all."

## **Off-Center-Fed Wire Antennas**

A wire antenna is cheap and easy. Buy a roll or two of #14 stranded antenna wire from Radio Shack or similar outlet. Or buy some copperweld from someone as reputable as the Wireman. Get two end insulators and some UV resistant dacron rope to support the ends. Buy a center insulator or try one of the ladder-line grabbers from EMTech. Purchase some good quality 450-ohm parallel feedline from a good outlet. Total cost: \$30 to \$40 dollars or so.

The next question for someone like me who wants to make a buck is this: "How can I sell these materials at a larger profit?" One good answer is to advertise them as convenient: everything you need in one place and package.

Now here is a bad answer: combine some trivial statements with some questionable statements that are hard to disprove, and add some easily obtainable rave notices from users who have never before used even a half-decently constructed wire antenna. The result: instant success, but I hope a batch of nightmares occasioned by twinges of conscience. Unfortunately, this is the impression that the off-center-fed wire antenna scene left me with after doing my own modeling investigations.

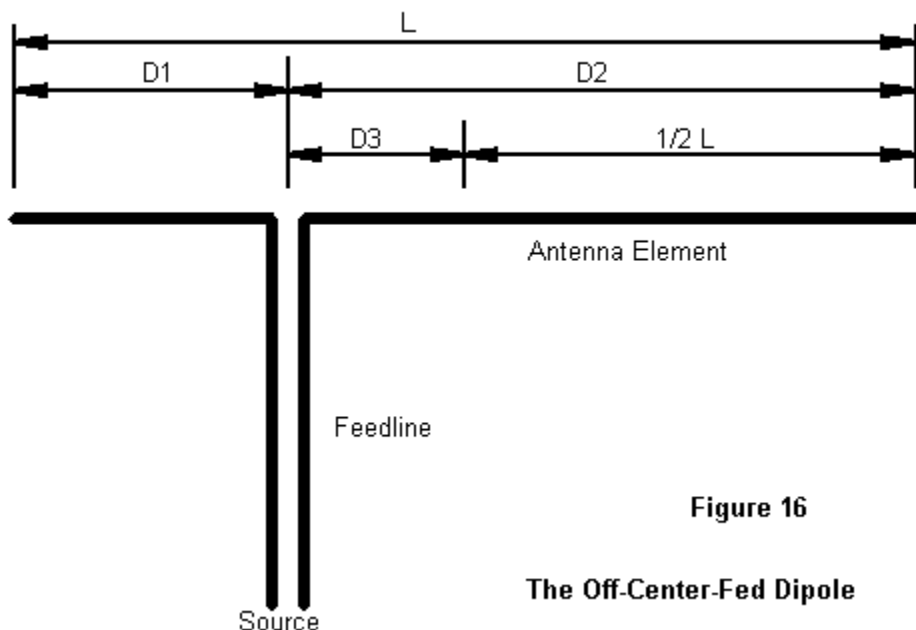
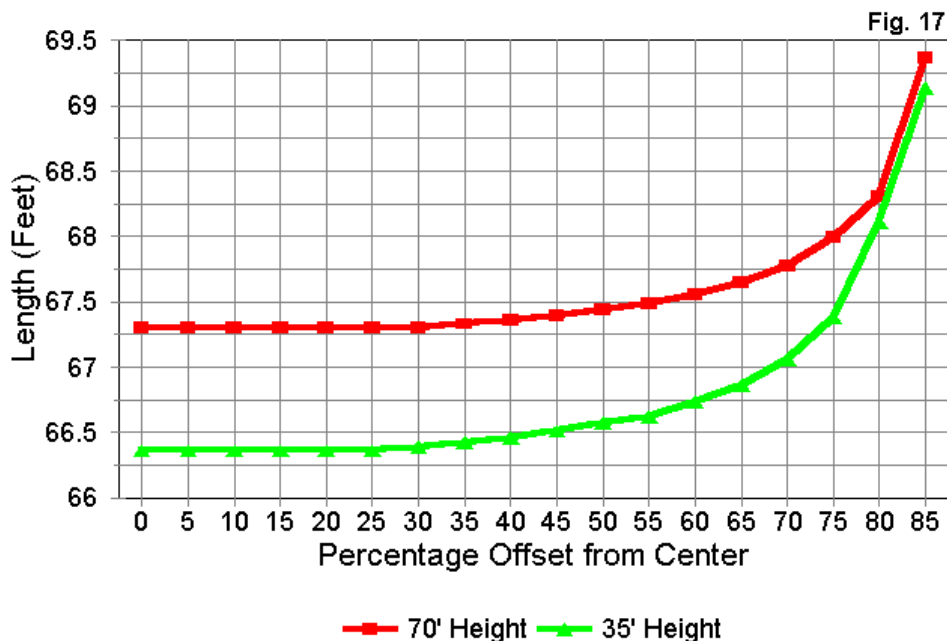
**Figure 16****The Off-Center-Fed Dipole**

Figure 16 shows the general layout of an off-center-fed half-wavelength wire antenna. As is the case with resonant center-fed dipoles, formulas for cutting the antenna abound--and occasionally work for someone. However, they are as imprecise as ever, so I shall not even list them. Instead, let's look at some results of modeling off-center-fed (OCF) antennas at 7.15 MHz.

## 1/2 WL Off-Center-Fed #14 Cu Wire

Off-Center Feed vs. Length at 7.15 MHz

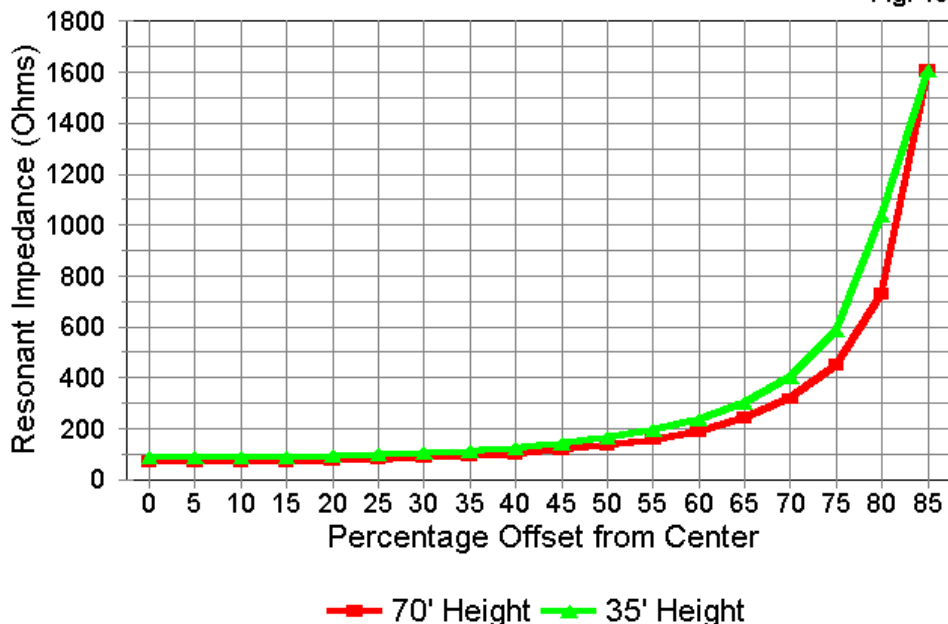


1. As shown in Figure 17, the resonant length of an OCF varies both with the antenna height and the distance from center it is fed. Hence, there is no magic length for an OCF.

## 1/2 WL Off-Center-Fed #14 Cu Wire

### Off-Center Feed vs. Z at 7.15 MHz

Fig. 18



2. Two popular points of feeding an OCF are the 100 ohms and the 300 ohms points. These points exist only if we do not model the feedline attached to the antenna wire. As Figure 18 demonstrates, these points vary considerably as antenna height is varied, even if the antenna is resonated for each test point. Notice that the hypothetical 300 ohms feedpoint occurs on a quite steep portion of the curve, and actually hitting this point is a test of luck, not skill. Hitting something close to 100 ohms is easier, but something of an illusion.

The reason I call the feedpoints illusory is that the feedline of an OCF will always be unbalanced. Therefore, it becomes a part of the antenna, at least to the degree that the feedline radiates. A large portion of the feedline currents are equal and opposite, so the feedline contributes only in small ways to overall radiation, but even a little radiation will throw the anticipated impedance point well off its mark.

3. The resonant lengths of an OCF on even harmonics are different than the resonant length of an OCF on its fundamental frequency of operation. The result is an antenna that exhibits considerable reactance at harmonics of the fundamental.

To create an OCF that provides a reasonable match to coax at the fundamental and even harmonics requires some significant efforts to smooth out the impedance problems. It is possible to do this advertently or inadvertently. B&W offers a doublet with a coax match on all HF bands by the express use of a parallel resistance across the feedpoint. This resistive element trades loss (around half power) for convenience, a trade that may fit military QRO needs, but which is not especially apt to QRP operations. It is also possible to insert matching or isolating elements at the feedpoint, elements which one may never realize are as lossy on some bands as B&W's resistor. The safest rule of thumb to follow appears to be this: if the match claim is too good, the matching system likely ain't.

4. Feedline radiation contributes little to the radiation pattern of the OCF on most frequencies. Most modeling studies of feedline radiation are flawed, because they assume that the feedline or the jacket of a length of coax is as much a part of the antenna element system as the main wire itself. This is easily disproved by the number of folks who successfully run coax to dipoles without a balun. Only under certain conditions, usually involving the angle between the wire and the feedline, does significant energy become coupled to the outside of a coax feedline.

For the OCF, the only way to model the system required modeling both the antenna wire and the parallel feedline. This produced very large models with long calculation periods. Nonetheless, the results showed a little modification of the basic patterns on some harmonics, but likely less than yard clutter was likely to induce.

Well, then the OCF is a bad wire antenna, right? Wrong, again! But, let us start all over again. Begin with a 135' long piece of wire, or thereabouts. Feed it off center--far enough off to be convenient to your shack but not so far off that you are nearly end-fed. Note that convenience to the shack is likely the best guide to the feedpoint. Use 300 ohm or 450 ohm feedline with no isolators, baluns, transformers, "special couplers," or other devices. Bring the feedline to a balanced tuner. Now operate. What can you expect?

See the APPENDIX that follows in this Chapter for the contents of Figure 19, which presents a compendium of patterns for a 135' OCF model fed about 50' from one end (D1) and 85' from the other (D2) about 35' above average ground. Some patterns will differ as the feedpoint is drawn farther away from center, since the lengths on either side of the feedpoint will approach or depart from special relationships. (For example, on some band, the off-center feedpoint may approximate a full wavelength antenna fed  $1/4$  wl in from one end. This would be true for one possible feedpoint value, but not for others.) Feedpoint values shown are ballpark values and should not be used for precise guidance, since they do not take into account the effects of feedline radiation.

The patterns for multiband use of the OCF are not vastly different from those for the center-fed doublet of the same length, except where the special length relationships may be in effect on upper bands. Gain is within a dB of that for the doublets. (Note that calling the antenna a "beam" or even "better than a beam" is simply not justified, since it produces only what one expects a wire antenna to produce, given length and frequency.)

The bottom line on the OCF is that it is a highly usable wire antenna with multiband capability. Its most efficient performance is likely to result from the



simplest possible construction. The performance is plenty good for a wire antenna of its length, but more than good wire performance is unlikely. It will remain unlikely so long as detailed modeling set-ups and labs tests remain hidden, if they exist at all, and as long as what does exist falls into the realm of advertising hype.

### **Let's End With the Zepp**

We have fed in the middle. We have fed to the side. Let's now take the final step and feed at the end. The antenna has been called the Zepp, Zeppelin, or end-fed Zepp. (The last arose when some writers called the 135' doublet a "center-fed Zepp.") Initially, the antenna was just a long piece of wire, end fed and trailing out the rear of the zeppelin. Feeding was relatively easy with direct connections to the output tanks of high impedance tube amplifiers. Ground operators added feedlines and produced the antenna that appears in Figure 20. Some argue on theoretical grounds that the antenna cannot work, but folks keep on building and successfully using this odd little antenna that never wants to get near to a piece of low impedance coax.

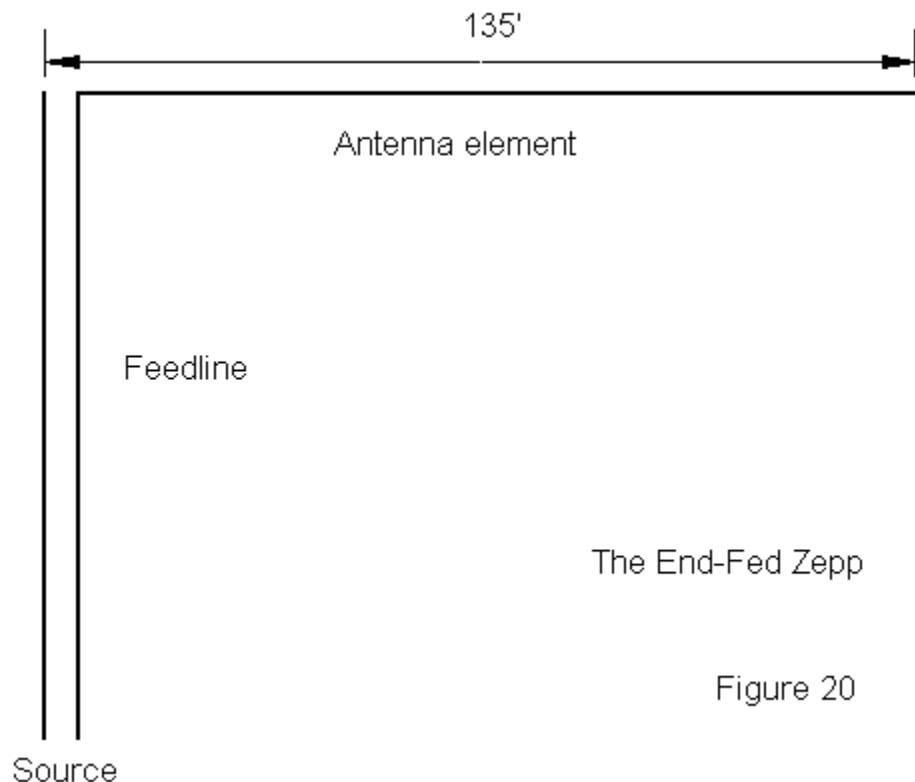


Figure 20

Actually, the antenna wire part is simple. It is a half wavelength of wire on its fundamental frequency, and the current distribution is identical to that of a center-fed antenna of the same length. The low-current, high-voltage feedpoint presents a very high impedance, requiring the use of parallel feedline.

How can you feed an antenna when one side of the line is connected to nothing and the other is connected to an antenna of finite length? The lines must be

radically unbalanced! Actually, the imbalance is not at all severe. First, the connection to nothing is not to absolute nothing, so the end of the open side of the line exhibits an extremely high but finite impedance. Likewise, the connected side of the line sees a super high impedance--and two highs make a pretty good balance.

Pretty good, but not perfect. However, precisely the imbalance remaining on the line--which yields some minor line radiation--permits the antenna to be matched at the shack end of the feedline. If the balance had been perfect, the feedpoint impedances on most bands would consist of thousands of ohms of resistance combined with thousands of ohms of reactance. Under these conditions, the impedance along most of the feedline would look like a more extreme version of Figure 21. The reactance would be low for much of each half-wavelength of line, but the resistance would be even lower, with values less than 1 ohm in many instances.

## R +/- jX Along a 450-Ohm Line

102' Dipole; 30 Meters; 50' Height

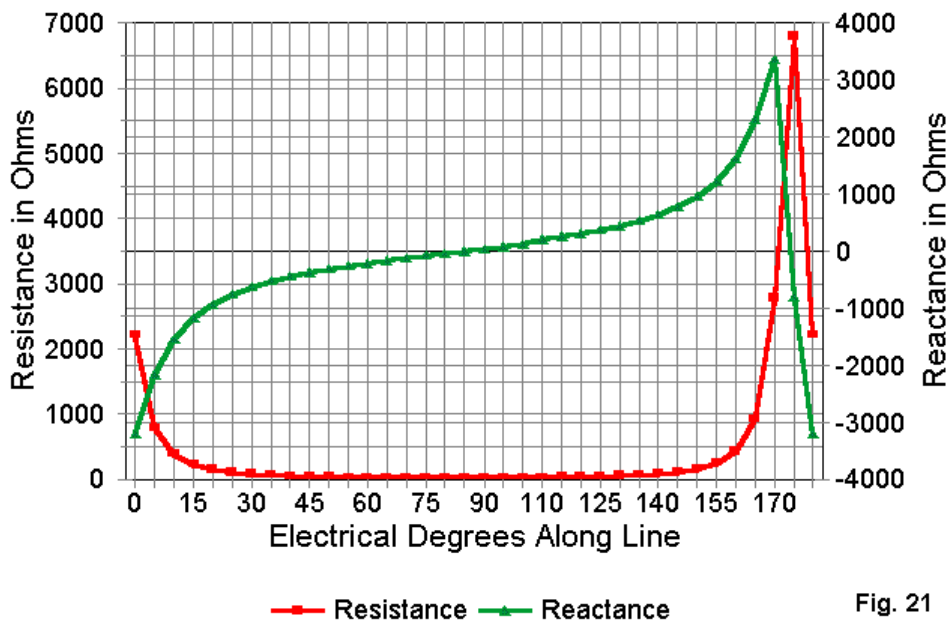


Fig. 21

Fortunately, the balance is not perfect. What the ATU is likely to see are values that are quite reasonably matched. Again, a good old-fashioned inductively coupled tuner is likely the best bet for the end-fed Zepp.

See Chapter ?? for the contents of Figure 22. What do we get for our end-fed trouble? Figure 22 tells most of the story: we get a multiband wire antenna where the lobes increase with frequency and the gain moves from broadside to off the end of the wire as the frequency increases. This familiar motif differs only in

detail from the summary remarks about the other two 135' antennas we have examined in detail.

## **Summary**

We have looked at low-lying dipoles and at wires used for multiband purposes for two good reasons. First, basic information is necessary to dispel novice mythology about dipoles and other wire antennas. Second, we have wanted to leave behind some compendia of antenna patterns to set some proper expectations for future antenna building.

We could go on for days looking at all the many ingenious wire set-ups that hams have invented over the years. Most of these antennas are designed to overcome circumstantial limitations. Whatever their designers have thought of them, they have brought no real improvements upon the dipole and its multiband counterparts. In fact, it is difficult to beat a wire doublet as high as one can get it--difficult, that is, without access to federal grants, crown jewels, or Superman's cape.

Wire does have some disadvantages that we just have to admit. It is very difficult to rotate a wire dipole or beam--something like pushing rope. However, I can install three wire antennas for far less than the cost of one modest rotator, let alone the cost of the tower and beam. Wire looks--well, so Novice! It lacks all the electromechanical glint and sophistication that we associate with beams. Of course, a broken wire antenna is invisible on the ground, while a broken beam transforms a backyard into a junk yard of embarrassment. And I do not have to take a bank loan to replace my wire antenna.

Just be sure you construct your antenna well. I am convinced that people believe that some of the commercial wire antennas work "better" simply because they did not spend the same construction care on their \$30 home brew job that they spent on the \$150 prepackaged antenna of the same design. A wire antenna has three dimensions. First is the electrical: make sure all connections are electrically

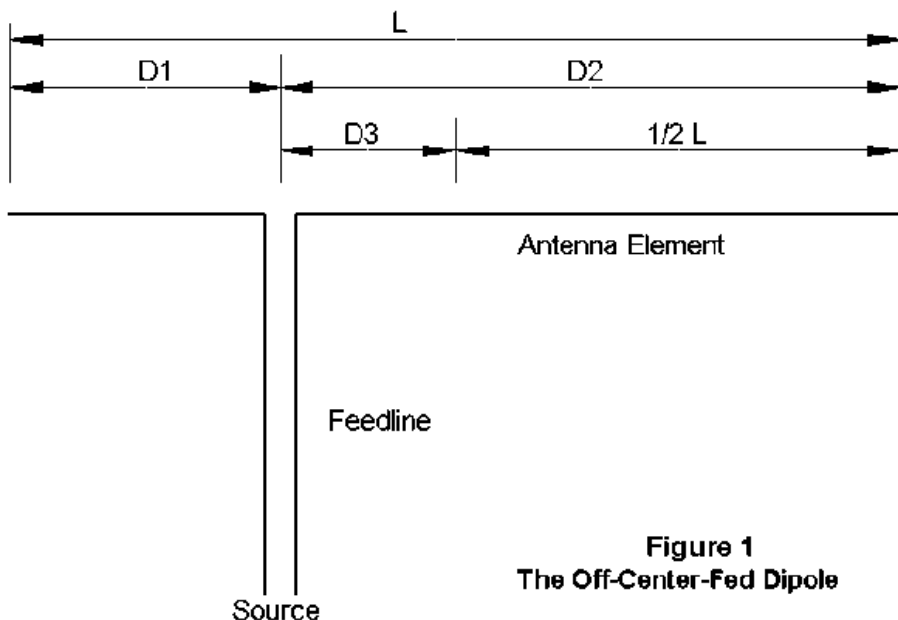
sound and durable. Second is the mechanical: use sound principles of mechanical security at physical connections and stress points. Third is maintenance: erect your antenna with an eye toward lowering it a couple of times a year to check both electrical and mechanical connections, and to clean the wire and transmission line. Some folks like auto polish on both to shed the rain and to restore a little glint in the setting sun.

The basic wire is long. The basic wire is as full size as we can make it. It is so basic that it does not need magic to make it work. But work it does. And when it falls down--despite our best maintenance efforts--it is cheap to reinstall. And it goes on working. Now you know why we are using wire--at least until the ship comes in carrying the professional installers and the 200' tower, rotator, and combined 80-40-30 meter quad.

## **APPENDIX**

### **135' Off-Center-Fed Multi-Band Dipole Data Compendium**

The fundamental concepts and realities of Off-Center-fed (OCF) wire antennas developed in terms of 40-meter models apply to any other fundamental band with adjustments of height in terms of fractions of a wavelength. However, several folks have asked for more specifics for an 80-meter-based OCF in order to have reasonable expectations of performance.



**Figure 1**  
**The Off-Center-Fed Dipole**

For an 80-meter fundamental OCF,  $L$  will equal about 135' if the antenna is resonant. If the antenna is fed with parallel transmission line to an ATU, the exact length is not critical. However, for the sample patterns, it has been made resonant.

We shall sample an 80-meter OCF at 35' height, a typical amateur installation. The frequency of basic resonance is 3.5 MHz to ensure that harmonics fall within the amateur bands. However, pattern samples will cover all 8 amateur bands between 80 and 10 meters.

We shall also sample two points of antenna element-to-feeder junction: the 100-ohm and the 300-ohm points. The antenna dimensions for these two antennas are as follows:

100-ohm Connection:  $L = 135.25'$   $D1 = 34.7'$   $D2 = 100.55'$

300-ohm connection:  $L = 135.67'$   $D1 = 18.2'$   $D2 = 117.47'$

Interestingly, this same antenna raised to a height of 70' shows the following resonant characteristics:

100-ohm Connection:  $L = 135.7'$   $D1 = 50.5'$   $D2 = 85.2'$

300-ohm Connection:  $L = 136.55'$   $D1 = 24.1'$   $D2 = 112.45'$

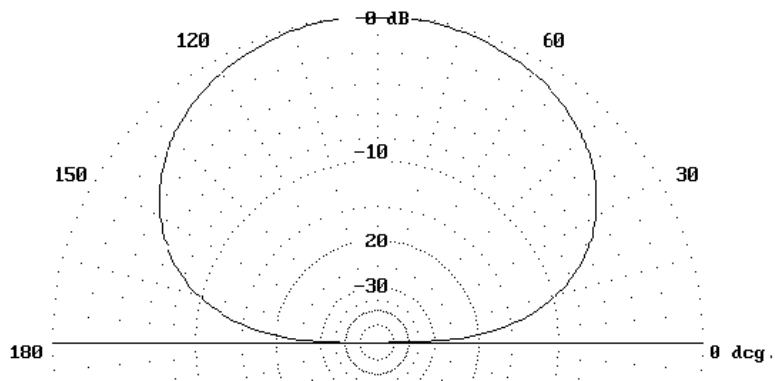
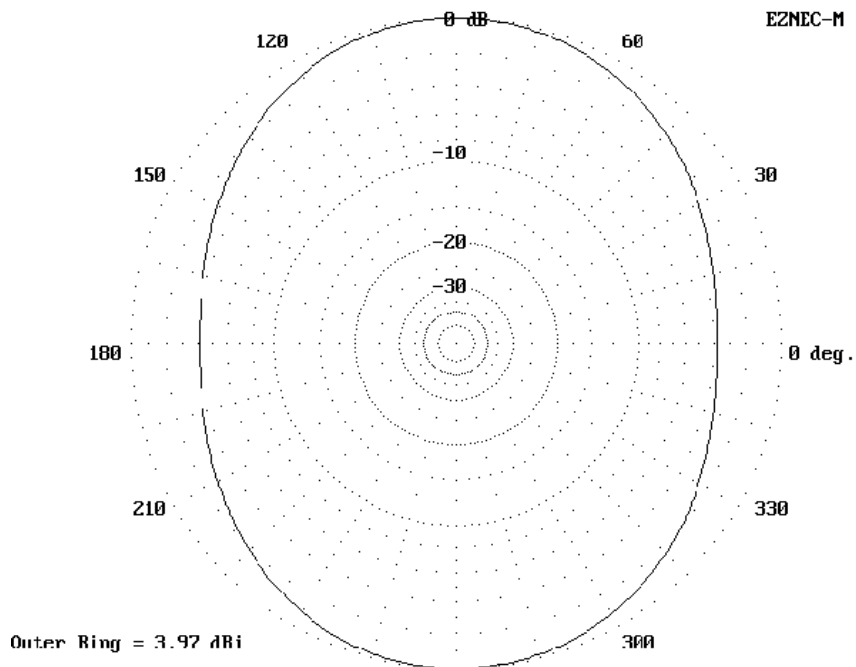
35' and 70' are  $1/8$  and  $1/4$  wavelength heights, respectively, a region where we can expect large changes of antenna characteristics with small changes in height. The patterns and numbers associated with the antennas should thus be used with due caution. They are indicators, not absolutes.

For each pattern, a feedpoint impedance figure,  $Z_i$ , is given.  $Z_i$  is the impedance assuming that the radiation is confined to the antenna element. Since this assumption will be violated in most installations using parallel feedline directly connected to the antenna, the impedance figures are best treated as indicators of moderate or high impedances, not as numbers to be expected in reality. The actual impedance presented to the ATU will be a complex combination of the degree to which the feedline contributes to radiation and the transformation of the antenna impedance along the line.

### **80 Meters: 3.6 MHz**

100-ohm Connection:  $Z_i = 120 + j100$  ohms -- Elevation angle = 45 degrees





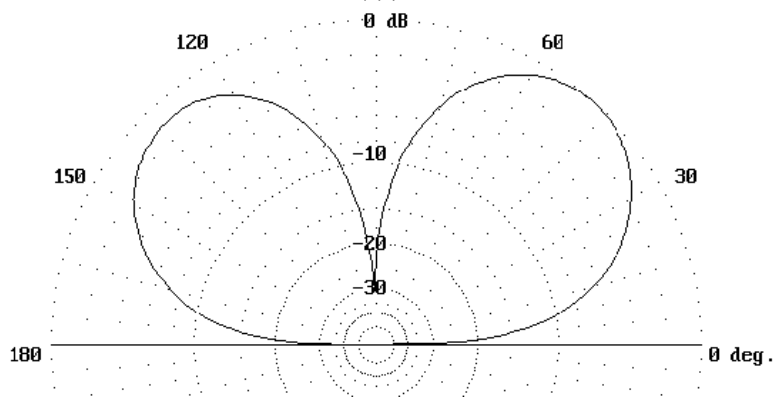
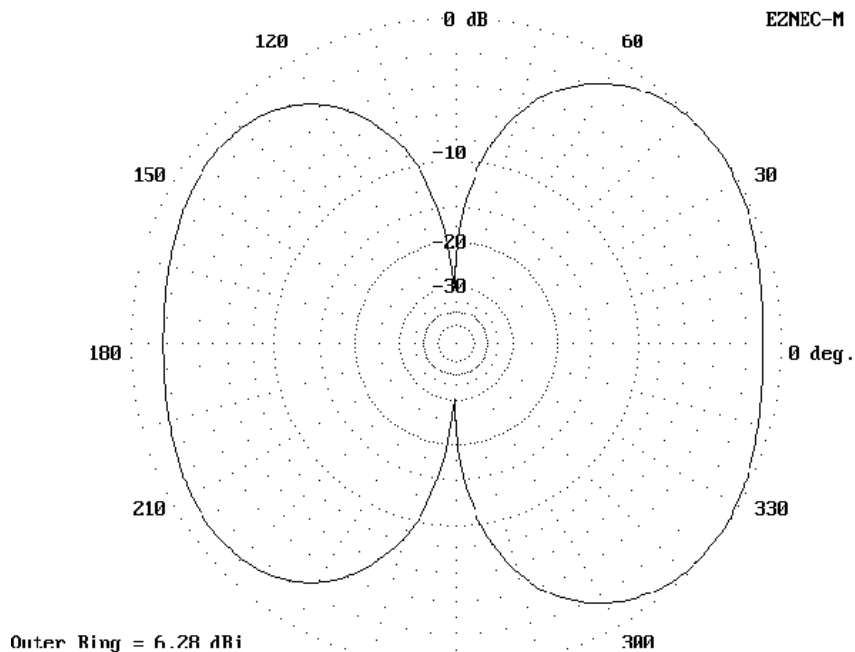
Note: Since the actual elevation angle of maximum radiation is greater than 45 degrees for 80 and 40 meters, the azimuth patterns are taken at an elevation angle of 45 degrees.

300-ohm Connection:  $Z_i = 455 + j310$  ohms -- Elevation angle = 45 degrees



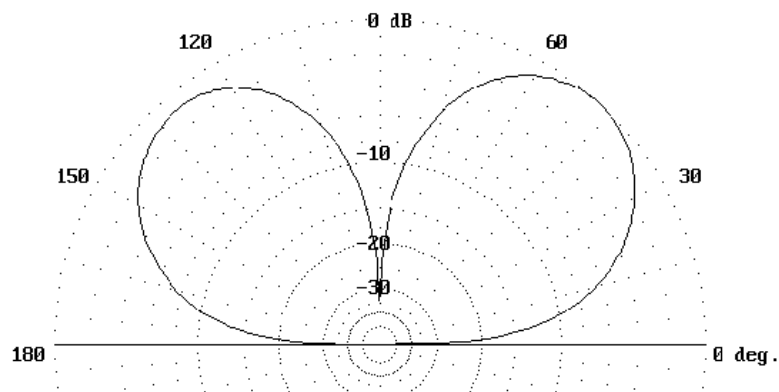
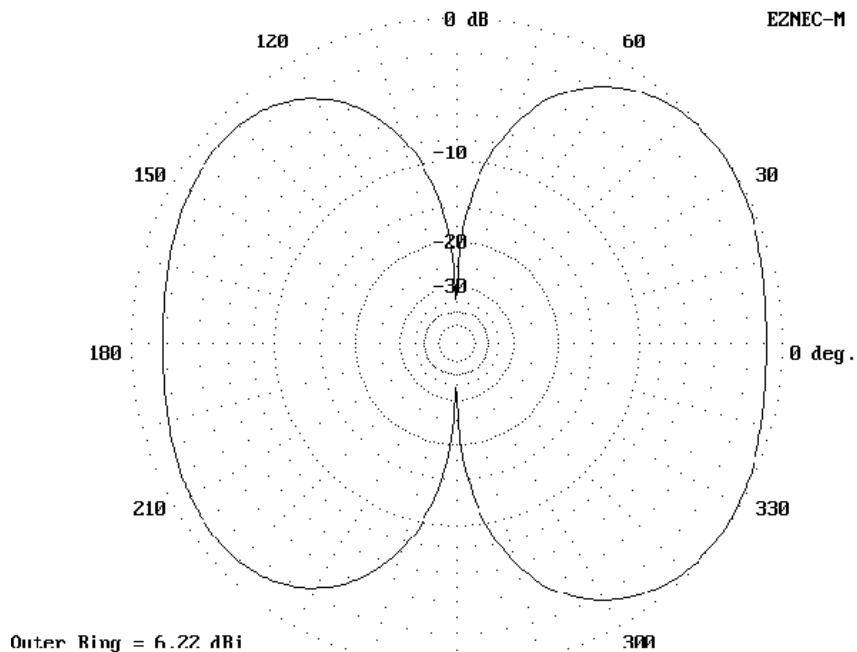
**40 Meters: 7.15 MHz**

100-ohm Connection:  $Z_i = 105 + j15$  ohms -- Elevation angle = 45 degrees



Note: For a different slant on OCF antennas, see Chapter 3 of Bill Orr, W6SAI, *HF Antenna Handbook*. He presents some interesting variations on the versions studied here.

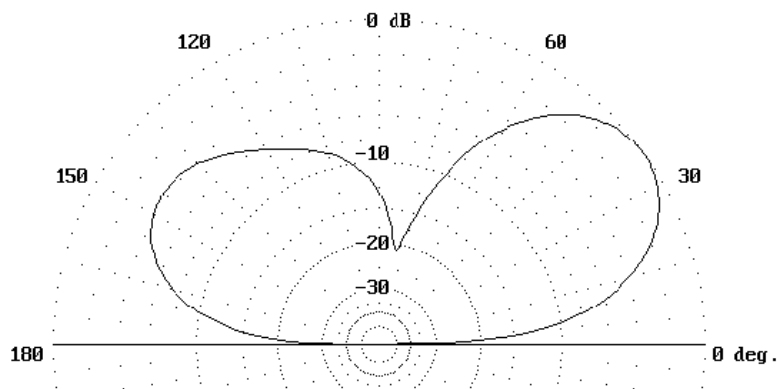
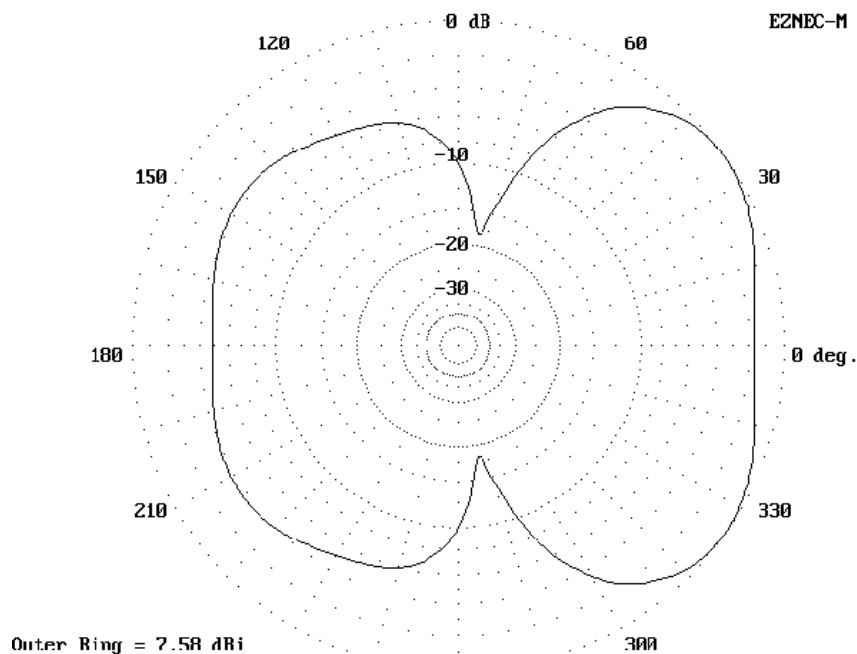
300-ohm Connection:  $Z_i = 185 + j20$  ohms -- Elevation angle = 45 degrees



### **30 Meters: 10.1 MHz**

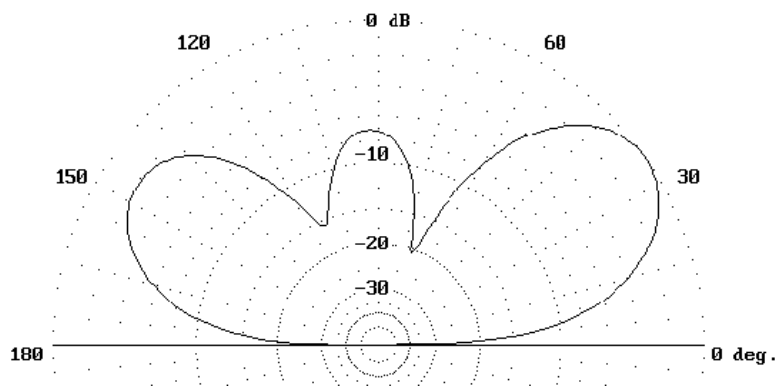
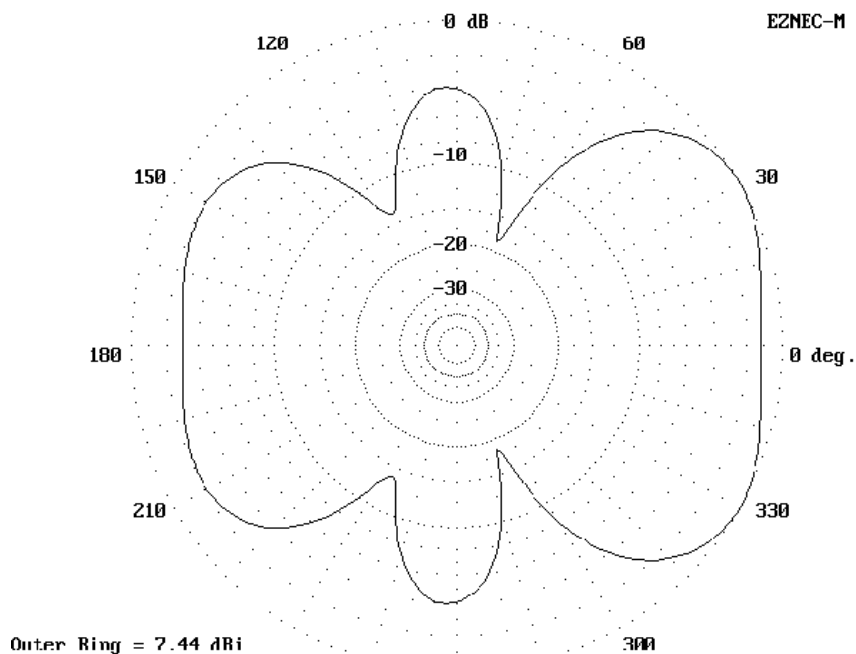
100-ohm Connection:  $Z_i = 690 - j890$  ohms -- Elevation angle = 37 degrees





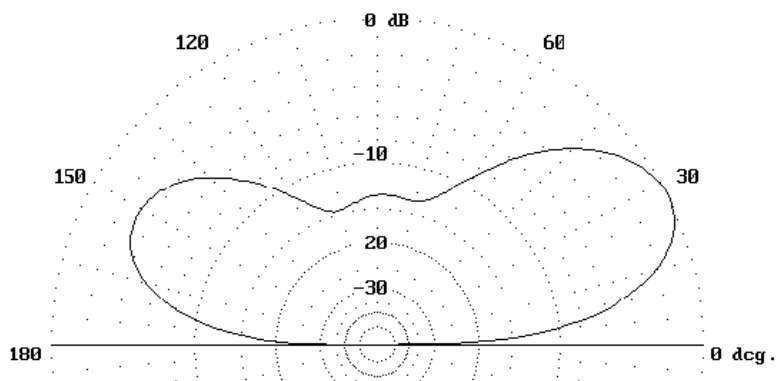
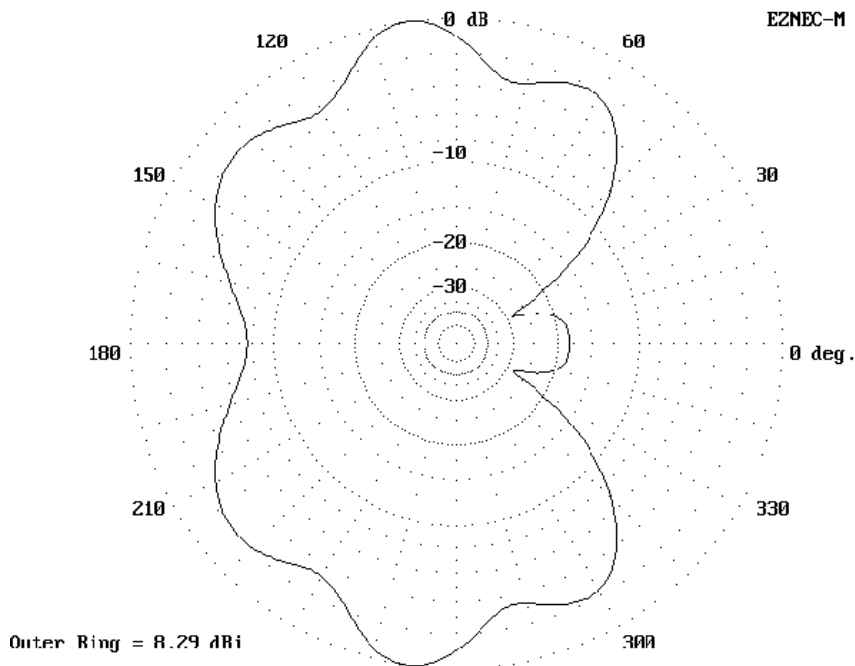
Note that differences between the 100-ohm and the 300-ohm patterns are beginning to appear with respect to both azimuth and elevation.

300-ohm Connection:  $Z_i = 90 - j295$  ohms -- Elevation angle = 36 degrees



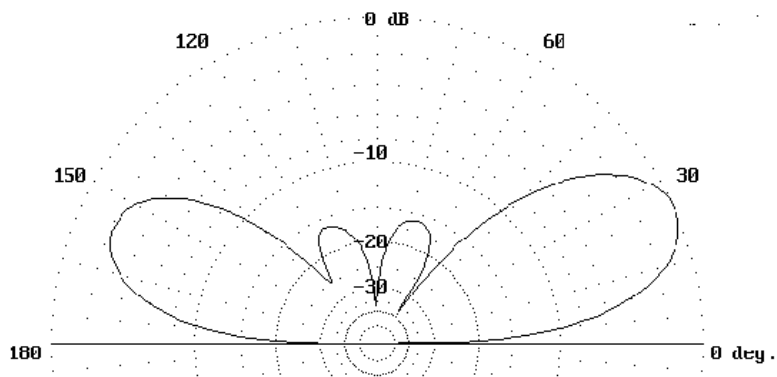
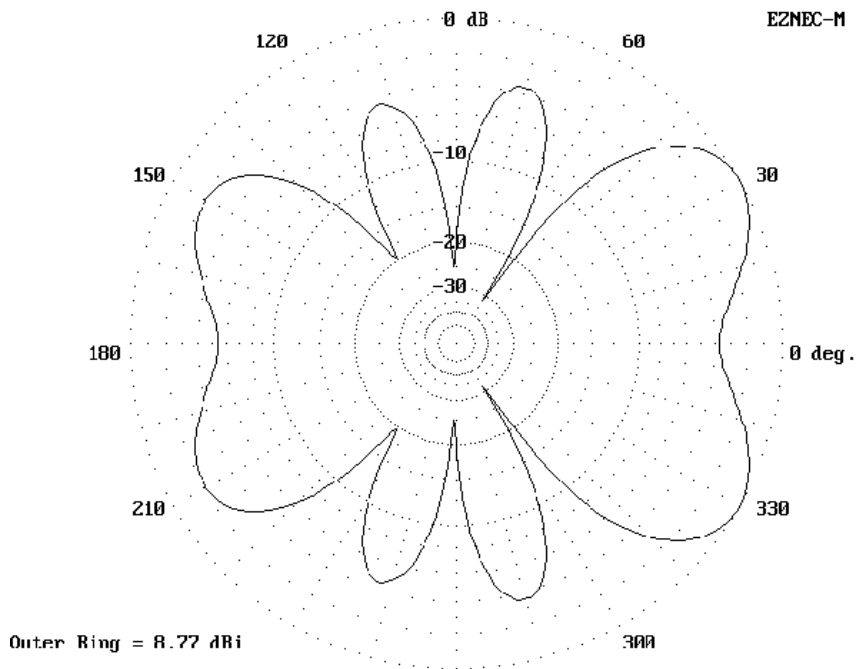
**20 Meters: 14.15 MHz**

100-ohm Connection:  $Z_i = 3145 - j1355$  ohms -- Elevation angle = 28 degrees



At 20 meters, there is a wide divergence between 100-ohm and 300-ohm patterns, with the 100-ohm pattern more closely resembling the pattern of a center-fed antenna.

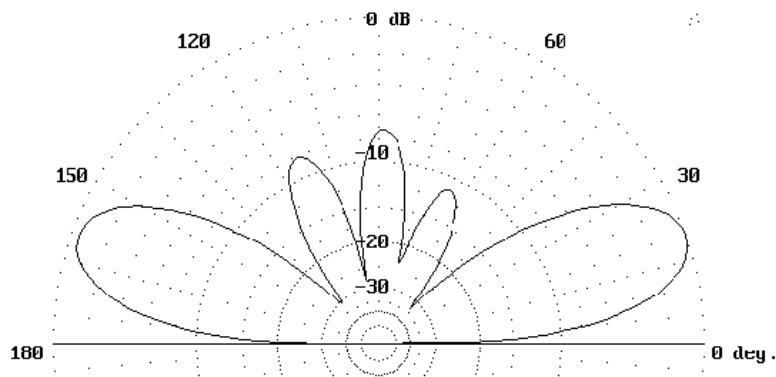
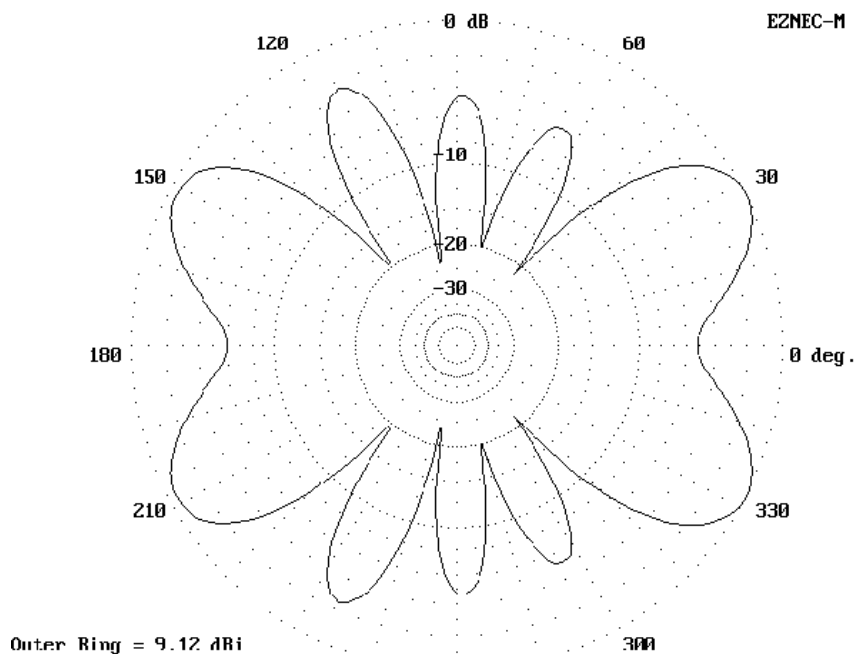
300-ohm Connection:  $Z_i = 120 - j105$  ohms -- Elevation angle = 25 degrees



**17 Meters: 18.1 MHz**

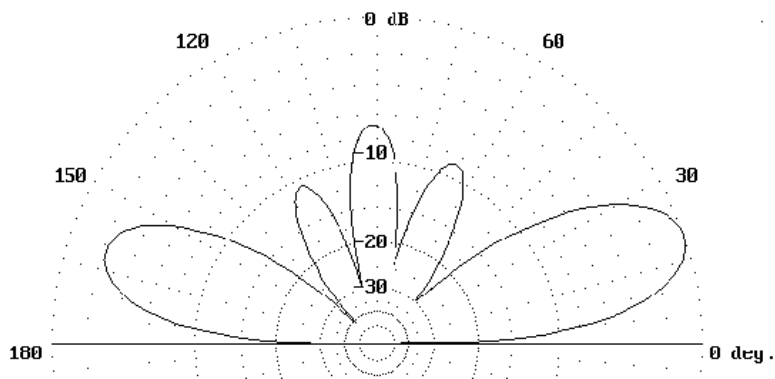
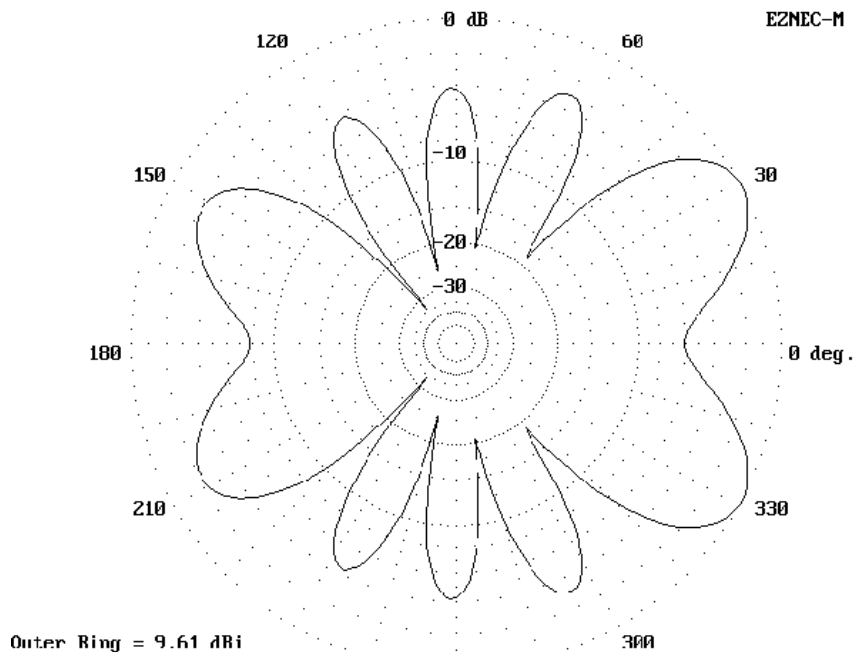
100-ohm Connection:  $Z_i = 205 + j15$  ohms -- Elevation angle = 20 degrees





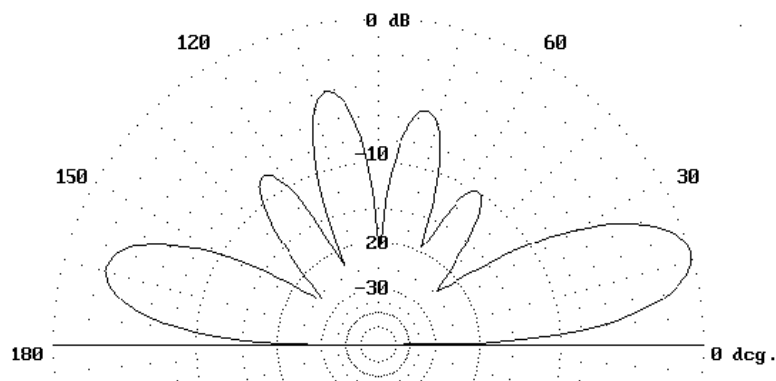
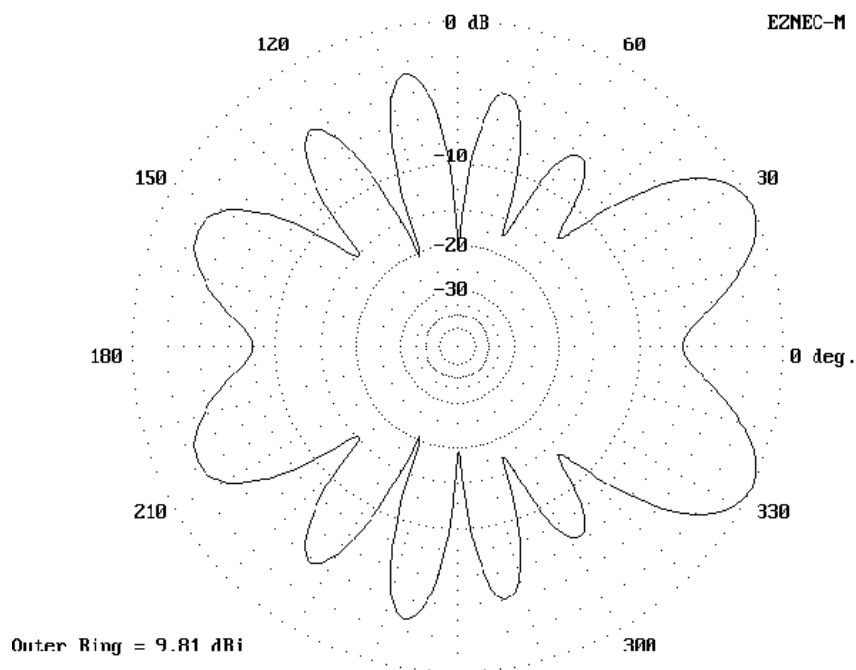
Note that the 100-ohm and 300-ohm patterns are again similar, with difference confined to the minor lobes.

300-ohm Connection:  $Z_i = 170 + j65$  ohms -- Elevation angle = 19 degrees



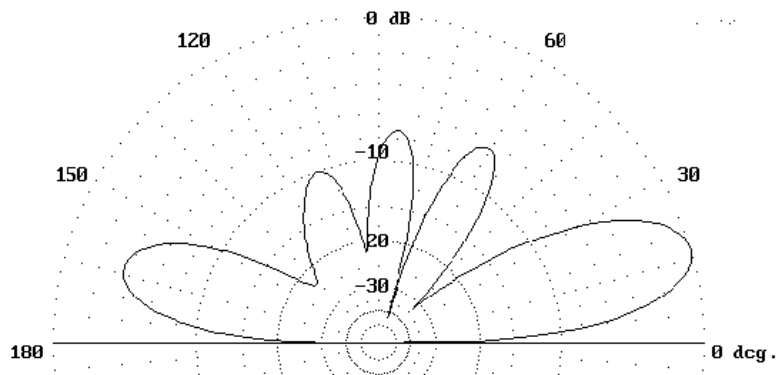
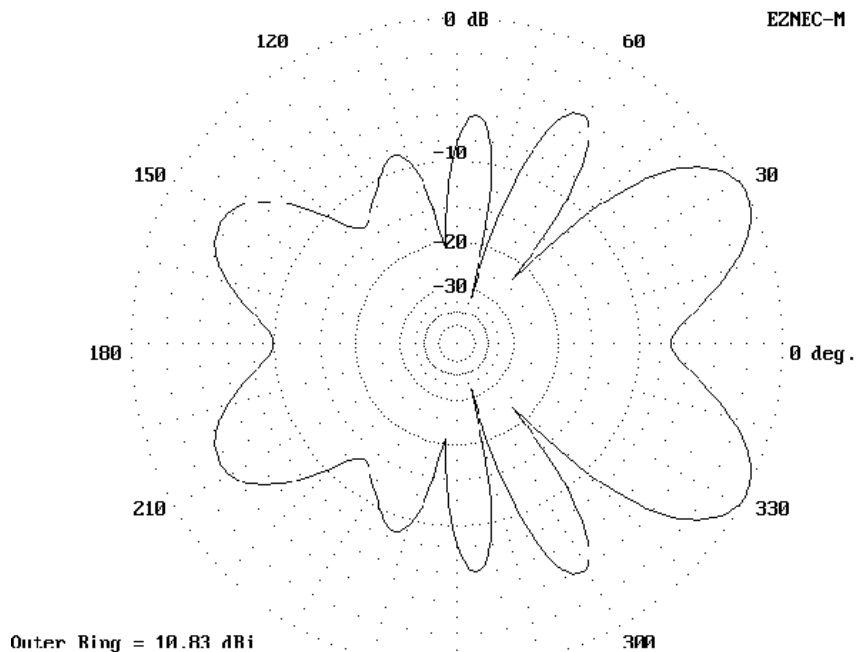
**15 Meters: 21.15 MHz**

100-ohm Connection:  $Z_i = 135 + j240$  ohms -- Elevation angle = 17 degrees



On 15 meters, the 300-ohm version of the antenna shows considerably less gain to the short side of the antenna element.

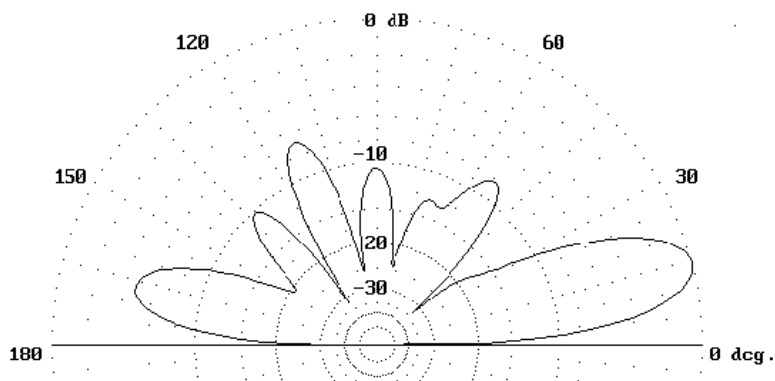
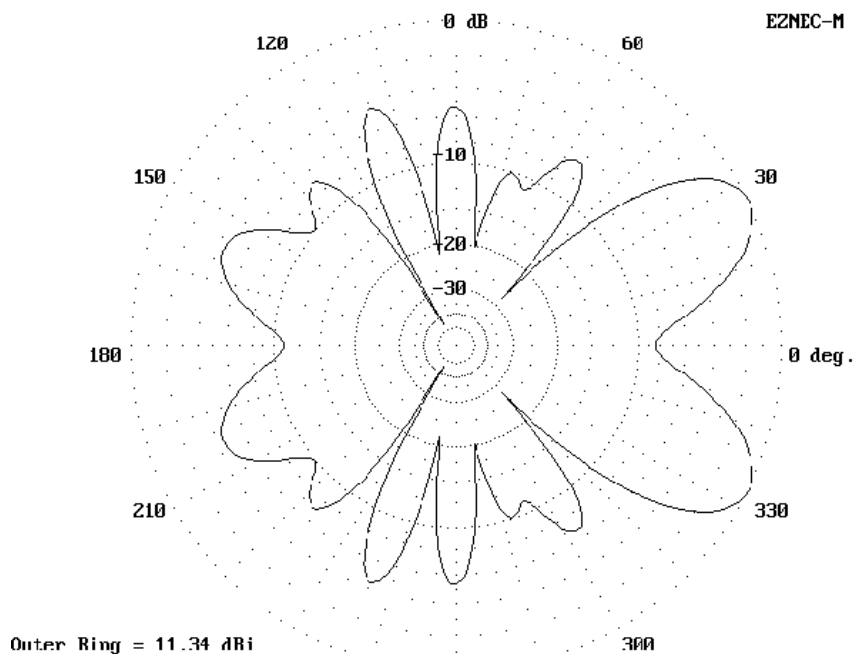
300-ohm Connection:  $Z_i = 920 - j600$  ohms -- Elevation angle = 17 degrees



**12 Meters: 24.95 MHz**

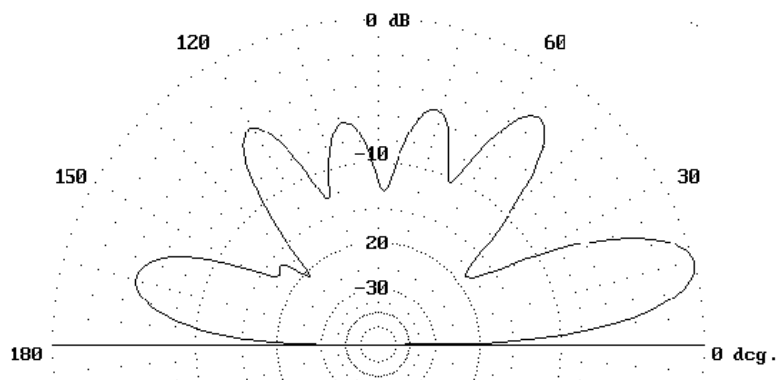
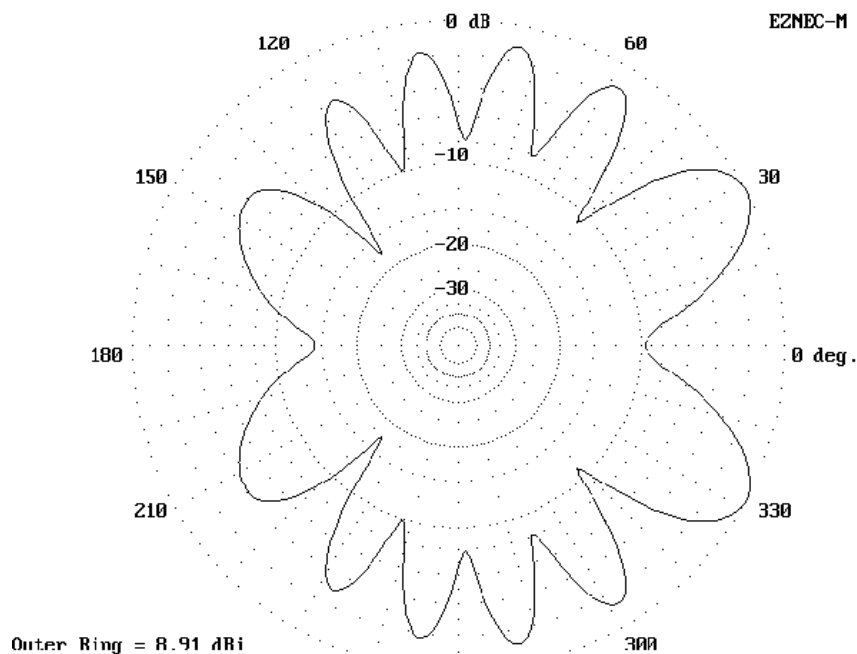
100-ohm Connection:  $Z_i = 545 - j420$  ohms -- Elevation angle = 15 degrees





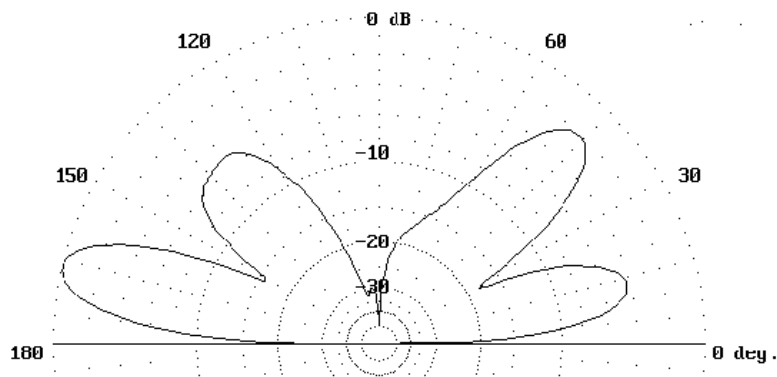
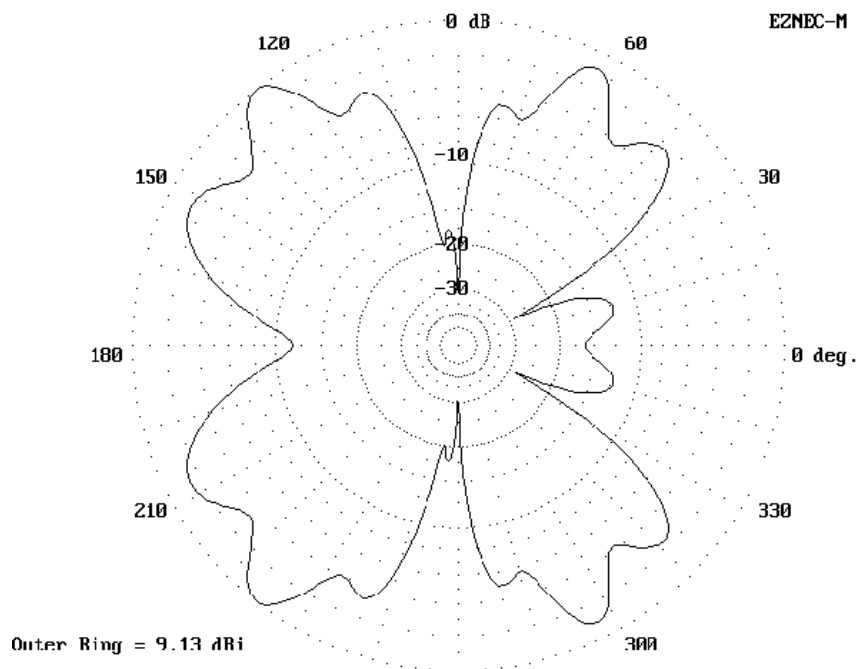
Note that, although the number of lobes are the same, the 300-ohm version puts more energy into high lobes and less into lobes off the ends of the antenna.

300-ohm Connection:  $Z_i = 2930 + j350$  ohms -- Elevation angle = 15 degrees



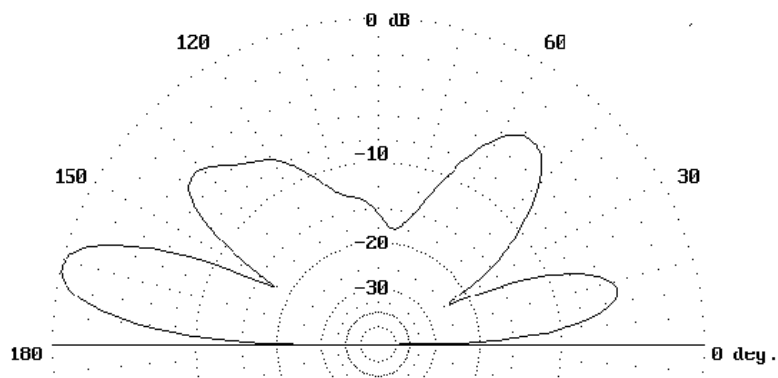
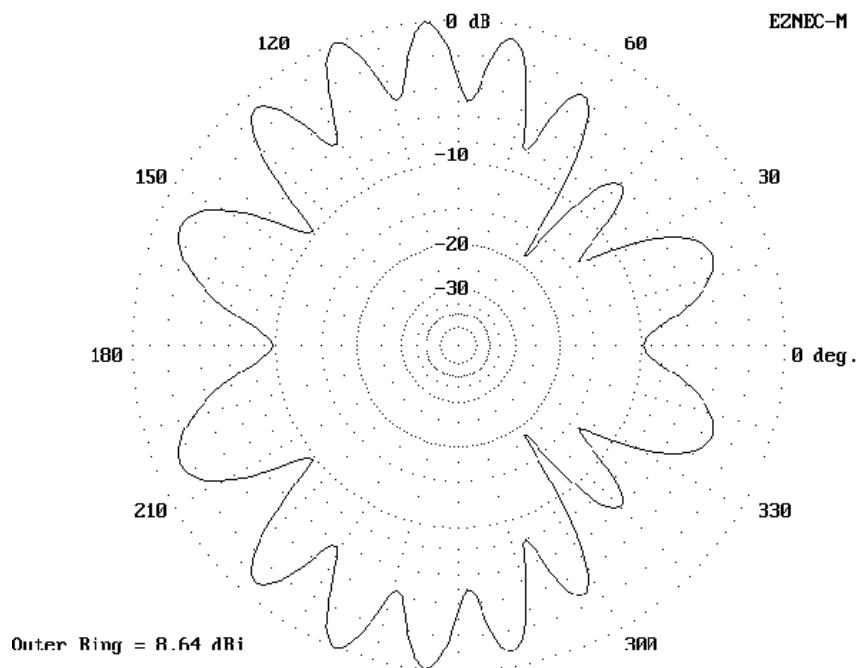
**10 Meters: 28.5 MHz**

100-ohm Connection:  $Z_i = 1755 - j905$  ohms -- Elevation angle = 14 degrees



Note the deep nulls broadside to the 100-ohm version of the antenna, compared to the smoother lobe structure of the 300-ohm version.

300-ohm Connection:  $Z_i = 875 - j925$  ohms -- Elevation angle = 15 degrees



## Chapter 4: Some Cutting Formulas

**F**or some reason buried deep in the human psyche, the newer antenna builder craves a set of cutting formulas in order to build an antenna. All cutting formulas have the same general form:

$$L_{(\text{feet})} = k / f_{(\text{MHz})} \text{ OR } L_{(\text{meters})} = k / f_{(\text{MHz})}$$

There are also occasional cutting formulas expressed in inches and millimeters. Of course, "k" is the magic number that allows easy calculation of the element length, even without a hand calculator.

Cutting formulas have a special lure. They look like precise equation, in a class with Ohm's Law.

$$I = E / R$$

They also appear to be universal so that one can calculate the element length for any band whatsoever. They are also independent of the element diameter, a complicating factor. In fact, cutting formulas seem so simple and precise that we have to wonder why all antenna designers do not show the formulas in their work. On the other hand, cutting formulas are so popular that a number of antenna designers have incorporated them into their articles, even when not needed.

Unfortunately, cutting formulas that appear in many references suffer from a number of faults.

1. Cutting formulas are usually imprecise.
2. Some cutting formulas are simply wrong.
3. Many cutting formulas are based on crude assumptions.
4. Cutting formulas fail to take into account the element diameter.

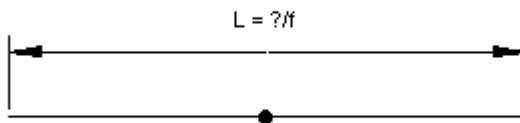


These faults tend to blunt the seemingly sharp edge of the cutting formula. In fact, I never use them, and I tend to avoid translating antenna designs into cutting formulas. They are too dangerous.

### The Simple Dipole

The most famous and perhaps nearly sacred cutting formula applies to resonant 1/2-wavelength dipoles. The situation appears in **Fig. 1**, and the following cutting formula fills in the question mark in the sketch.

#### 1/2-Wavelength Dipole Cutting Formula



**Fig. 1**

$$L_{(\text{feet})} = 468 / f_{(\text{MHz})}$$

If you wish the length in meters, then use 143 instead of 468. Now let's trace the origins of this famous equation that most radio amateurs commit to memory.

1. The magic number derives from shortening the number necessary for a true half-wavelength in free space: 492. This half-wavelength magic number derives from the number we would use for a full-wavelength: 984. However, even the  $k$ -number of a full wavelength is imprecise. The frequency at which a wavelength is exactly 1 meter is 299.7925 MHz (with more decimal places possible within the limits of the current figure given in science and engineering sources.) So the magic number for a full wavelength in feet is closer to 983.57 and the corresponding number for a half wavelength is 491.79 (or thereabouts).

The reply to this news is normally that cutting formulas are designed for backyard wire cutting, not for precise physical laws. Of course, this admission directly contradicts one of the lures of cutting formulas: their appearance of precision. But it is a good admission, a step in the direction of a cure to the cutting-formula affliction.

2. The move from 492 down to 468 rests on some assumptions about wire dipole operation. There is a shortening effect based on the fact that wire has a physical diameter. Wire also has ends, creating what some simply call the "end effect." As well, wire has a finite conductivity, which also has a shortening effect. The sum of all "real-world" shortening effects for bare wire is about 5%, according to the assumption.  $0.95 * 492 = 467.4$ , which we shall round upward for some unspecified reason to 468. (Note that this applies to bare wire. Insulation also adds to the shortening effect by another 2% to 5%, depending on the relative permittivity and the thickness of the insulation.)

If we press the assumption of a 5% shortening, it dissolves into a much more complex affair. Shortening effects due to the impossibility of using a wire with an infinitesimal diameter become highly dependent upon the wire diameter. Matters become even more complex at lower frequencies, where we use multiple parallel wires to simulate a single fat wire. At VHF, wire diameters may vary from a thin wire to a large tube or rod.

So we have to add another element of imprecision into the cutting formula magic number. The cutting formula is looking more and more like a simple phantom of an equation. But we are not done.

Let's model a simple resonant 1/2-wavelength dipole at various heights about ground. Below a height of about 2 wavelengths, a dipole is more susceptible to influences of the ground than many other sorts of horizontally polarized antennas. We shall look at 2 dipoles for 14 MHz. One is composed of AWG #12 (0.0808" diameter) copper wire. The other is formed from 1" aluminum tubing. We shall place the dipole at heights of 1/4, 1/2, 3/4, and 1 wavelength above average ground, with a free-space entry just for reference. The following table

will show the resonant length as a function of a wavelength. That means translating the wire diameters into fractions of a wavelength. AWG #12 wire is very close to  $1e-4$  wavelength at 14 MHz, while the 1" diameter tube is close to  $1e-3$  wavelength in diameter. The table will also list the resonant impedance, but only to show that the NEC-4 modeling achieved resonance within  $\pm 0.1$  Ohm. Finally, the table will show the calculated "magic" number that should replace 468 for the conditions of the individual test.

Cutting Formula Numbers for a 14-MHz Resonant 1/2-Wavelength Dipole						
Diameter	1e-4 WL			1E-3 WL		
Height	Length	Impedance	K	Length	Impedance	K
WL	WL	R+/-jX Ohms		WL	R+/-jX Ohms	
Free Space	0.4848	72.79 + j0.03	476.8	0.4777	72.06 + j0.05	469.9
1/4	0.4802	80.42 + j0.09	472.3	0.4714	79.21 + j0.06	463.7
1/2	0.48795	69.94 - j0.05	479.9	0.4821	69.49 - j0.03	474.2
3/4	0.4826	74.23 + j0.07	474.7	0.4746	73.25 - j0.02	466.8
1	0.48655	71.90 - j0.05	478.6	0.4802	71.35 + j0.07	472.3

Interestingly, none of the values for K falls on the value of 468. Although the cutting formula is based on wire, all of those values are well above 468. At 14 MHz, one has to reach a 1" diameter to come reasonably close to 468. Since scaling the dimensions involves changing not only the wire length, but the diameter as well, at 80 meters, we would need a 4" diameter wire to get similar results. An 80-meter dipole made from AWG #14 or #12 wire or 2-mm wire in metric nations) would need to be much longer.

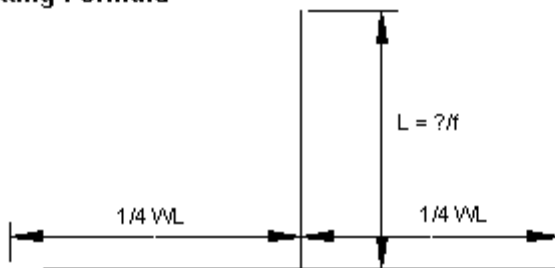
We might speculate that the originators of the sacred dipole cutting formula were--consciously or not--using real-life experience in arriving at their formula, a real life filled with trees, buildings, power lines, and other antenna field impediments. If that speculation has any merit--and it may not--then it neglects the very high variability of antenna fields as we move around the country from tree-filled forests and building-laden urban sites out to wide open spaces in the midwest and west. As well, the origins of the dipole cutting formula go back to the days when amateurs used wavelengths in the 200-meter range.

In the end, the dipole cutting formula is simply a crude approximation. From the table, we can easily see the wisdom of cutting the wire very much longer than the

formula dictates. We shall need some wire to wrap around the insulator to make a mechanically secure connection. We can always make the wrap longer or cut off the excess. Unfortunately, this eminently practical approach to making a wire antenna does not work for any antenna using rods or tubes for elements. If a cutting formula leads us to make an element too long, we can always shave the length. However, if it leads us to make the element too short, we are back to square 1, with a tubular tomato plant stake to show for our initial efforts.

A variation on the dipole cutting formula is the one used, mainly at VHF/UHF, for 1/4-waveoength monopoles. **Fig. 2** outlines the situation.

### VHF Monopole Cutting Formula



**Fig. 2**

Let's assume that we cut 4 radials, each 1/4-wavelength long. How long should we make the vertical monopole? The most common answer is to take the magic dipole number and halve it, usually with a conversion to inches for common US ways of measuring.

$$L_{(\text{feet})} = 234 / f_{(\text{MHz})} \text{ OR } L_{(\text{inches})} = 2808 / f_{(\text{MHz})}$$

Allowing for rounding, of course, we know this is only an approximation. More exactly, but not perfectly exactly, the length of a wave in inches is about  $11802.54/f$  in MHz. That adjustment would change the value of  $k$ , the magic number for the cutting formula. More significantly, the diameter of the element will change the value even more. Since VHF monopoles at 146 MHz are normally at least 2 wavelengths or more above ground, we can simply compare free-space monopoles (and radials) made from AWG #12 (0.808" or about  $1e-3$  wavelength diameter) and from 3/8" (about  $5e-3$  wavelength) diameter.

**Cutting Formula Numbers for a 146-MHz Resonant 1/4-Wavelength Monopole with 4 Radials**

Note: all radials exactly 1/4-wavelength long.

Diameter		1e-3 WL		5E-3 WL		K
Height	Length	Impedance	K	Length	Impedance	
WL	WL	R+/-jX Ohms		WL	R+/-jX Ohms	
Free Space	0.2473	23.59 - j0.04	2918.8	0.2450	28.91 + j0.07	2891.7

The classic cutting formula magic number is about 5% off the mark and low. In most cases, builders end up either sloping the radials or making them shorter, while increasing the monopole length to come closer to a 50-Ohm feedpoint impedance. As we make these changes, the length of the monopole portion of the antenna changes. We could have easily started with a simple 1/4-wavelegth calculation and been on more solid ground than the cutting formula offers, since it usually ends up with an element that is too short.

The dipole and monopole examples are sufficient to illustrate 3 out of the 4 faults that we listed for cutting formulas. Cutting formulas are usually imprecise. They are often based on crude assumptions. Finally, they fail to take into account the element diameter.

## Delta Loops

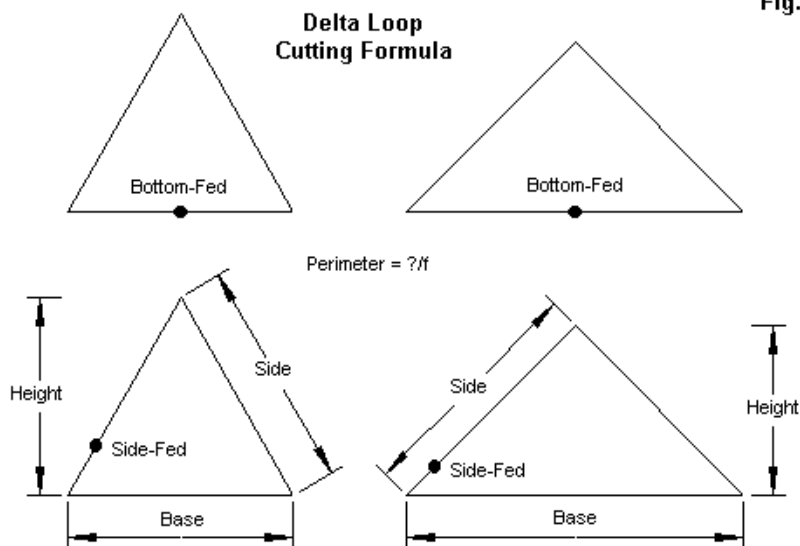
Some cutting formulas are simply wrong. However, the sacred dipole cutting formula is not so far off the mark that we can simply call it wrong. We have to turn to another formula for that honor.

For reasons that we shall examine further on, the classic magic number usually given for a closed 1-wavelength loop of any shape is 1005. That is,

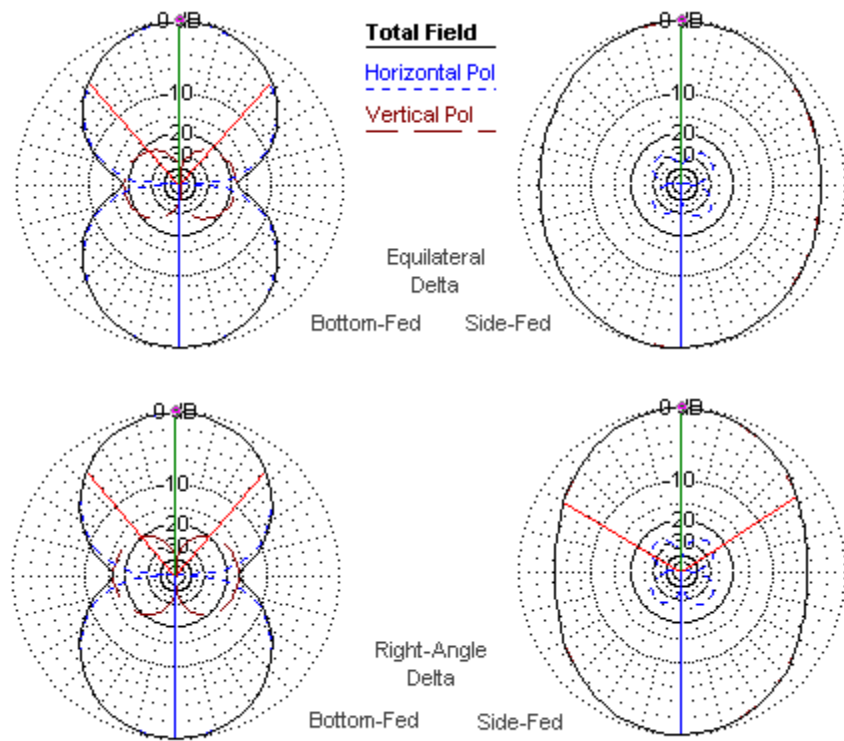
$$L_{(\text{feet})} = 1005 / f_{(\text{MHz})}$$

To test this value, let's model 4 variations of the vertically oriented delta loop in free space. First, we can construct an equilateral triangle (base down, although that does not really matter in free space). We can feed it typically at the center of the bottom wire for primarily horizontal polarization. Alternatively, we can feed it about 25% of the up (or 1/4-wavelength down) one side for primarily vertical polarization. We can create a similar pair of triangles with a right angle at the apex, using either feed point. In order to be about 1/4-wavelength from the apex, the side-fed right-angle delta has a feedpoint about 16% up from the corner. **Fig. 3** outlines the alternatives, along with some critical dimensions for figuring the physical lengths of the sides.

Fig. 3



If we use an equilateral triangle, the height is about 0.866 times the length of a side, and all 3 sides are the same length. In a right-angle delta, the height is 1/2 the length of the bottom of base wire, and each sloping side is about 1.414 times the height. Where we feed the delta has a major impact on the radiation pattern, as shown in **Fig. 4**.



**Fig. 4** **Delta Patterns**

The two left-side azimuth patterns show only small pairs of brown kidneys, which is the remnant vertically polarized radiation. The dominant radiation is horizontally polarized for these two bottom-fed deltas. On the right, we have the equilateral and right-angle deltas using side feeding. The blue clover at the pattern center is about 25-dB down from maximum radiation and represents the remnant horizontally polarized component of the total field. The side-fed delta is a vertically polarized antenna.



Against this background, we can now try to find the length of resonant loops and from that information calculate the value of the magic cutting formula number  $k$ . We shall use AWG #12 wire at 14 MHz, so the wire is about  $1\text{e-}4$  wavelength in diameter. For these loops, I have relaxed my definition of resonance to a remnant reactance of  $\pm j1$  Ohm. The antennas are in free space.

Cutting Formula Numbers for a 14-MHz Resonant 1-Wavelength Delta Loop

Note: All antennas use  $1\text{e-}4$  wavelength diameter wire

Feedpoint	Length	Bottom		K	Length	Side		K
		Impedance				Impedance		
Delta Type	WL	R+/-jX Ohms			WL	R+/-jX Ohms		
Equilateral	1.0650	117.6 + j0.9	1047.5		1.0656	116.9 + j0.1	1048.1	
Right-Angle	1.0490	196.5 + j0.7	1032.1		1.0720	50.21 + j0.03	1054.3	

We know that the calculated numbers will change if we keep the #12 wire but change frequency, because then the wire will have a different diameter when measured in wavelengths. We also know that the value of  $k$  will change if we increase the element diameter. Unlike linear elements whose resonant lengths shrink as the element gets fatter, closed loops (and some nearly closed loops) require a larger perimeter length for resonance with fatter elements.

However, there are two much more important factors revealed by this exercise. First, the value of  $k$  for a cutting formula is different for all 4 delta loops. Second, none of the values is anywhere near 1005. For delta loops, the cutting-formula value is simply wrong.

## Quads From 1 to 3 Elements

Perhaps the quad antenna is the real home for the magic loop perimeter number of 1005 in cutting formulas. So let's explore quad antennas ranging from 1 to 3 elements, as outlined in **Fig. 5**. Of course, the loop perimeter is 4 times the length of a side, since we shall look only at square loops, where the feedpoint is always at the center of one side.

## Quad Loop and Beam Cutting Formulas

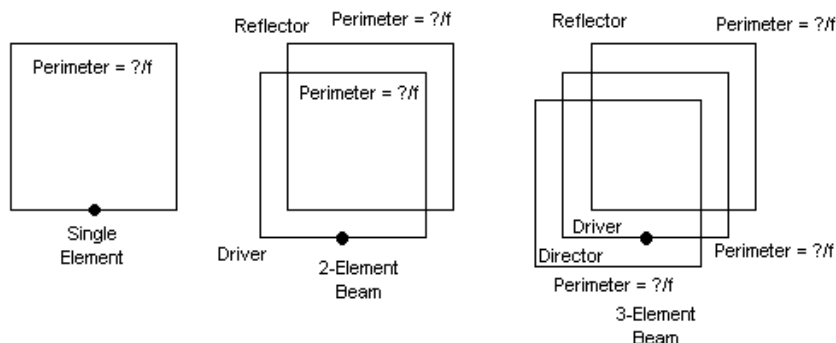


Fig. 5

Let's begin our exploration of quad-loop antennas with the single loop. For this antenna, the 1005 magic value of  $k$  is routinely cited in cutting formulas. For a change of pace, let's test the value at 28.5 MHz, using AWG #12 copper wire for one version of the free-space square loop and 1" aluminum for the other.

Cutting Formula Numbers for a 28.5-MHz Resonant 1-Wavelength Square Loop						
Diameter	AWG #12		K	1"		K
Environment	Perimeter WL	Perimeter Feet		Perimeter WL	Perimeter Feet	
Free Space	1.0261	36.672	1045.2	1.11398	38.445	1095.7

The magic cutting formula value for #12 wire at 10 meters is around the values calculated for similar wire in 20-meter delta loops. The 1" version of the antenna shows the effect on  $k$  of having a closed loop: the fatter the element, the larger the loop perimeter for resonance at any given frequency. The classic number of 1005 is badly off base, even with thin wire.

Perhaps the number fares better in the context of a 2-element quad. The most common number in various texts for cutting the elements of a 2-element driver-

reflector quad are 1005 for the driver and 1030 for the reflector. Once we enter the realm of multi-element antennas, we must also have a cutting formula number for the element spacing. Classically, no numbers appear, although the some sources list values from about 120 to 125, for a spacing of about 1/8-wavelength. Once more, we can contrast AWG #12 copper wire 2-element quad beams with 1" aluminum versions. The elements are in free space. The quads are optimized for the best combination of gain, front-to-back ratio, and operating bandwidth.

Cutting Formula Numbers for a 28.5-MHz Resonant 1-Wavelength Square Loop 2-Element Quad Beam

Element	Perimeter WL	AWG #12	K	Perimeter WL	1"	K
		Perimeter Feet			Perimeter Feet	
Driver	1.0131	34.693	996.5	1.0250	35.372	1008.2
Reflector	1.0737	37.056	1056.1	1.1214	38.701	1103.0
Spacing	0.1590	5.489	156.4	0.1663	5.740	163.6

Again, the classic cutting formula numbers prove irrelevant to actual 2-element monoband quad beam design. They are simply too far off to be of use and they fail to account for changes in the diameter of the elements.

We cannot leave the arena of quads without considering the 3-element quad beam. The conclusions will not change, but examining 3 element quads allows us to consider two other facets of magic cutting formula use and misuse. The first aspect of quad cutting formula numbers concerns their history. The numbers appearing and reappearing for 3-element quads are 975 for the director, 1005 for the driver, and 1030 for the reflector. These numbers arose in the 1970s as a function of an actual published design. The author calculated cutting formulas for his design, ostensibly as an aid to scaling it to other frequencies, but the source and function of the numbers grew dim with time as they gradually underwent editorial truncation into virtually absolute numbers for all quads, whatever the number of elements or the element diameter. The original set of numbers did not contain values for spacing. In the 1970s, most 20-meter quads used one of two standard spacing schemes. The reflector-driver spacing was either 8' or 10', and the driver-director spacing was usually 8'.

Since those days, we have learned a great deal more about quad beam design and performance. For example, we learned that we may design 3-element quads to feature different subsets of the performance values, because we cannot enhance all of the properties simultaneously. This is the second new facet of 3-element quad design: we can design at least 2 different types of 3-element quads. One will have reasonable 3-element gain, but superior front-to-back ratio and operating bandwidth. The other type of design will maximize the gain and front-to-back ratio, but will have a narrower operating bandwidth. Here, the notion of operating bandwidth does not just apply to the feedpoint SWR, but as well to the gain and front-to-back figures. **Fig. 5** presents a dual-pattern overlay of the azimuth patterns of the two quad types on their design frequency. Of course, the pattern can only show the gain aspect of the design differences.

Comparative Patterns of 3-Element Quad Beams  
Wide-Band Red) and High-Gain (Blue) Designs

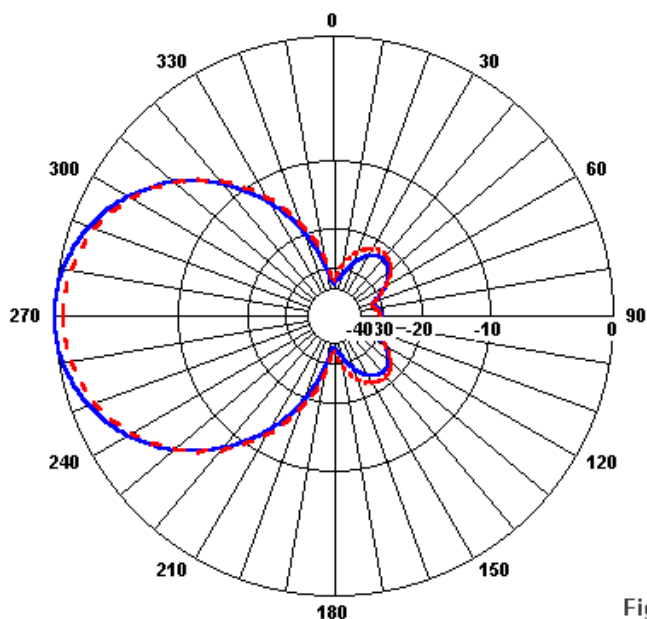


Fig. 6

The two different design goals result in two different sets of dimensions. The following table samples the diversity of the dimensions--and the resulting values for K--for AWG #12 wire versions of each type of design.

Cutting Formula Numbers for 28.5-MHz Resonant 1-Wavelength Square Loop 3-Element Quad Beams

Version Element	Perimeter WL	Wide-Band Perimeter Feet	K	Perimeter WL	High-Gain Perimeter Feet	K
Driver	1.0127	34.950	996.1	1.0218	35.265	1005.0
Reflector	1.0618	36.644	1044.4	1.0581	36.517	1040.7
Dr-Ref Spacing	0.1592	5.493	156.6	0.1773	6.117	174.4
Reflector	0.9398	32.433	924.4	0.9821	33.894	966.0
Dr-Dir Spacing	0.2986	10.305	293.7	0.2230	7.796	219.3

In the high-gain design, we can find traces of the original cutting formulas that emerged from earlier days of quad design when builders kept boom lengths short for mechanical integrity. However, the high-gain values also tell us that cutting formulas are dangerous in beam design, since the loop perimeter will vary with the element spacing as well as with the other variables in quad design. Of course, the values for k that emerge also vary with the goals of the design, with considerable differences in dimensions between the wide-band and the high-gain designs. I should not need to note that the values for k developed from actual designs in these notes are themselves next to useless. They appear only for the contrast with the classically received and very wrong cutting formulas that still populate some antenna articles and texts.

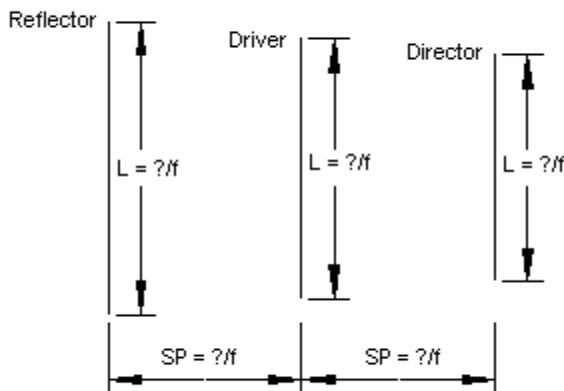
## A Yagi Case

Advances in quad design are less well known than enhancements to the design of Yagi arrays over the last quarter century. Hence, I was surprised to find a set of cutting formula values for a 3-element Yagi beam in one text that I explored. The magic numbers are as follows.

- **Reflector: 492**
- **Driver: 478**
- **Director: 461.5**
- **Spacing: 142**

**Fig. 7** shows the application of these numbers in terms of the Yagi structure. Note that the spacing applies equally to the reflector-driver spacing and to the driver-director spacing. As usual, the resulting dimensions are in feet for HF use.

### Yagi Cutting Formulas



**Fig. 7**

At 14 MHz, these formulas result in the following element lengths and element spacing.

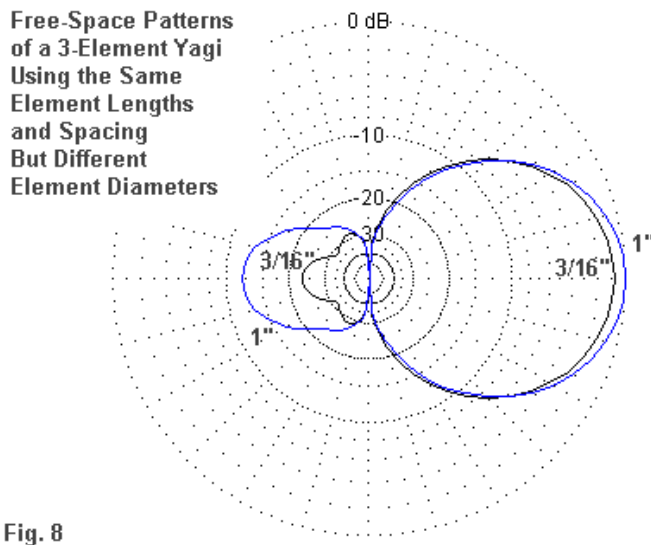
- **Reflector: 34.173'**
- **Driver: 35.143'**
- **Director: 32.964'**
- **Spacing: 10.143'**
- **Boom Length: 20.286'**

To test these cutting formulas, I construct a NEC-4 model of the Yagi, using 1" diameter aluminum elements. The feedpoint impedance was so low that I gradually reduced the element size until the array showed a resonant feedpoint impedance. The successful element diameter was 3/16" (0.1875"). The performance values for the two versions of the antenna--using the exact element lengths and spacing specified by the cutting formula magic numbers--appear in the following table.

Cutting-Formula Yagi for 14 MHz: NEC-4 Free-Space Performance Reports

Element Diameter	Gain dBi	Front-to-Back Ratio dB	Feedpoint Impedance R +/- jX Ohms
1"	8.74	12.04	8.77 + j19.3
0.1875"	7.98	22.32	19.19 + j 0.9

Fig. 8 shows the azimuth patterns of the 2 versions of the Yagi.





The 1" version of the antenna comes closest to the element diameter that a builder might actually use. However, despite its higher gain, it shows a mediocre front-to-back ratio compared to most current designs, and the feedpoint impedance is far lower than current design use to minimize power loss at mechanical junctions and similar lossy parts of construction. The thin-element version is not realistic at 20 meters, but does show better front-to-back and feedpoint impedance values.

Now let's add a third factor into the mix. Most HF beam elements use nested tubing in several sizes. The tapered diameter of the resulting elements will call for length adjustments to take this factor into account. The amount of adjustment will vary with the total amount of taper and the relative lengths of each size of tubing used for parts of each element. No simple cutting formula can account for all of the variations possible in developing the element taper for an HF beam.

As a result of these considerations, cutting formulas for HF beams using tubular elements are completely useless. The prospective builder must either adhere to a published design in all the details of element structure or the builder must redesign the beam to the materials that he wishes to use. That task has no cutting formulas. However, there are antenna modeling software packages that can eliminate most of the field trials and failures on the road to a successful design.

## **Conclusions**

We have explored the world of cutting formulas and found them to be more of a hindrance than an advantage. The best of them--for example, the dipole formula--is at most a very crude approximation of required wire length based on equally crude assumptions about the necessary shortening effects of real-world wire antennas. It failed to account for element diameter and for ground effects on the resonant length of a 1/2-wavelength dipole.

Some classic cutting formulas have proven to be simply wrong by wide margins, as in the case for the magic value of  $k$  normally given for 1-wavelength closed loops. The value of 1005 emerged long ago in a certain context and, by continual repetition and editorial truncation of the context, it came to be viewed as an absolute--an absolutely wrong absolute.

Cutting formulas for multi-element arrays are also useless. Most value sets originate in outdated designs of yesteryear and fail to account for more recent design developments--especially those developments that now routinely allow us to create multiple versions of a design type, each version optimized to feature a subset of the total performance parameters of the antenna.

As long as cutting formulas remain a staple of handbooks, texts, articles, and what we teach to new hams, they will continue to create more misunderstanding about antennas than their absence will create troubles getting started with the first amateur band antenna. While it is not possible to eliminate the classic dipole cutting formula from handbooks, since it has sacred status emerging from the mists of the long-ago era of early radio, perhaps we can make some progress by eliminating all other cutting formulas. All of the rest of them are attempts to apply a blunt instrument where a precision tool is both required and available.

## Chapter 5: Antenna Bandwidth

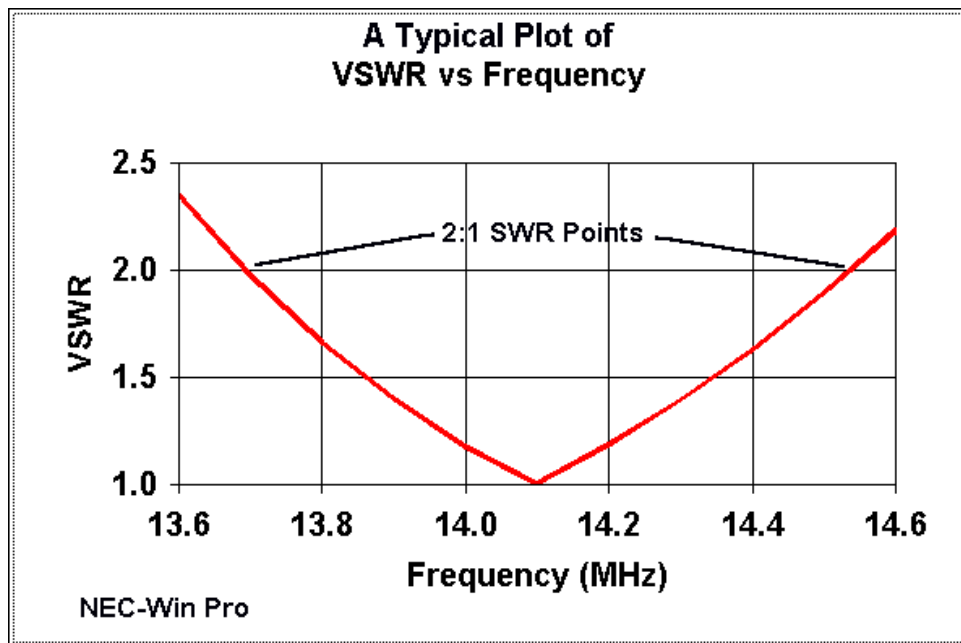
**F**or most of us, the antenna's bandwidth is the number of Hz for which the antenna will exhibit a less than 2:1 SWR. We usually measure bandwidth at the transmitter output, and hence put a large pile of variables on top of the basic idea of SWR bandwidth. So let's begin again and see how the concept actually works.

An antenna--for example, a resonant half-wavelength dipole operated on its fundamental frequency--has a natural feedpoint impedance. For a lossless wire dipole in free space, that figure is just about 72 ohms. In fact, NEC-2 models of just such an antenna using wire diameters from #30 to over 2.5" show less than 1 ohm variation in the 72-ohm feedpoint impedance.

Relative to that impedance, a 2:1 SWR will occur as the feedpoint impedance (off resonance, a complex of resistance and reactance) reaches about 144 ohms at points higher or lower than resonance. The number of Hz (of kHz or MHz) between those frequencies is the 2:1 SWR bandwidth of the antenna. The bandwidth will vary with the diameter of the antenna element in a regular but nonlinear manner.

2:1 SWR bandwidth is approximately (but again, nonlinearly) proportional to frequency. For a given wire size, a resonant dipole at 28 MHz will have (about) twice the bandwidth of a resonant dipole at 14 MHz.

Below is a typical frequency vs. bandwidth plot for a free space lossless thin-wire dipole, plotted against a 72-ohm resonant feedpoint impedance.



To help you gain a reasonable expectation of the 2:1 SWR bandwidth of resonant half-wavelength dipoles, I am attaching a small BASIC utility program that will produce bandwidth tables for any HF frequency for wires from #30 (0.01" diameter) to 2.5" diameter. It is roughly calibrated to NEC-2 models for lossless wire resonant dipoles in free space and to 72 ohms. The algorithms are generally accurate to about 5%, with some matrix-center variations reaching about 10%. The figures are roughly applicable also to resonant quarter-wavelength vertical antennas.

Table 1 summarizes a few data points for thin, medium, and thick antenna elements on 80, 40, 20, and 10 meters. The increase of bandwidth with frequency for a given wire size is evident. Notice also that it takes nearly a 100:1

wire size increase to double the bandwidth of the antenna on any given frequency.

**Table 1: Selected 2:1 SWR Bandwidths in MHz for Wire Antennas**

<i>Frequency</i>	<i>3.5 MHz</i>	<i>7 MHz</i>	<i>14 MHz</i>	<i>28 MHz</i>
#28 AWG (0.013")	0.17	0.35	0.73	1.63
#12 AWG (0.081")	0.19	0.40	0.86	1.91
#4 AWG (0.204")	0.22	0.46	0.98	2.18
(1")	0.30	0.63	1.35	3.06

The degree of error in the program is of no concern, since real antennas and antenna systems will introduce larger variations that no table can account for in advance. Hence, the program is only for setting some reasonable expectations, not for predicting bandwidth with precision. The bandwidth you actually measure will vary with the following variables:

1. Antenna type: Low impedance antenna types will generally (but not always) have wider bandwidths than high impedance antennas.
2. Antenna material: Copper and aluminum have losses that affect antenna bandwidth, especially with small diameter wires (less than #20).
3. Antenna environment: Placing an antenna some height above ground less than about 2 wavelengths will alter both the natural feedpoint impedance and the bandwidth at that impedance. Ground clutter in the near field of the antenna will affect both in ways that are for practical purposes unpredictable.

4. Feedline mismatch: Feeding a 72-ohm antenna with our common 50-ohm coax starts us out at 1.4:1 SWR, hence decreasing the 2:1 SWR bandwidth. As a rule of thumb, the reduction is approximately the same as the ratio of feedpoint impedance to the feedline impedance--or the inverse of the lowest SWR obtainable. Hence, we should expect about 70% of the program's estimated bandwidth when feeding the dipole with 50-ohm coax. (This fact explains why some claim a slightly wider band width for inverted Vee configurations: being closer to 50 ohm natural feedpoint impedance, Vees introduce less bandwidth narrowing due to the slight mismatch).

5. Feedline losses: Even well-matched transmitter-feedline-antenna systems introduce some losses in the feedline. The effect of these losses is to reduce the SWR at the transmitter end of the line, thus giving a wider 2:1 SWR bandwidth. This wider bandwidth is usable, so long as we understand and evaluate the acceptability of the power losses involved.

6. Antenna shortening and loading: Although antenna loading for the sake of shortening reduces the feedpoint impedance, it introduces components that raise antenna Q and narrow the bandwidth. As a rule of thumb, bandwidth is reduced by the percentage of shortening of the antenna. For example, a 33' vertical on 80 meters is about half size, and its bandwidth is about 70 kHz for most common loading schemes--just about half the bandwidth of a full size quarter-wave vertical.

Understanding these bandwidth-altering factors along with the basic output of the program can give us reasonable expectations for antenna bandwidth for the various bands. If our antenna system is more than about 20% off the mark, then we begin to search for possible problems.

Remember that these notes do not apply to antennas fed with parallel feedline and an ATU: those we always tune for 1:1 SWR and maximum power output to the line and antenna.

Finally, if you do not like typing BASIC programs or converting them to C, a version of the program appears in VE3ERP's HAMCALC collection.

```

10 ' BW.BAS
20 CLS:SCREEN 0: COLOR 2,,4:CLS
30 ER$=STRING$(70,32):BW$="###.###":WIRE$="#.###":S$=STRING$(10,32):T$=STRING$(6,
32)
40 ' Estimates 2:1 SWR bandwidth of halfwavelength dipoles for a range of
    common wire and tubing sizes. Algorithm is based on NEC models of
    lossless wire dipoles in free space and is based on a feedpoint
50 ' impedance of 72 ohms. Program does not account for material losses,
    feedline losses, mismatches, or the antenna environment. Accuracy
    averages 5%.
60 PRINT " Estimated 2:1 SWR bandwidth of half-wavelength dipoles at any HF
frequency"
70 LOCATE 2,25:PRINT "by L. B. Cebik, W4RNL"
80 LOCATE 3,15:INPUT "Enter any frequency from 3 - 30 MHz: ",F
90 IF F>30 OR F<3 THEN LOCATE 3,5:PRINT ER$:GOTO 80
100 PRINT "Wire size","Wire dia.,""Bandwidth";S$;"Wire
dia.";T$;"Bandwidth":PRINT " AWG ","inches"," MHz ";S$;" inches";T$;"
MHz "
110 FOR J=30 TO 2 STEP -2
120 AWG$=MKS$(J):N=J:AWG=J
130 K#=(.46/.005)^(1/39):WIRE=.46/K#^(N+3):DIA=WIRE
140 DIA2=DIA-((.4343*LOG(30/F))*(DIA/(2*(2.56/DIA))))
150 BWBASE=(.0469+(((F/3)-1)*(.0116/9)))*F
160 BW=((SQR(DIA2))+.9)*BWBASE
170 PRINT AWG,:PRINT USING WIRE$;WIRE,:PRINT " ",:PRINT USING BW$;BW
180 NEXT
190 FOR J=.375 TO 2.5 STEP .125
200 DIA=J
210 DIA2=DIA-((.4343*LOG(30/F))*(DIA/(2*(2.56/DIA))))
220 BWBASE=(.0469+(((F/3)-1)*(.0116/9)))*F
230 BW=((SQR(DIA2))+.9)*BWBASE
240 K=(J*8)+3:LOCATE K,50
250 PRINT USING WIRE$;J,:PRINT S$,:PRINT USING BW$;BW
260 NEXT
270 LOCATE 23,5:PRINT "Another (F)requency or (Q)uit"
280 A$=INKEY$
290 IF A$="f" OR A$="F" THEN 10 ELSE IF A$="q" OR A$="Q" THEN 300 ELSE 280
300 END

```

## Chapter 6: Effective Height of an Antenna

**T**he question of antenna height in the HF region mysteriously remains somewhat a mystery to many amateurs. We know some basic facts about the antenna, like its height in feet or meters. But many of us fail to realize what the physical height implies about performance. So let's spend some time looking at a couple of standard cases--where the antenna is all at one height--to find out what height means to performance. Then, let's look at a few antennas that have multiple heights of interest. For example, the inverted-V has a peak height at the center and an end height. The quad beam has an upper and lower height. Finally, a stack of two or three Yagis has a top beam and a bottom beam.

Notice that our discussion will involve only antennas that are essentially horizontal. The height of vertical antennas is another discussion entirely, and we shall reserve it for another occasion.

### The 1-Height Antenna

The basic height of an antenna is only indirectly connected with the physical height. The more important question is how high the antenna is as measured in wavelengths at the operating frequency. We can perform an easy approximation. Take the height in feet and convert it to meters by multiplying the height by 0.3048. Now check the operating band. If your height works out to 10 meters and you are using the antenna on 20 meters, then the height is roughly 1/2 wavelength. I call the value "rough" because the band designators for amateur allocations are only approximate. But the exercise will get you started in the right direction.

The next stage is to figure out what the antenna height in wavelengths tells us that might be important. Basically, the antenna height tells us what the angle will be for our elevation pattern. Since the elevation pattern determines the skip angle for our antenna, we shall soon discover whether the antenna is good for DX or only for local and/or regional communications. (Remember that



propagation can do funny things, and even an antenna that is mostly useful for shorter range contacts can sometimes let us contact the rare DX station.)

There is an equation for determining the elevation angle of each lobe in the pattern of a horizontal antenna:

$$A_{LN} = \arcsin \frac{N}{4h}$$

$A_{LN}$  is the elevation of the lobe or null above the horizon. We count for this equation by assigning lobes odd numbers (N). So the first lobe is 1, while the second lobe (if it exists) is 3. (Nulls get even numbers, and ground level--0--is the first null.) The antenna height (h) is in wavelengths or fractions of a wavelength. **Table 1** lists the values for the ideal first-lobe elevation angle based on the equation.

Table 1. Equation-based elevation angles  
for the first lobe of a horizontal antenna.

Height (h)	Elevation angle ( $A_{LN}$ )
$\lambda$	degrees
0.5	30.0
1.0	14.5
2.0	7.2

We shall discover that these values are a bit too high. The equation presumes perfect ground and a simple dipole. Real ground and the antenna structure will slightly modify these values. However, as a rule of thumb, these values are good ones to memorize as an easy reference. Note, of course, that as we raise the height of the antenna, the first elevation lobe has its peak gain at a lower angle. Since propagation angles for long-distance communication tend to favor lower

angles, we can see the wisdom of the old advice that with a horizontal antenna, height comes before almost any other concern.

Let's start our survey of real antennas with a 1/2-wavelength dipole made from wire, and let's place it over average ground. Our main modeling tests will be at 20 meters (14.175 MHz), which is about in the middle of the amateur HF region. Let's see what happens when we run a dipole with heights or 0.5, 1.0, and 2.0 wavelengths. **Fig. 1** shows the antenna and the elevation patterns, while **Table 2** provides the numerical data.

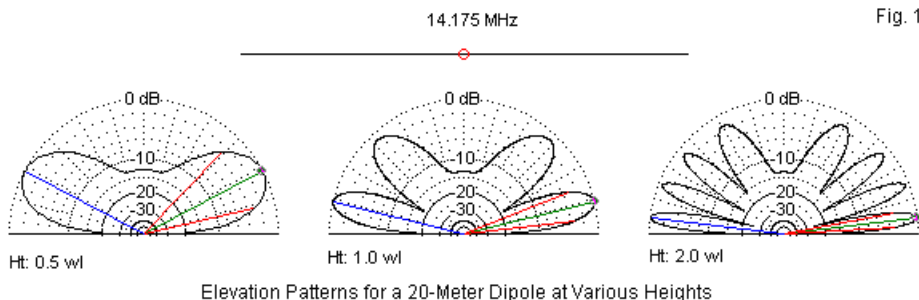


Table 2. First-lobe elevation angle of a 20-meter dipole at various heights.

Height (h)	Max. Gain	Elevation angle	Beamwidth
$\lambda$	dBi	( $A_{LN}$ ) degrees	degrees
0.5	7.30	27.5	33.1
1.0	7.64	13.7	14.7
2.0	7.85	6.9	7.2

First, we notice that the elevation angle of the first lobe is lower than predicted by the equation for each of our sample heights. Second, there is no magic in the exact number for that angle. Terrain will make a difference to its real value. As well, I have recorded the vertical beamwidth value for the lobe to illustrate that there is a span of angles (and not simply a single angle) that marks the range of

angles of strong radiation (and equally strong sensitivity for reception). Third, take note of the fact that as we raise the antenna, we obtain slightly more gain.

To establish that these phenomena are quite general, let's substitute a 10-meter dipole for our original 20-meter antenna. The 10-meter dipole will have half the physical height of the longer antenna in order to establish our test heights from 0.5 wavelengths to 2 wavelengths. **Fig. 2** and **Table 3** provide the patterns and the data.

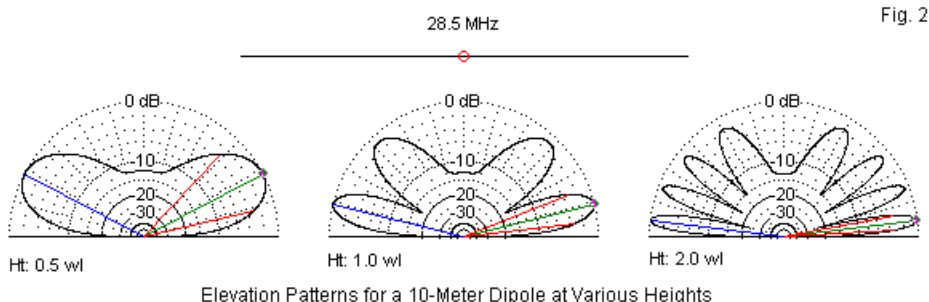


Table 3. First-lobe elevation angle of a 10-meter dipole at various heights.

Height (h)	Max. Gain	Elevation angle	Beamwidth
$\lambda$	dBi	( $A_{LN}$ ) degrees	degrees
0.5	7.20	27.5	33.5
1.0	7.60	13.8	14.8
2.0	7.84	6.9	7.2

The values for the elevation angle of the first lobe and the lobe's vertical beamwidth are virtually identical to those for the 20-meter dipole. Almost incidentally, we can note the slight differences in the maximum gain values. The lower the antenna, the lower the 10-meter gain is relative to the 20-meter gain. The amount is far too low to make an operational difference, but the fact that the lower gain shows up is a function of the fact that ground losses increase with

frequency. As we raise the antenna farther from ground, it has less effect on a horizontal antenna. By a height of 2 wavelengths, the effect is nearly completely gone.

Many amateurs (erroneously) believe that making a horizontal antenna longer may improve the radiation angle. To test this belief, let's create a 20-meter 1-wavelength center-fed wire. It is twice as long as the original 20-meter dipole. If length does make a difference to the elevation angle, the effect should show up. Now let's examine **Fig. 3** and the data in **Table 4**. The representation of the antenna carries the current distribution curves to establish that it is not just another 1/2-wavelength dipole.

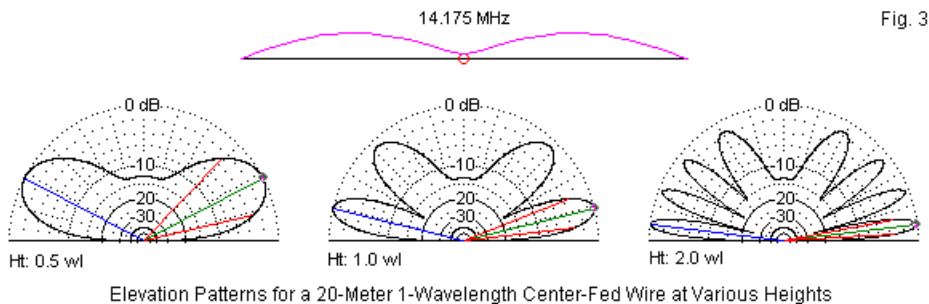


Table 4. First-lobe elevation angle of a 20-meter 1- $\lambda$  center-fed wire at various heights.

Height (h)	Max. Gain	Elevation angle	Beamwidth
$\lambda$	dBi	( $A_{LN}$ ) degrees	degrees
0.5	9.02	27.3	33.1
1.0	9.28	13.6	14.7
2.0	9.44	6.9	7.2

We can easily see the added gain that the 1-wavelength wire gives is. As with all horizontal antennas, the gain increases slowly with increasing antenna height. However, we do not find any difference in the elevation angle or the vertical

beamwidth. (The decimal place in the values for the angles is not operationally significant. It will only play a role a bit later on in this discussion, when we look at antennas having more than one height of interest to us.)

While we are looking at antennas that have only one height, let's see what we obtain for values from antennas having gain in a favored direction. We can begin with a 3-element Yagi of fairly standard design. **Fig. 4** and **Table 5** tell the essential story.

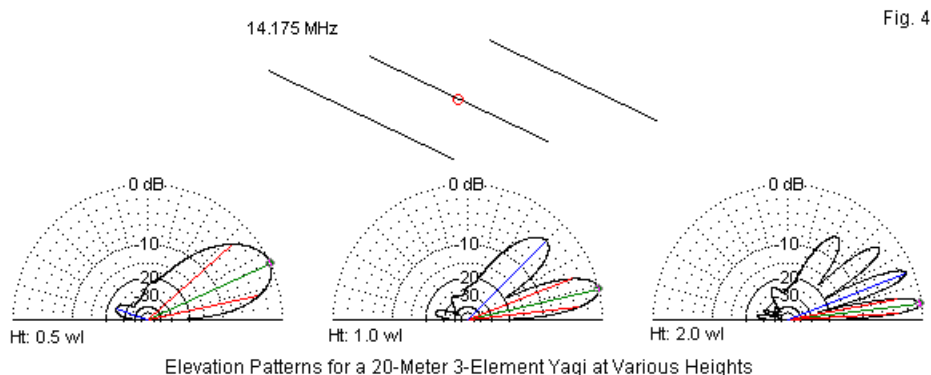


Table 5. First-lobe elevation angle of a 20-meter 3-element Yagi at various heights.

Height (h)	Max. Gain	Elevation angle	Beamwidth
$\lambda$	dBi	( $A_{LN}$ ) degrees	degrees
0.5	12.30	24.5	29.8
1.0	13.40	13.4	14.5
2.0	13.83	7.0	7.1

The gain increase with increasing height once more shows up. In fact, the phenomenon is so universal to horizontal antennas that we shall only mention it one more time from this point forward. More significant is the elevation angle behavior. If we look at the table from the bottom up, which means from the

highest level down, we see that the numbers gradually depart from the dipole values. The lower that we place the Yagi, the lower its elevation angle becomes relative to the standard values for the dipole. Again, we have the ground to thank for the variation. A Yagi radiates from its entire structure, not just from the driver. Each element has a set of "rays" that intercept the ground at very slightly different angles due to the physical displacement of the elements from each other. The closer to the ground we bring the antenna, the more these differences show up in the antenna's radiation pattern. The complex interactions show up as a lower elevation angle at the lowest sample height. As we move the antenna upward, the effect grows less noticeable. By a height of 2 wavelengths, the effect is virtually gone.

At the same time, note the vertical beamwidth of the lowest lobe generally tracks with the elevation angle. At lower mounting heights, the beamwidth is slightly greater than the elevation angle of the lobe. The difference decreases as we raise the antenna and lower the elevation angle of the lowest lobe. For VHF antennas that we normally mount quite a few wavelengths above ground, we can equate the two numbers without fearing any error.

Let's increase the antenna size and forward gain a bit more. A 5-element Yagi at 20 meters often serves as a big antenna for the DXer. **Fig. 5** and **Table 6** show us what happens.

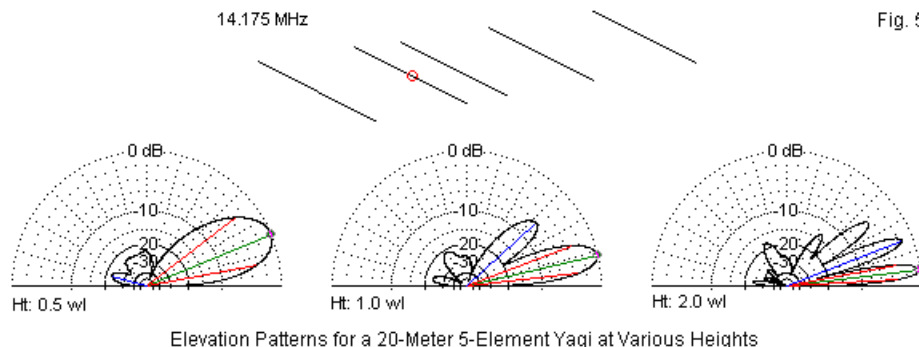


Table 6. First-lobe elevation angle of a 20-meter 5-element Yagi at various heights.

Height (h)	Max. Gain	Elevation angle	Beamwidth
$\lambda$	dBi	( $A_{LN}$ ) degrees	degrees
0.5	13.89	22.3	26.2
1.0	15.49	13.1	14.3
2.0	16.01	7.0	7.1

The long-boom Yagi shows a further lowering of the elevation angle when we mount it at the unlikely height of 1/2 wavelength above ground. Ground effects still show up--although not to an operationally significant degree--when the antenna is 1 wavelength above ground. However, by the time we move the antenna to 2 wavelengths above ground, those effects have completely disappeared.

Our last mention of the antenna gain-vs.-height situation requires that we look at the tables for all of the 20-meter antennas. For the single wire antennas, the total gain difference between heights of 0.5-wavelength and 2.0 wavelengths is only about 0.5 dB. That difference grows to about 1.5 dB for the 3-element Yagi and to 2.1 dB for the 5-element Yagi. The difference is becoming not only noticeable, but also significant. For this reason, many DXers like to mount their long-boom Yagis as high as they can safely maintain.

Our small survey gives us a fairly good foundation in knowing what to expect from a horizontal antenna at any height above ground, when we measure the height in wavelengths. More significant to the rest of our work in these notes is the fact that the demonstrations show what significance we place on the height of horizontal antennas in terms of our anticipations of performance for long-distance communications. Height correlates to the elevation angle of the lowest lobe, and that factor relates to the propagation angles that most usually come into and go out of our antenna. (Note that in many circumstances, incoming and outgoing angles of propagating signals may differ with respect to the ionospheric conditions between my antenna and yours.)

The net result is this: we may equate the height of two antennas if they have the same elevation angles for the lowest lobe in the pattern. The equation cannot be exact, since--as we have seen--the antenna may have some structural factors that affect the elevation angle at lower mounting heights. However, we can come close.

### **Six Sample Multi-Level Antennas**

The equation for estimating the elevation angle of the first lobe of a horizontal antenna applies only when the elements are linear relative to the ground and when we have only one X-Y plane for the elements. The equation does not guide us when we have sloping elements, such as the ones we find in an inverted-V. As well, the equation fails us when we have an antenna with multiple X-Y planes, that is, when we have a vertical stack of antennas.

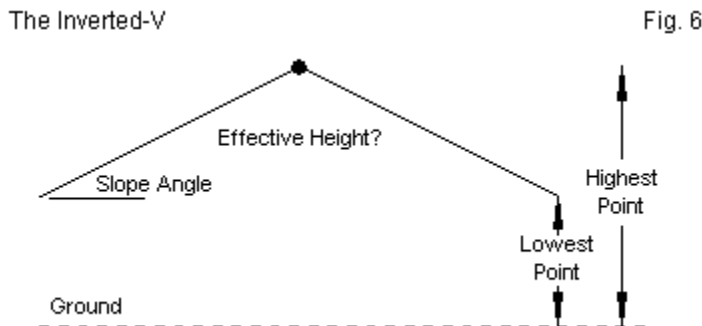
There is a rule of thumb: the *effective height* of an antenna with multiple height considerations is about 2/3 of the distance between the lowest height and the highest height for the antenna. Like the human thumb, which varies in size and shape from one person to the next, this rule of thumb varies in its accuracy depending on the type of antenna and the actual lowest and highest heights. If we look at several types of antennas and place them at various heights above ground, we might be able to refine the rule. Of course, once we run the exercise,



we likely shall no longer need the rule, since we shall have some data that will allow more precise interpolations.

### Case 1: the Inverted-V

Inverted-V antennas are less common on 20 meters than they are on 160, 80, and 40 meters. However, to be consistent in our comparisons, we shall use a 20-meter wire inverted-V as the subject antenna. We shall seek out the effective height of an inverted-V to see if it corresponds with the lowest point, the highest point, or some other point between the two. **Fig. 6** shows the outline of our project.



One useful way to find an effective height is to compare the inverted-V to a linear dipole. The V is simply a sloping version of the dipole, although the slope does modify the antenna's performance characteristics. Suppose that we take the TO angles for the dipole and move the V up and down until it yields about the same TO angle (within a few tenths of a degree). Then the lowest and highest points of the V will tell us something about how the 2 antennas are related. However, inverted-Vs come in many angles of slope, where the angle of slope is the angle of each half element relative to flat ground. We cannot cover every possible

angle, but we can sample inverted-Vs with slope angles of 30 degrees and 45 degrees.

The 30-Degree V: The data for the 30-degree V appear in **Table 7**, while the patterns are in **Fig. 8**.

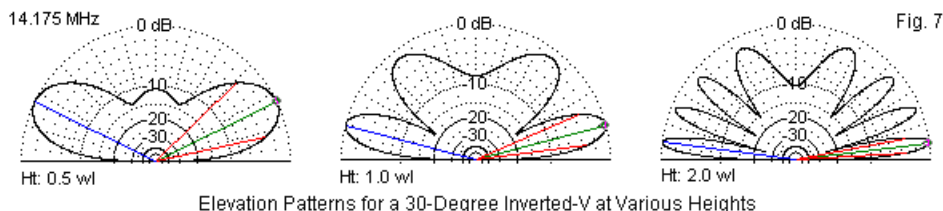


Table 7. First-lobe elevation angle of a 20-meter 30° inverted-V at various heights.

Effective Height (h)	Bottom Height $\lambda$	Top Height $\lambda$	Max. Gain dBi	Elevation angle ( $A_{LN}$ ) degrees	Beamwidth degrees
0.5	0.417	0.54	7.01	27.6	33.5
1.0	0.847	0.97	7.06	14.8	15.9
2.0	1.867	1.99	7.50	7.1	7.4

In the table, note that the left-most column shows the effective height, that is, the physical height that most closely approximates a linear dipole at 0.5, 1.0, or 2.0 wavelengths above ground. The next 2 columns list the lowest and upper heights of the 30-degree V. The remaining data provides a basis for making comparisons with **Table 2**, the data for the linear dipole. We may instantly notice that the 30-degree V has slightly less gain than a linear dipole at the same effective height, but not enough less to be operationally noticeable. As well, if we compare the pattern in **Fig. 7** with those in **Fig. 1**, we can see some small differences, but again, not sufficient to worry us in the least.

Perhaps the most interesting fact to emerge from the data is that the 30-degree V has an apex that is above the dipole height only for the lowest version. As we increase the V's height, the apex height and the effective height come together. (The very slight differences between the top height and the effective height are well within the boundaries for calling them equal, since the TO angles do not change fast enough to allow for greater precision.) Therefore, the rule of thumb, if it applies at all, works only for inverted-Vs with top heights below 1/2 wavelength. Of course, most 30-degree inverted-Vs for 160 through 40 meters tend to be well below 1/2-wavelength at the top, and their ends are much closer to the ground as a fraction of a wavelength. Hence, the 2/3-rule is more likely to be accurate for Vs on the lower HF bands. Higher Vs tend to act almost exactly like linear dipoles with respect to their TO angle.

**The 45-Degree V:** For smaller spaces, amateurs often give the inverted-V a slope angle of up to 45 degrees. What happens with this version of the inverted-V appears in **Fig. 8** and in **Table 8**.

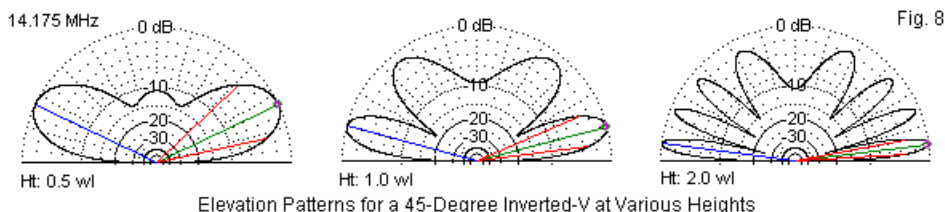


Table 8. First-lobe elevation angle of a 20-meter 45° inverted-V at various heights.

Effective Height (h)	Bottom Height $\lambda$	Top Height $\lambda$	Max. Gain dBi	Elevation angle ( $A_{LN}$ ) degrees	Beamwidth degrees
0.5	0.382	0.56	6.66	27.5	33.6
1.0	0.825	1.00	6.82	14.8	15.7
2.0	1.835	2.01	7.22	7.1	7.4

Since the 45-degree inverted-V patterns are for their effective heights relative to the TO angle of a comparable dipole, they show virtually no difference from the 30-degree V patterns. The clues to the effects of the higher slope angle appear in the numerical data, especially in the gain column. Relative to a dipole, the 45-degree V loses the better part of a dB of gain at every height. The lost gain would reappear in radiation along the axis of the wire. Otherwise, the 45-degree V replicates what we discovered for the 30-degree V. If the height is low, then the apex of the V is above the effective height. The lower the height as a function of a wavelength, the higher the apex will be with respect to the effective height. However, if we raise the 45-degree V to a wavelength, then the apex and the effective height are just about equal. Once more, the 2/3-rule of thumb is applicable only to those low inverted Vs for 160 through 40 meters that we see in backyards.

Note that we are separating the TO angle from the overall pattern shape for the inverted Vs. The maximum gain value is an indicator that an inverted-V's azimuth pattern is likely to be more oval than the azimuth pattern for a linear dipole when both patterns have the same TO angle, that is, are at the same effective height. In a different exercise, we might easily confirm this fact. However, the direction of radiation at the TO angle does not itself effect (and is not affected by) the TO angle to any significant degree. With very low inverted-Vs, the ground can get into the overall sum of influences, but for higher Vs, the TO angle is relatively independent of the gain.

In this exercise, we are working with inverted-V antennas used on their fundamental frequency, that is, when they are about 1/2 wavelength long and close to being resonant. Under these conditions, we see only small differences in performance between the 30-degree and the 45-degree V. Multi-band use of the inverted-V is another matter. In this application, the slope angle may make a big difference in performance on bands well above the fundamental operating frequency

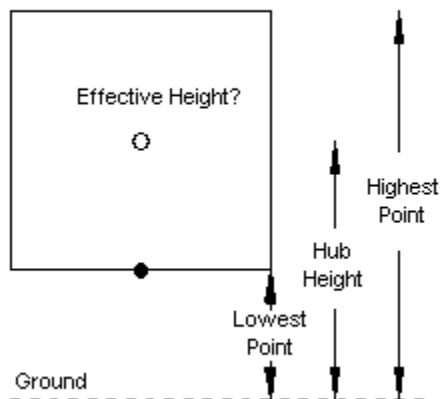
*Case 2: the Quad Beam*

A quad loop consists of two dipoles that are in phase. Because they are only 1/4-wavelength apart, the ends can fold down and touch, forming a continuous loop with a single feedpoint. A single quad loop has a gain advantage over a linear dipole of about 1.15 dB. When we add one or more parasitic loops, we end up with a beam whose principles are the same as for a Yagi with the same number of elements. In this case study, we shall look at 2-element quad beams.

The procedures will be the same as those used with the inverted-V. We need to make two adjustments. The first is to add one more measurement to the list of heights with which we are concerned. Besides the lowest and highest points of the quad loops, we shall also note the height of the boom or the hub. This point is halfway between the upper and lower elements. See **Fig. 9** for an outline of this situation.

The Square Quad Beam

Fig. 9



The square quad beam: Commonly we find two forms of the quad: the square shape and the diamond. (The delta is also a form of quad with 3 sides instead of 4. As well, we can make many-side quad loops, including perfect-or imperfect-circles.) In general, we shall follow the inverted-V procedure, but we also need a new comparator. A quad beam has front-to-back structure. Therefore, we shall use the TO values for the 3-element Yagi as the most similar single-plane antenna. We shall move the quad beam up and down until the TO angle is about the same as we obtained from the Yagi. **Fig. 10** and **Table 9** show the results of our juggling.

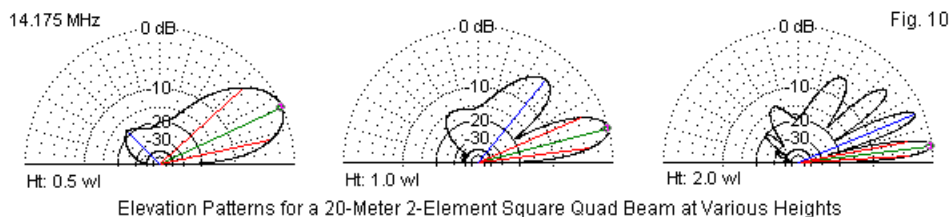


Table 9. First-lobe elevation angle of a 20-meter 2-element square quad beam at various heights.

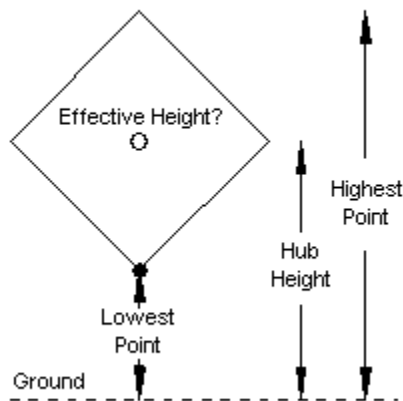
Effective Height (h)	Bottom Height $\lambda$	Hub Height $\lambda$	Top Height $\lambda$	Max. Gain dBi	Elevation angle ( $A_{LN}$ ) degrees	Beamwidth degrees
0.5	0.357	0.490	0.623	11.08	24.7	30.3
1.0	0.784	0.914	1.043	12.08	14.5	15.9
2.0	1.819	1.949	2.078	12.67	7.1	7.3

The patterns for the 2-element square quad resemble those for the 3-element Yagi, but not perfectly. Most of the differences are in the rear quadrants and at the highest angles. The maximum gain of the quad is a little more than 1 dB under the Yagi's capabilities. The physical height midpoint--the hub--is always below the effective height by a few per cent. Otherwise expressed, the effective height is a little more than halfway up the distance between the lower and the upper wires. Had we used the dipole as the comparator for marking effective heights, the difference would have been greater--perhaps enough to approach the 2/3-rule of thumb.

The diamond quad beam: The most common alternative structure for a quad is the diamond, which gives us somewhat different upper and lower points for measurement. Still, as shown in **Fig. 11**, the hub remains at the center of the structure and provides a good point to compare with the effective height.

The Diamond Quad Beam

Fig. 11



In general, the performance of the square and the diamond quads are equivalent. The patterns in **Fig. 12** and the data in **Table 10** bear out this situation. The gain values for the two types of quads do not vary enough at any of the sampled heights to be detected in operation. The patterns at each height are virtually identical to those in **Fig. 10**.

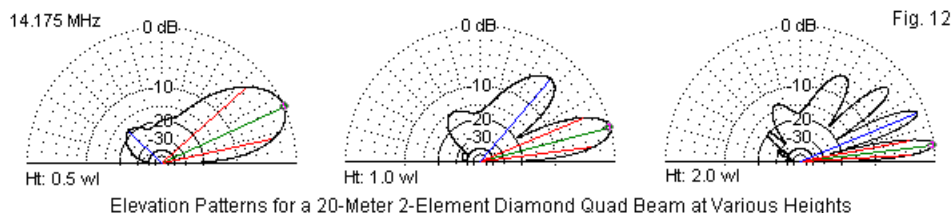


Table 10. First-lobe elevation angle of a 20-meter 2-element diamond quad beam at various heights.

Effective Height (h)	Bottom Height $\lambda$	Hub Height $\lambda$	Top Height $\lambda$	Max. Gain dBi	Elevation angle ( $A_{LN}$ ) degrees	Beamwidth degrees
0.5	0.325	0.503	0.681	11.13	24.5	29.6
1.0	0.752	0.930	1.108	12.04	14.4	15.6
2.0	1.752	1.930	2.108	12.56	7.1	7.4

The relationship between the effective heights and the hub heights for the diamond quad also follow the pattern set by the square quad. Had we used a 2-element Yagi as the comparator, its TO angle at the lowest height would have been about midway between the TO angles for the dipole and for the 3-element Yagi. Finding the physical quad height for that slightly higher TO angle would have brought the hub height below 0.5 wavelength. Overall, the hub of the diamond quad is at or below the effective height of the antenna. The average distance from the lowest to the highest points for the effective height is about 56-57% of the total distance. The rule of thumb may use too large a value, but it serves as an indicator that the effective height of a quad is somewhat higher than the hub.

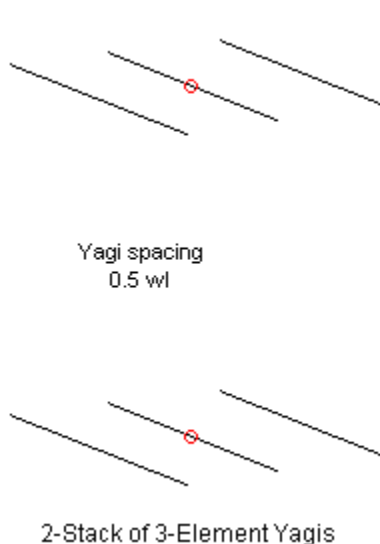
### Stacked Yagis

In the past, stacked Yagis gave a misimpression. Two identical Yagis in a vertical array with both antennas fed in phase certainly yielded more gain than a single Yagi. Some folks also believed that the stack had a TO angle that was lower than the TO angle of either antenna alone. In fact, the TO angle is always lower than the bottom Yagi's solitary TO angle, but it is always higher than the TO of the top



Yagi when used alone. Where in the middle the TO angle lies is what we wish to know. To sample the field, let's stack Yagis at 1/2-wavelength vertical intervals and feed them in phase. The 1/2-wavelength spacing does not yield the highest possible gain. However, it is a convenient height for our work. Once we know the TO angle of the stack, we can set up a single Yagi of the same general type and find the height at which it has the same TO angle as the stack.

A stack of 2 3-element Yagis: The 2-stack is perhaps the simplest place to begin. A 2-stack of 3-element Yagis will add a bit more than 2-dB to the array gain over a single Yagi. **Fig. 13** outlines the stack as a reference.



The tables for our Yagi stacks will differ from preceding ones by listing the heights of the Yagis in the stack. In this case, we shall set the Yagis at 0.5 and 1.0, 1.0 and 1.5, and finally 1.5 and 2.0 wavelengths above ground. The height at

which a single Yagi yields the same TO angle registers the effective height of the array. **Fig. 14** and **Table 11** record the results of our work.

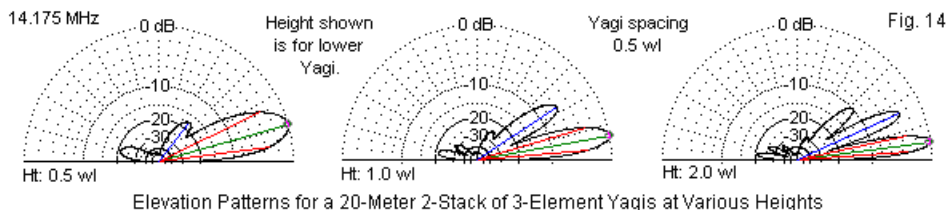


Table 11. First-lobe elevation angle of a 20-meter 2-stack of 3-element Yagis at various heights.

Heights (h) $\lambda$	Max. Gain dBi	Elevation angle ( $A_{LN}$ ) degrees	Beamwidth degrees	Single Yagi height ( $\lambda$ )	Percent of Stack Height
0.5 - 1.0	14.72	15.6	18.0	0.85	70
1.0 - 1.5	15.82	10.3	11.3	1.33	66
1.5 - 2.0	16.20	7.7	8.1	1.79	58

The use of 1/2-wavelength spacing between Yagis changes the appearance of the elevation patterns relative to those for a single Yagi in **Fig. 4**. Half-wavelength spacing tends to suppress very high-angle radiation. Therefore, the highest lobes of the patterns in **Fig. 14** are "under-developed" relative to those in **Fig. 4**.

The most notable aspect of the tabular data is the height of the single Yagi that produces the same TO angle as the stack and its distance from the lowest to the highest beam in the stack. The closer the stack is to the ground, the higher the effective height as measured by the TO angle. With stack heights of 1 and 1.5 wavelengths, the distance just about matches the rule of thumb.

A stack of 3 3-element Yagis: A 3-stack is a major structural undertaking for any amateur, but 3-stacks are quite common among avid DXers and contesters. **Fig. 15** outlines the 3-stack situation.

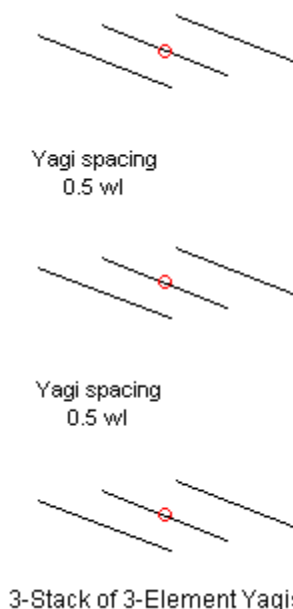


Fig. 15

I shall follow the same procedure for the 3-stack that I used for the 2-stack. The only difference in the tabular data is that the basic height column will list 3 values. The bottom heights will be 0.5, 1.0, and 1.5 wavelengths, with corresponding middle and top heights at 0.5-wavelength intervals. Once we know the stack TO angle, we can set a single 3-element Yagi at a height that produces the same TO angle and call that the effective height of the stack. **Fig. 16** and **Table 12** provide the patterns and the numerical data.

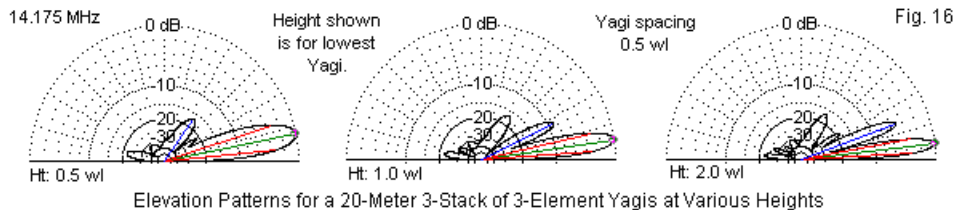


Table 12. First-lobe elevation angle of a 20-meter 3-stack of 3-element Yagis at various heights.

Heights (h) $\lambda$	Max. Gain dBi	Elevation angle ( $A_{LN}$ ) degrees	Beamwidth degrees	Single Yagi height ( $\lambda$ )	Percent of Stack Height
0.5 - 1.0 - 1.5	16.26	11.4	12.9	1.19	69
1.0 - 1.5 - 2.0	17.29	8.5	9.2	1.61	61
1.5 - 2.0 - 2.5	17.72	6.7	7.0	2.05	55

The 3-stack patterns show relatively greater suppression of higher-angle lobes than for a single Yagi or for a 2-stack. The most significant data in the table (with respect to this exercise) is the range of effective stack heights. The range runs from 69% of the distance from the lowest to the highest antenna in the stack for the lowest array down to 55% for the highest set of 3 Yagis. The distances are slightly lower than for the 2-stack when measured as a percentage of the distance from stack bottom to top, but still close enough to the rule of thumb to make it a useful quick estimate.

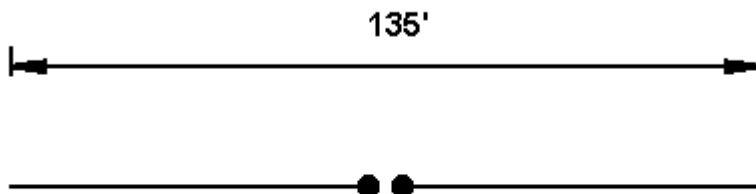
## Conclusion

We have looked at the basics of antenna height and its relationship to the elevation angle of the lowest lobe--the one that we tend to presume is doing most of the work in long-distance amateur communications in the HF range. Because antennas having horizontal polarization but a vertical physical dimension present complex situations, we examined a number of typical antennas in this very general class. The lower that we place an inverted-V, the closer it comes to meeting the rule of thumb, but as we raise the V, the more its TO angle corresponds to the angle for a linear dipole. Quads and Yagi stacks respond in a

different manner. The effective height of these types of arrays is always above the mid-point between the lowest and the highest points in the array. While the rule of thumb is inadequate to precisely characterize the effective height of these types of antennas, it is rarely much off the mark to say that the effective height is about  $2/3$  the way from array bottom to array top. If you have a special interest in any one of the antenna types in our little survey, the tabular data will provide a more accurate means of estimating the effective height for the antennas that you encounter.

## Chapter 7: Most Popular Multiband Wire Antenna

The most popular multiband wire antenna is the 80-meter dipole fed with parallel transmission line and an antenna tuning unit (ATU). It goes under many names. Likewise, it has many recommended lengths. We shall somewhat arbitrarily use 135' as our length. The models will assume #14 copper wire over average earth. Figure 1 illustrates the antenna.



**Figure 1. The 135' multiband doublet**

It is important to understand that the pattern of lobes and nulls varies with each band. This information is useful for orienting the antenna and for properly anticipating performance. The precise length of the antenna between 130' and 140' will have little effect on the individual band patterns.

Changes of length will have a more profound effect upon the feedpoint impedance, as will changes of height. In contrast, changes of wire diameter between AWG #18 and #10 will have little noticeable effect.

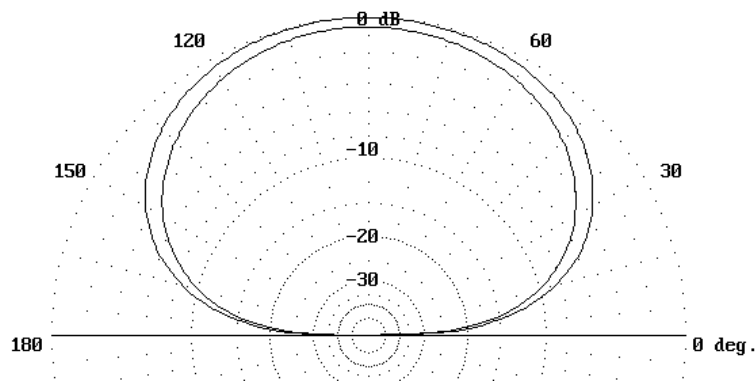
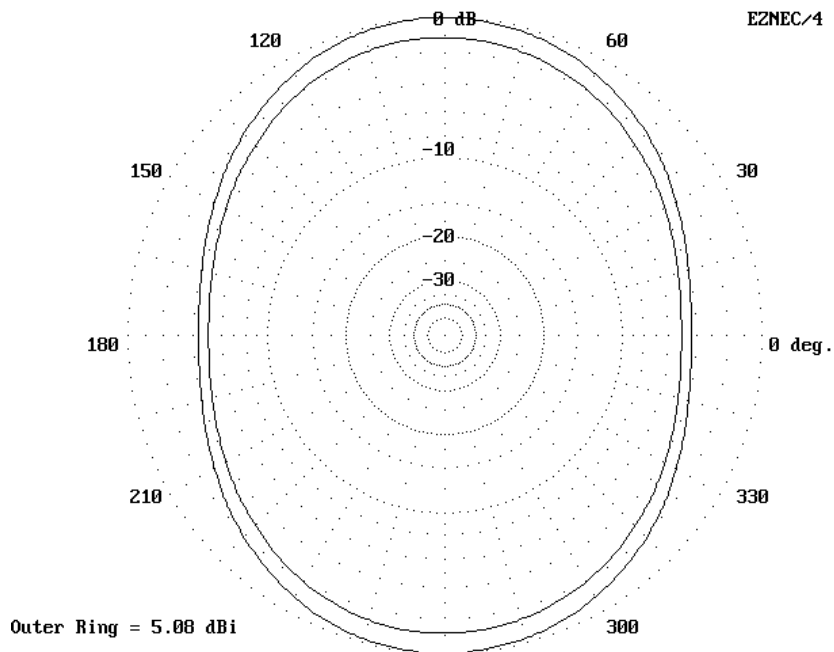
The pages to follow are designed to allow the antenna builder to have some reasonable expectations both for antenna patterns and for impedances presented to the ATU by the antenna and its feedline. Each column in the

following pages is devoted to the performance of the antenna on one of the HF bands from 80 to 10 meters. For each band there is a composite pattern plot and a pair of tables.

The patterns show NEC-2 plots of the antenna at heights of 35' and 50'. The 35' pattern is always the inner or weaker of the two patterns. If the angle of maximum radiation is greater than  $45^\circ$ , then the azimuth pattern is taken at an elevation angle of  $45^\circ$ . If the angle of maximum radiation is less than  $45^\circ$ , then the take-off angle is used. The elevation patterns are taken at the azimuth angle of the strongest lobe. Therefore, interpreting the patterns requires that you consider azimuth and elevation together.

The tables list, in highly rounded numbers, the impedance presented along parallel transmission lines every  $20^\circ$  (electrical) for a half wavelength. Standard 450-ohm (Velocity Factor = 0.95) and 300-ohm (VF = 0.80) lines are given. Note that each electrical degree represents a different length in feet and meters for each band and line type. Values are for lossless lines from the 50' high antenna.

Since impedance values repeat themselves every  $180^\circ$  along a feedline, you may estimate (very broadly at best) the impedance presented to your ATU. Divide the length in feet or meters of your transmission line by the length of a half-wavelength ( $180^\circ$ ) of the same line. Ignore the integer and multiply the fraction of a half wavelength by 180 to arrive at the value in degrees to check against the applicable table.





80 meters: 3.6 MHz

AZ plots: Elevation angles = 45°

EL plots: Azimuth angles = 90°

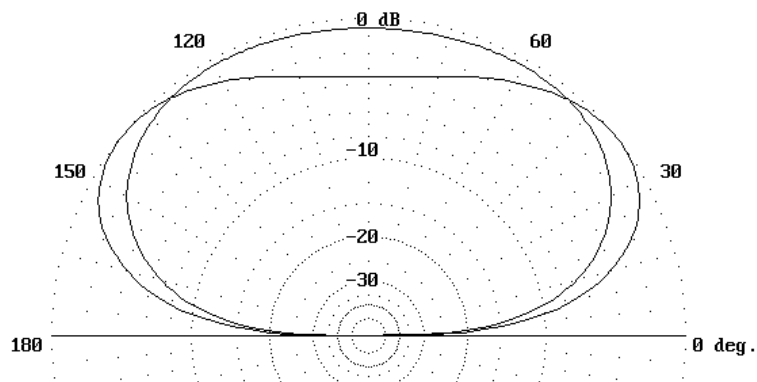
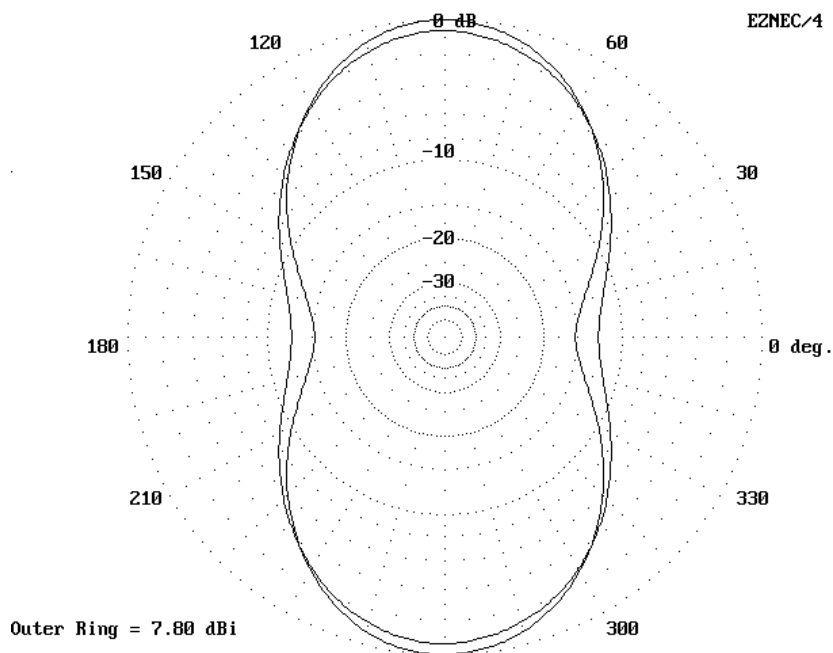
Feedpoint Z ( $R \pm jX$ ): 75 + 55 ohms

TL = 450 ohm; VF = .95

Deg	Feet	Meters	$R \pm jX$ (ohms)
0	0	0	75 + 55
20	14.4	4.4	95 + 220
40	28.8	8.8	155 + 455
60	43.3	13.2	420 + 890
80	57.7	17.6	2450 + 770
100	72.1	22.0	680 - 1107
120	86.5	26.4	200 - 555
140	101.0	30.8	105- 280
160	115.4	35.2	80 - 100
180	129.8	39.6	75 + 55

TL = 300 ohm; VF = .80

Deg	Feet	Meters	$R \pm jX$ (ohms)
0	0	0	75 + 55
20	12.1	3.7	95 + 165
40	24.3	7.4	170 + 315
60	36.4	11.1	450 + 540
80	48.6	14.8	1220 - 55
100	60.7	18.5	415 - 525
120	72.9	22.2	160 - 305
140	85.0	25.9	95 - 155
160	97.1	29.6	75 - 45
180	109.3	33.3	75 + 55



40 meters: 7.15 MHz

AZ plots: El. Angle = 45° @ 35';  
39° @ 50'

EL plots: Az. Angles =  $90^\circ$

Feedpoint Z ( $R \pm jX$ ): 4760 - 1270 ohms

TL = 450 ohms; VF = .95

Seq	Feet	Meters	R ± jX (ohms)
1	10	3.05	0.0000 ± j0.0000
2	20	6.10	0.0000 ± j0.0000
3	30	9.14	0.0000 ± j0.0000
4	40	12.19	0.0000 ± j0.0000
5	50	15.24	0.0000 ± j0.0000
6	60	18.29	0.0000 ± j0.0000
7	70	21.34	0.0000 ± j0.0000
8	80	24.38	0.0000 ± j0.0000
9	90	27.43	0.0000 ± j0.0000
10	100	30.48	0.0000 ± j0.0000
11	110	33.53	0.0000 ± j0.0000
12	120	36.58	0.0000 ± j0.0000
13	130	39.63	0.0000 ± j0.0000
14	140	42.67	0.0000 ± j0.0000
15	150	45.72	0.0000 ± j0.0000
16	160	48.77	0.0000 ± j0.0000
17	170	51.82	0.0000 ± j0.0000
18	180	54.87	0.0000 ± j0.0000
19	190	57.92	0.0000 ± j0.0000
20	200	60.97	0.0000 ± j0.0000
21	210	64.02	0.0000 ± j0.0000
22	220	67.07	0.0000 ± j0.0000
23	230	70.12	0.0000 ± j0.0000
24	240	73.17	0.0000 ± j0.0000
25	250	76.22	0.0000 ± j0.0000
26	260	79.27	0.0000 ± j0.0000
27	270	82.32	0.0000 ± j0.0000
28	280	85.37	0.0000 ± j0.0000
29	290	88.42	0.0000 ± j0.0000
30	300	91.47	0.0000 ± j0.0000
31	310	94.52	0.0000 ± j0.0000
32	320	97.57	0.0000 ± j0.0000
33	330	100.62	0.0000 ± j0.0000
34	340	103.67	0.0000 ± j0.0000
35	350	106.72	0.0000 ± j0.0000
36	360	109.77	0.0000 ± j0.0000
37	370	112.82	0.0000 ± j0.0000
38	380	115.87	0.0000 ± j0.0000
39	390	118.92	0.0000 ± j0.0000
40	400	121.97	0.0000 ± j0.0000
41	410	125.02	0.0000 ± j0.0000
42	420	128.07	0.0000 ± j0.0000
43	430	131.12	0.0000 ± j0.0000
44	440	134.17	0.0000 ± j0.0000
45	450	137.22	0.0000 ± j0.0000
46	460	140.27	0.0000 ± j0.0000
47	470	143.32	0.0000 ± j0.0000
48	480	146.37	0.0000 ± j0.0000
49	490	149.42	0.0000 ± j0.0000
50	500	152.47	0.0000 ± j0.0000
51	510	155.52	0.0000 ± j0.0000
52	520	158.57	0.0000 ± j0.0000
53	530	161.62	0.0000 ± j0.0000
54	540	164.67	0.0000 ± j0.0000
55	550	167.72	0.0000 ± j0.0000
56	560	170.77	0.0000 ± j0.0000
57	570	173.82	0.0000 ± j0.0000
58	580	176.87	0.0000 ± j0.0000
59	590	179.92	0.0000 ± j0.0000
60	600	182.97	0.0000 ± j0.0000
61	610	186.02	0.0000 ± j0.0000
62	620	189.07	0.0000 ± j0.0000
63	630	192.12	0.0000 ± j0.0000
64	640	195.17	0.0000 ± j0.0000
65	650	198.22	0.0000 ± j0.0000
66	660	201.27	0.0000 ± j0.0000
67	670	204.32	0.0000 ± j0.0000
68	680	207.37	0.0000 ± j0.0000
69	690	210.42	0.0000 ± j0.0000
70	700	213.47	0.0000 ± j0.0000
71	710	216.52	0.0000 ± j0.0000
72	720	219.57	0.0000 ± j0.0000
73	730	222.62	0.0000 ± j0.0000

$$0 \quad 0 \quad 0 \quad 4760 - 1270$$

20      7.3      2.2      285 - 1085

40      14.5      4.4      90 – 500

60      21.8      6.6      50 - 245

80      29.0      8.9      40 - 70

100    36.3    11.1    40 + 90

120    43.6    13.3    55 + 270

$$140 \quad 50.8 \quad 15.5 \quad 100 + 550$$

160    58.1    17.7    365 + 1240

180    65.3    19.9    4760 - 1270

TL = 300 ohms; VF = .80

Seq	Feet	Meters	R ± jX (ohms)
1	10	3.05	0.0000 + j0.0000
2	20	6.10	0.0000 + j0.0000
3	30	9.14	0.0000 + j0.0000
4	40	12.19	0.0000 + j0.0000
5	50	15.24	0.0000 + j0.0000
6	60	18.29	0.0000 + j0.0000
7	70	21.34	0.0000 + j0.0000
8	80	24.38	0.0000 + j0.0000
9	90	27.43	0.0000 + j0.0000
10	100	30.48	0.0000 + j0.0000
11	110	33.53	0.0000 + j0.0000
12	120	36.58	0.0000 + j0.0000
13	130	39.63	0.0000 + j0.0000
14	140	42.67	0.0000 + j0.0000
15	150	45.72	0.0000 + j0.0000
16	160	48.77	0.0000 + j0.0000
17	170	51.82	0.0000 + j0.0000
18	180	54.87	0.0000 + j0.0000
19	190	57.92	0.0000 + j0.0000
20	200	60.97	0.0000 + j0.0000
21	210	64.02	0.0000 + j0.0000
22	220	67.07	0.0000 + j0.0000
23	230	70.12	0.0000 + j0.0000
24	240	73.17	0.0000 + j0.0000
25	250	76.22	0.0000 + j0.0000
26	260	79.27	0.0000 + j0.0000
27	270	82.32	0.0000 + j0.0000
28	280	85.37	0.0000 + j0.0000
29	290	88.42	0.0000 + j0.0000
30	300	91.47	0.0000 + j0.0000
31	310	94.52	0.0000 + j0.0000
32	320	97.57	0.0000 + j0.0000
33	330	100.62	0.0000 + j0.0000
34	340	103.67	0.0000 + j0.0000
35	350	106.72	0.0000 + j0.0000
36	360	109.77	0.0000 + j0.0000
37	370	112.82	0.0000 + j0.0000
38	380	115.87	0.0000 + j0.0000
39	390	118.92	0.0000 + j0.0000
40	400	121.97	0.0000 + j0.0000
41	410	125.02	0.0000 + j0.0000
42	420	128.07	0.0000 + j0.0000
43	430	131.12	0.0000 + j0.0000
44	440	134.17	0.0000 + j0.0000
45	450	137.22	0.0000 + j0.0000
46	460	140.27	0.0000 + j0.0000
47	470	143.32	0.0000 + j0.0000
48	480	146.37	0.0000 + j0.0000
49	490	149.42	0.0000 + j0.0000
50	500	152.47	0.0000 + j0.0000
51	510	155.52	0.0000 + j0.0000
52	520	158.57	0.0000 + j0.0000
53	530	161.62	0.0000 + j0.0000
54	540	164.67	0.0000 + j0.0000
55	550	167.72	0.0000 + j0.0000
56	560	170.77	0.0000 + j0.0000
57	570	173.82	0.0000 + j0.0000
58	580	176.87	0.0000 + j0.0000
59	590	179.92	0.0000 + j0.0000
60	600	182.97	0.0000 + j0.0000
61	610	186.02	0.0000 + j0.0000
62	620	189.07	0.0000 + j0.0000
63	630	192.12	0.0000 + j0.0000
64	640	195.17	0.0000 + j0.0000
65	650	198.22	0.0000 + j0.0000
66	660	201.27	0.0000 + j0.0000
67	670	204.32	0.0000 + j0.0000
68	680	207.37	0.0000 + j0.0000
69	690	210.42	0.0000 + j0.0000
70	700	213.47	0.0000 + j0.0000
71	710	216.52	0.0000 + j0.0000
72	720	219.57	0.0000 + j0.0000
73	730	222.62	0.0000 + j0.0000

$$0 \quad 0 \quad 0 \quad 4760 - 1270$$

20      6.1      1.9      135 - 765

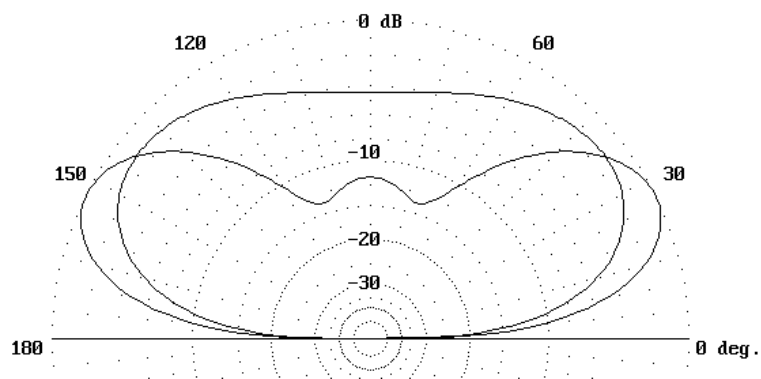
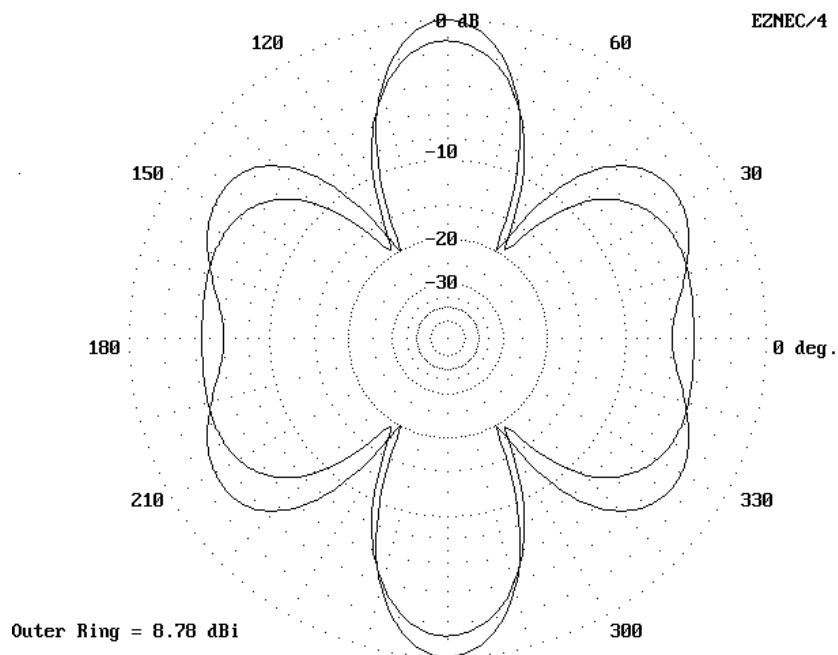
40 12.2 3.7 40 - 345

60      18.3      5.6      25 - 165

80      24.5      7.5      20 - 50

$$100 \quad 30.6 \quad 9.3 \quad 18.3 + 60$$
$$120 \quad 36.7 \quad 11.2 \quad 25 + 180$$
$$140 \quad 42.8 \quad 13.0 \quad 45 + 365$$
$$160 \quad 48.9 \quad 14.9 \quad 160 + 840$$

180    55.0    16.8    4760 - 1270



30 meters: 10.125 MHz

AZ plots: El. Angle = 39° @ 35';  
27° @ 50'

EL plots: Az. Angles = 90°

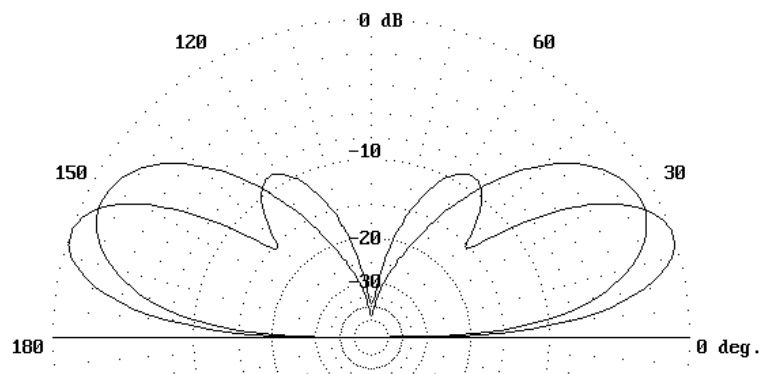
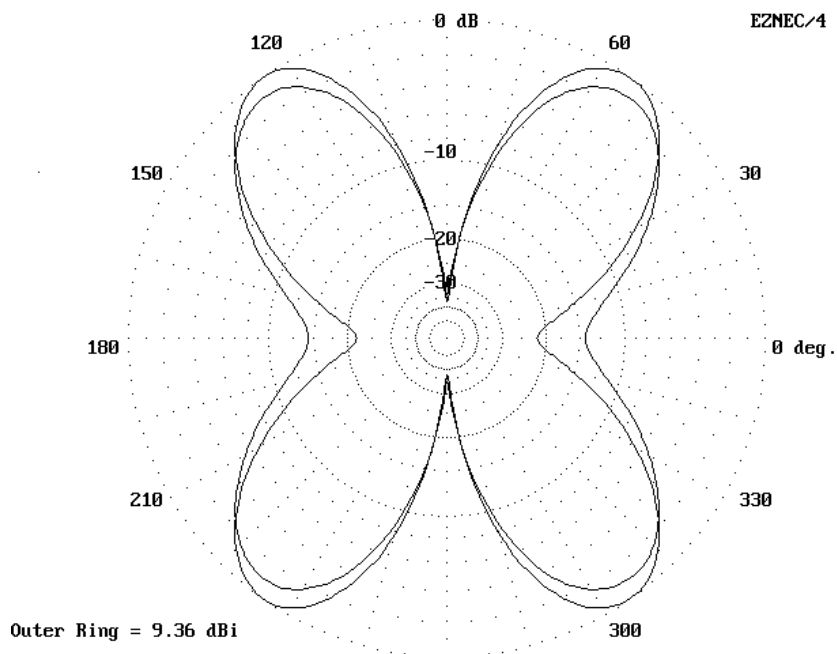
Feedpoint Z ( $R \pm jX$ ): 95 - 330 ohms

TL = 450 ohm; VF = .95

Deg	Feet	Meters	$R \pm jX$ (ohms)
0	0	0	95 - 330
20	5.1	1.6	65 - 135
40	10.3	3.1	60 + 20
60	15.4	4.7	70 + 185
80	20.5	6.3	110 + 405
100	25.6	7.8	270 + 805
120	30.8	9.4	1805 + 1645
140	35.9	10.9	910 - 1445
160	41.0	12.5	195 - 655
180	46.1	14.1	95 - 330

TL = 300 ohms; VF = .80

Deg	Feet	Meters	$R \pm jX$ (ohms)
0	0	0	95 - 330
20	4.3	1.3	55 - 165
40	8.6	2.6	40 - 45
60	13.0	4.0	40 + 55
80	17.3	5.3	55 + 175
100	21.6	6.6	100 + 350
120	25.9	7.9	330 + 730
140	30.2	9.2	2160 - 230
160	34.5	10.5	290 - 685
180	38.9	11.8	95 - 330



20 meters: 14.15 MHz

AZ plots: El. Angle = 27° @ 35';  
19° @ 50'

EL plots: Az. Angles = 52° @ 35';  
55° @ 50'

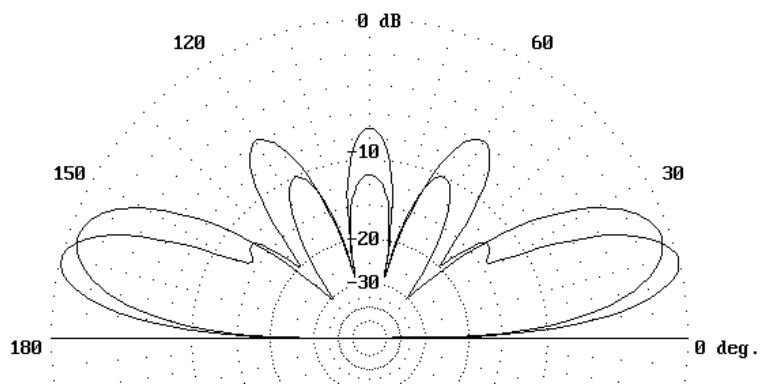
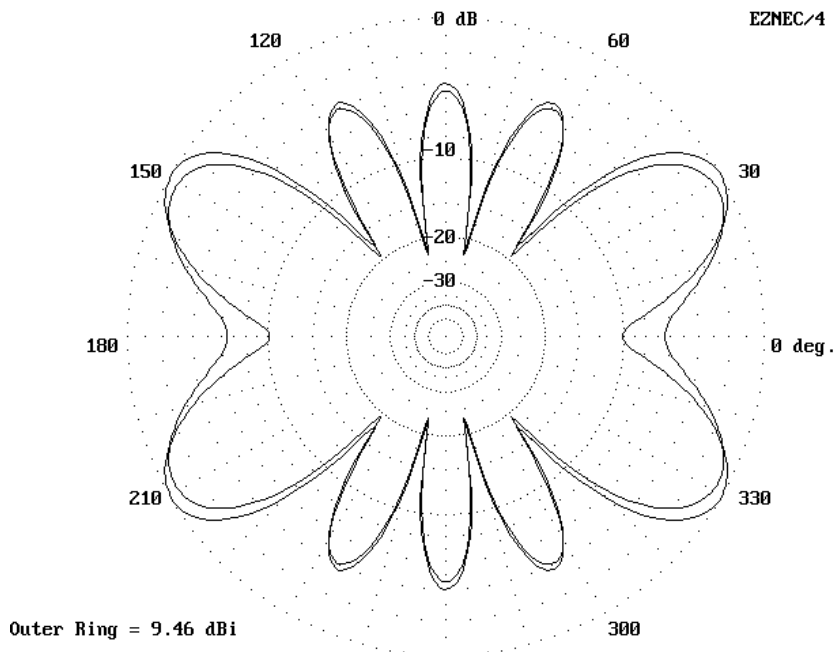
Feedpoint Z ( $R \pm jX$ ): 4270 - 1005 ohms

TL = 450 ohm; VF = .95

Deg	Feet	Meters	$R \pm jX$ (ohms)
0	0	0	4270 - 1005
20	3.8	1.1	405 - 1215
40	7.3	2.2	115 - 550
60	11.0	3.4	60 - 270
80	14.7	4.5	45 - 90
100	18.3	5.6	45 + 70
120	22.0	6.7	60 + 240
140	25.7	7.8	100 + 500
160	29.4	9.0	320 + 1070
180	33.0	10.1	4270 + 1005

TL = 300 ohm; VF = .80

Deg	Feet	Meters	$R \pm jX$ (ohms)
0	0	0	4270 - 1005
20	3.1	0.9	180 - 830
40	6.2	1.9	50 - 365
60	9.3	2.8	25 - 180
80	12.4	3.8	20 - 60
100	15.5	4.7	20 + 50
120	18.5	5.7	25 + 165
140	21.6	6.6	45 + 345
160	24.7	7.5	150 + 760
180	27.8	8.5	4270 - 1005





17 meters: 18.1 MHz

AZ plots: El. Angle = 19° @ 35';  
14° @ 50'

EL plots: Az. Angles = 29° @ 35';  
30° @ 50'

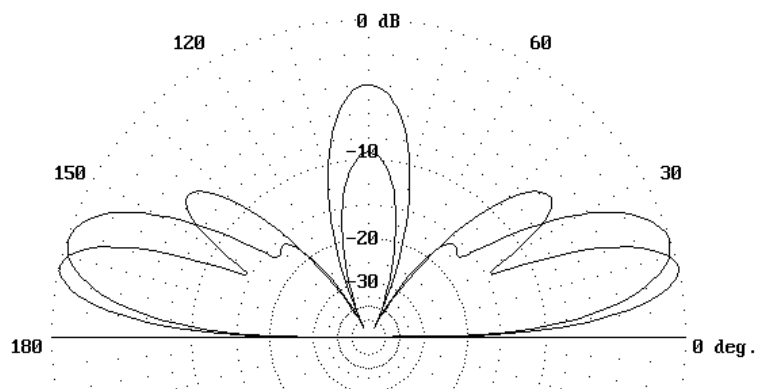
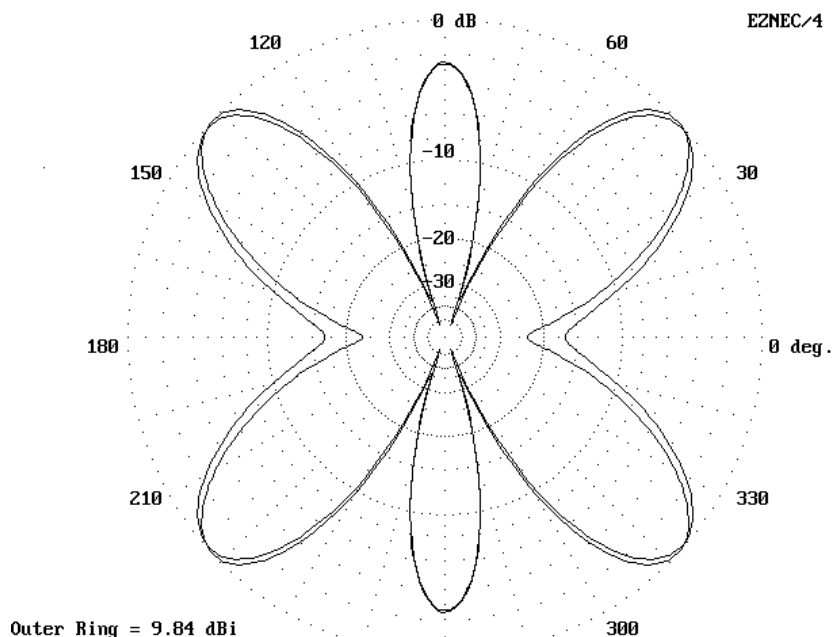
Feedpoint Z ( $R \pm jX$ ): 125 + 5 ohms

TL = 450 ohm; VF = .95

Deg	Feet	Meters	$R \pm jX$ (ohms)
0	0	0	125 + 5
20	2.9	0.9	145 + 155
40	5.7	1.8	205 + 335
60	8.6	2.6	420 + 585
80	11.5	3.5	1210 + 645
100	14.3	4.4	1155 - 670
120	17.2	5.2	400 - 575
140	20.1	6.1	205 - 325
160	22.9	7.0	140 - 145
180	25.8	7.9	125 + 5

TL = 300 ohm; VF = .80

Deg	Feet	Meters	$R \pm jX$ (ohms)
0	0	0	125 + 5
20	2.4	0.7	140 + 90
40	4.8	1.5	195 + 185
60	7.3	2.2	340 + 280
80	9.7	2.9	635 + 195
100	12.1	3.7	610 - 215
120	14.5	4.4	320 - 275
140	16.9	5.2	190 - 180
160	19.3	5.9	140 - 85
180	21.7	6.6	125 + 5



15 meters: 21.15 MHz

AZ plots: El. Angle = 18° @ 35';  
13° @ 50'

EL plots: Az. Angles = 41° @ 35';  
43° @ 50'

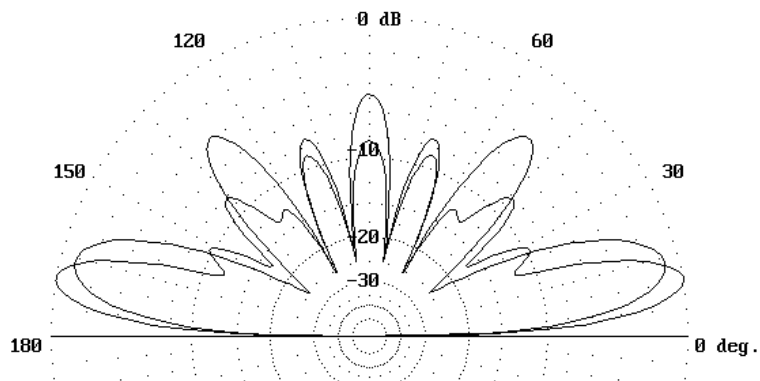
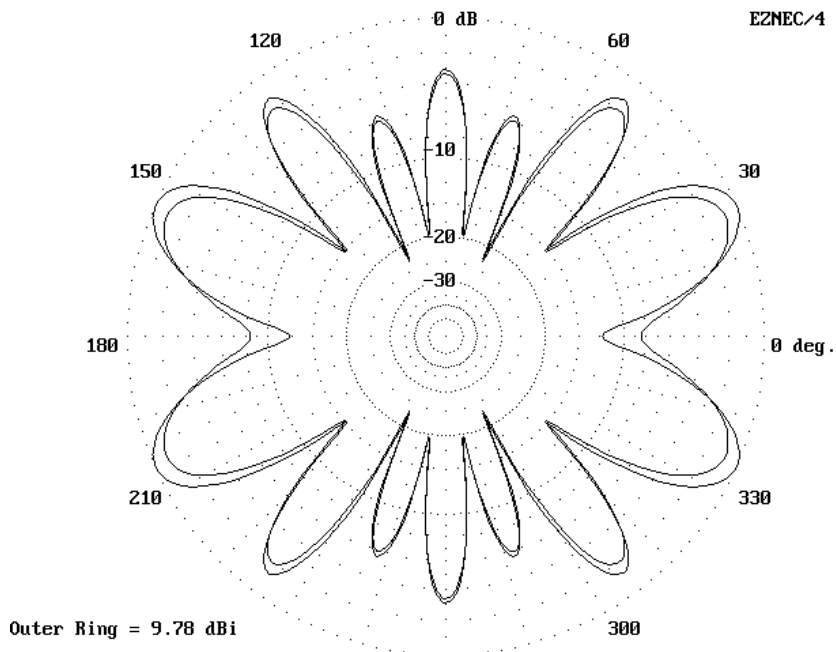
Feedpoint Z ( $R \pm jX$ ): 2330 + 1435 ohms

TL = 450 ohms; VF = .95

Deg	Feet	Meters	$R \pm jX$ (ohms)
0	0	0	2330 + 1435
20	2.5	0.8	735 - 1300
40	4.9	1.5	185 - 605
60	7.4	2.2	90 - 305
80	9.8	3.0	65 - 120
100	12.3	3.7	65 + 40
120	14.7	4.5	75 + 205
140	17.2	5.2	125 + 435
160	19.6	6.0	320 + 870
180	22.1	6.7	2330 + 1435

TL = 300 ohm; VF = .80

Deg	Feet	Meters	$R \pm jX$ (ohms)
0	0	0	2330 + 1435
20	2.1	0.6	310 - 905
40	4.1	1.3	75 - 395
60	6.2	1.9	40 - 195
80	8.3	2.5	30 - 70
100	10.3	3.2	30 + 35
120	12.4	3.8	35 + 150
140	14.5	4.4	60 + 310
160	16.5	5.0	170 + 660
180	18.6	5.7	2330 + 1435



12 meters: 24.95 MHz

AZ plots: El. Angle = 14° @ 35';  
10° @ 50'

EL plots: Az. Angles = 23° @ 35';  
24° @ 50'

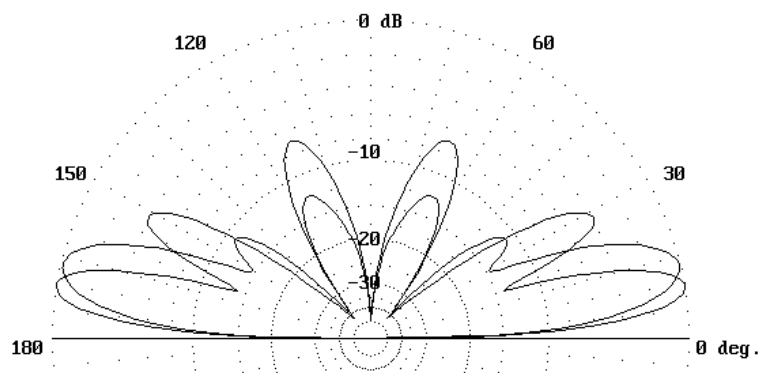
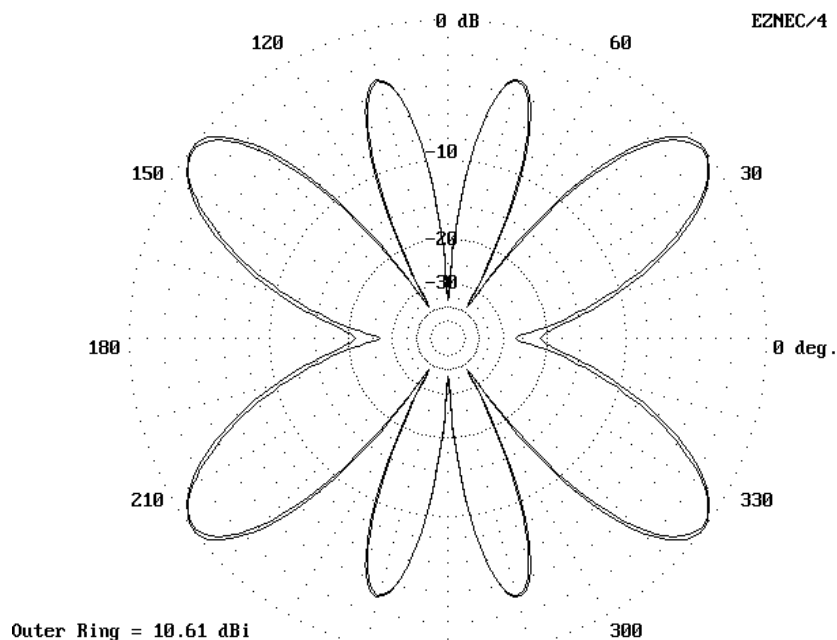
Feedpoint Z ( $R \pm jX$ ): 130 - 180 ohms

TL = 450 ohm; VF = .95

Deg	Feet	Meters	$R \pm jX$ (ohms)
0	0	0	130 - 180
20	2.1	0.6	110 - 25
40	4.2	1.3	120 + 130
60	6.2	1.9	170 + 305
80	8.3	2.5	325 + 565
100	10.4	3.2	1020 + 855
120	12.5	3.8	1490 - 675
140	14.6	4.4	440 - 670
160	16.6	5.1	200 - 375
180	18.7	5.7	130 - 180

TL = 300 ohm; VF = .80

Deg	Feet	Meters	$R \pm jX$ (ohms)
0	0	0	130 - 180
20	1.8	0.5	100 - 70
40	3.5	1.1	95 + 25
60	5.3	1.6	110 + 125
80	7.0	2.1	170 + 250
100	8.8	2.7	370 + 410
120	10.5	3.2	920 + 205
140	12.3	3.7	575 - 440
160	14.0	4.3	230 - 320
180	15.8	4.8	130 - 180



10 meters: 28.5 MHz

AZ plots: El. Angle = 13° @ 35';  
                                   10° @ 50'

EL plots: Az. Angles = 36° @ 35';  
                                   37° @ 50'

Feedpoint Z ( $R \pm jX$ ): 2070 + 1225 ohms

TL = 450 ohms; VF = .95

Deg	Feet	Meters	$R \pm jX$ (ohms)
0	0	0	2070 + 1225
20	1.8	0.6	835 - 1230
40	3.6	1.1	215 - 605
60	5.5	1.7	105 - 310
80	7.3	2.2	75 - 120
100	9.1	2.8	70 + 35
120	10.9	3.3	85 + 200
140	12.8	3.9	135 + 420
160	14.6	4.4	345 + 825
180	16.4	5.0	2070 + 1225

TL = 300 ohms; VF = .80

Deg	Feet	Meters	$R \pm jX$ (ohms)
0	0	0	2070 + 1225
20	1.5	0.5	360 - 895
40	3.1	0.9	90 - 395
60	4.6	1.4	45 - 195
80	6.1	1.9	35 - 70
100	7.7	2.3	30 + 35
120	9.2	2.8	40 + 145
140	10.7	3.3	65 + 305
160	12.3	3.7	190 + 640
180	13.8	4.2	2070 + 1225

## Chapter 8: Multiband Dipole for Small Yards

If you cannot fit a 135' dipole in your yard, perhaps an antenna about 102' long will fit. 102' is about  $3/8$  wl at 80 meters, which is about as short as you dare go for decent feedpoint impedances and minimal gain. (In dire circumstances, of course use what you have, even if shorter. It will work, but just not as well as something longer.)

We shall feed the 102' wire with parallel transmission line all the way to the ATU. With this feed system, the exact length is not critical  $\pm 5'$  or so. The patterns will be mostly unaffected, but variations in length and height will change the feedpoint resistance and reactance more significantly.

100' flattops or doublets have been used as long as any old timer remembers. The precise 102' length became famous when G5RV developed a feed system that he hoped would allow hams to use the antenna on harmonically related bands with about 33' of 450-ohms line or 29' of 300-ohms line, and the rest 50-ohms coax. Two problems changed fame into controversy. First, the WARC bands opened, adding nonharmonically related frequencies to the multiband antenna wish list. Second, on the low bands, small changes of length and height alter the feedpoint impedance, thus disrupting the low SWR match effected by the parallel line lengths.

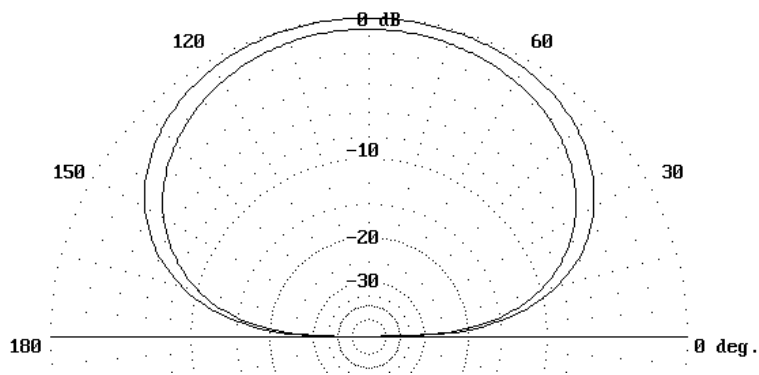
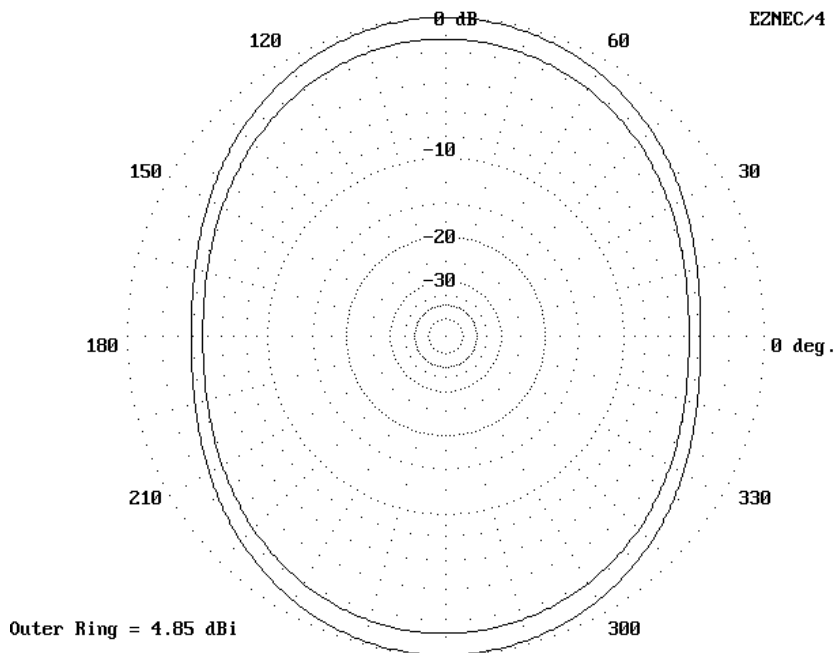
But the 102' doublet (= any center-fed wire) does work well with parallel line all the way to the ATU. However, its patterns and impedances along parallel transmission line differ from those of the 135' dipole. Therefore, the 102' antenna deserves a data compendium of its own.

See the preceding installment of this series for instructions on interpreting the patterns and the feedline impedance tables, along with the method for calculating the ballpark impedance presented to your own ATU.



The line impedances are calculated from the feedpoint impedance of the NEC-2 model of the antenna at a 50' height. For intermediate values at 5 deg. intervals, see the transmission line performance program in HAMCALC. If you need values that account for line loss, ARRL's N6BV has written a fine program, but it calculates one value at a time.

The impedance values are intended only as indicators of the magnitude of resistance and reactance and the rising or falling direction of those magnitudes along the line. The accuracy of the values for any given ham installation, with its typical domestic "clutter," is no more than about 20%, considering variations in height and antenna length. At most, they can tell you that a longer or a shorter line might be better for a given band. In other words, they can suggest why your tuner may be having difficulties in matching the antenna on a given band. It is usually cheaper to add a little line length than to add a new tuner to the system.



80 meters: 3.6 MHz

AZ plots: Elevation angles = 45 deg.

EL plots: Azimuth angles = 90 deg.

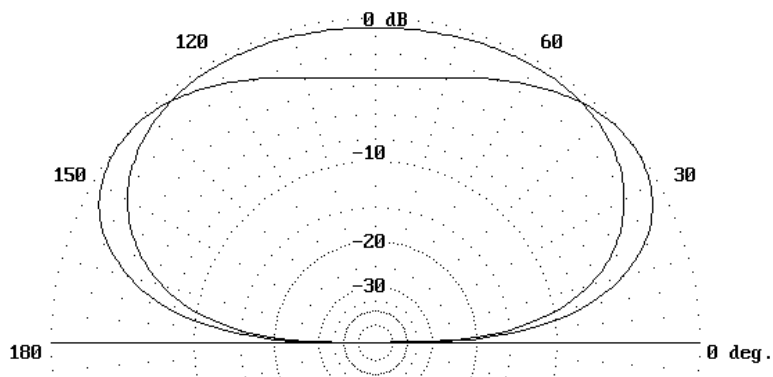
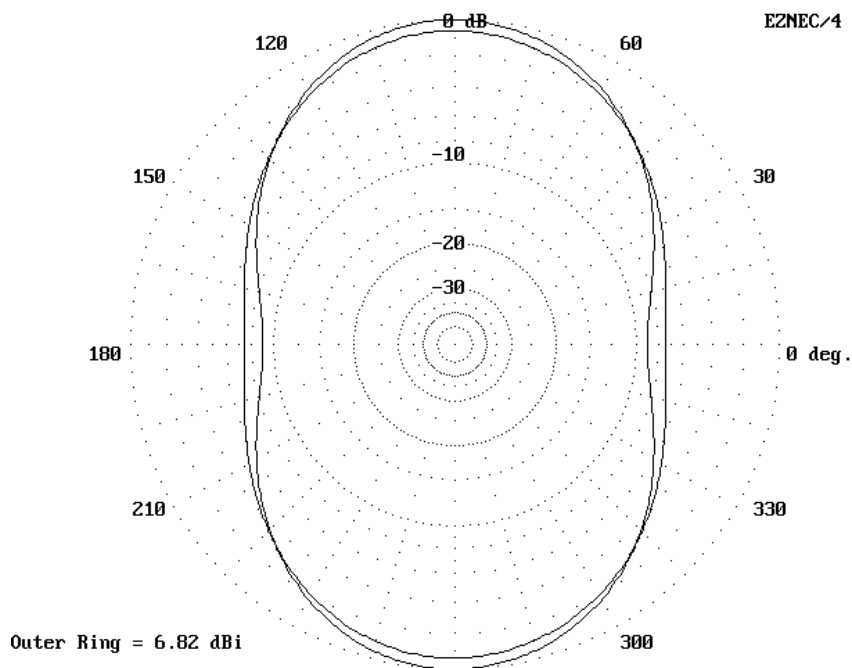
Feedpoint Z ( $R \pm jX$ ): 35 - 420 ohms

TL = 450 ohms; VF = .95

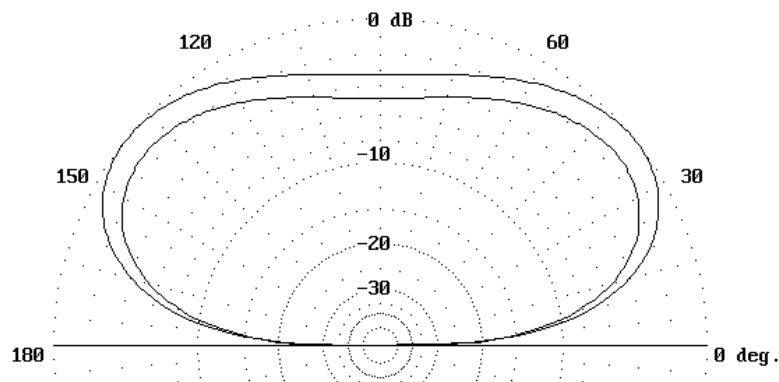
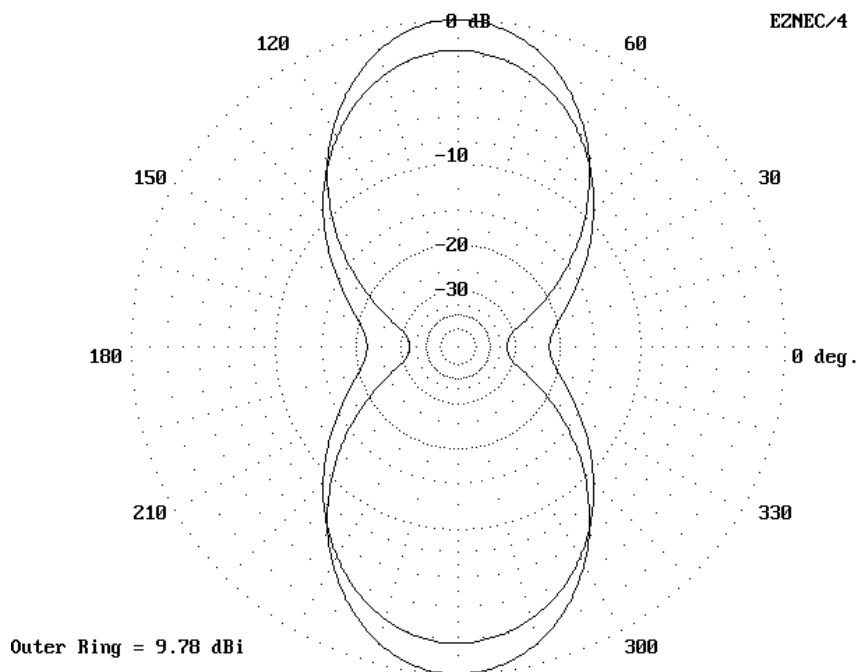
Deg	Feet	Meters	$R \pm jX$ (ohms)
0	0	0	35 - 420
20	14.4	4.4	20 - 190
40	28.8	8.8	20 - 25
60	43.3	13.2	20 + 135
80	57.7	17.6	30 + 335
100	72.1	22.0	60 + 685
120	86.5	26.4	350 + 1870
140	101.0	30.8	1165 - 3330
160	115.4	35.2	90 - 880
180	129.8	39.6	35 - 420

TL = 300 ohms; VF = .80

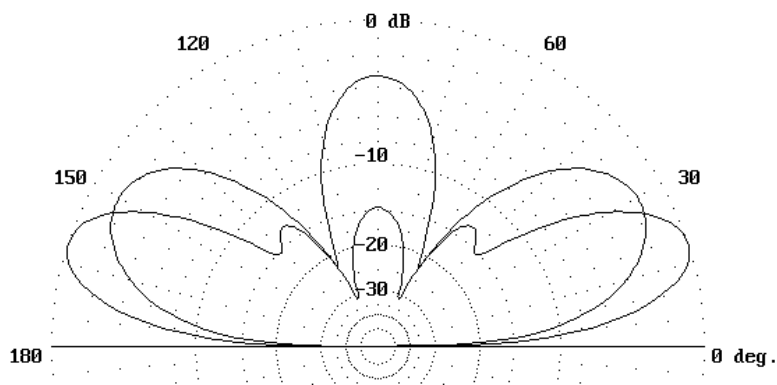
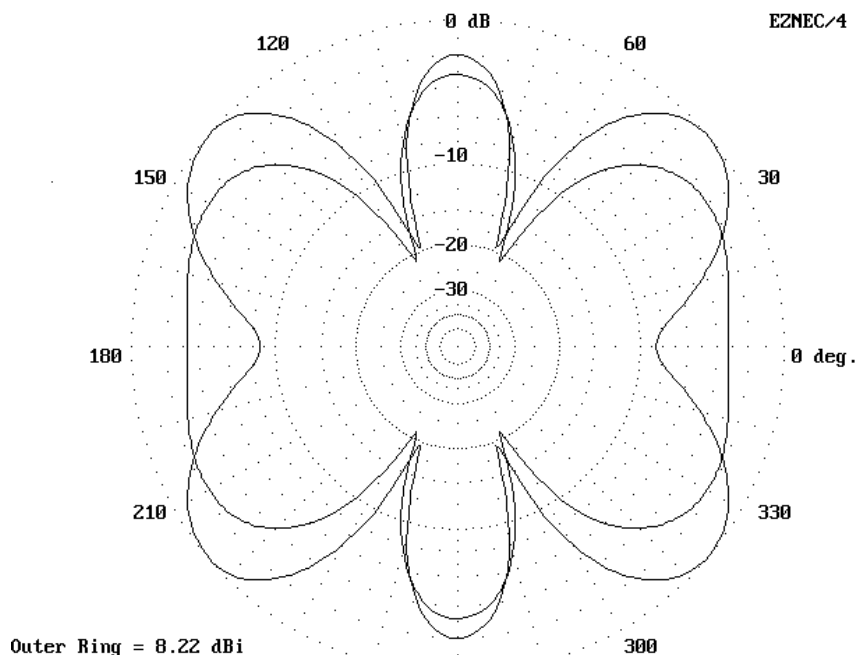
Deg	Feet	Meters	$R \pm jX$ (ohms)
0	0	0	35 - 420
20	12.1	3.7	15 - 205
40	24.3	7.4	15 - 80
60	36.4	11.1	10 + 30
80	48.6	14.8	15 + 140
100	60.7	18.5	25 + 305
120	72.9	22.2	70 + 650
140	85.0	25.9	1475 + 3010
160	97.1	29.6	165 - 1065
180	109.3	33.3	35 - 420













20 meters: 14.15 MHz

AZ plots: El. Angle = 26 deg. @ 35';  
19 deg. @ 50'

EL plots: Az. Angles = 37 deg. @ 35';  
40 deg. @ 50'

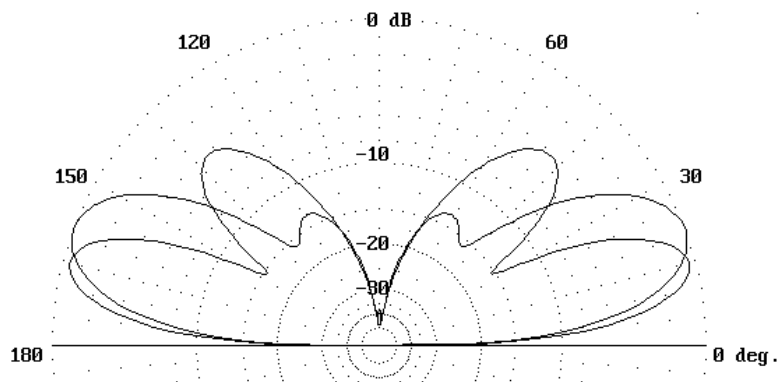
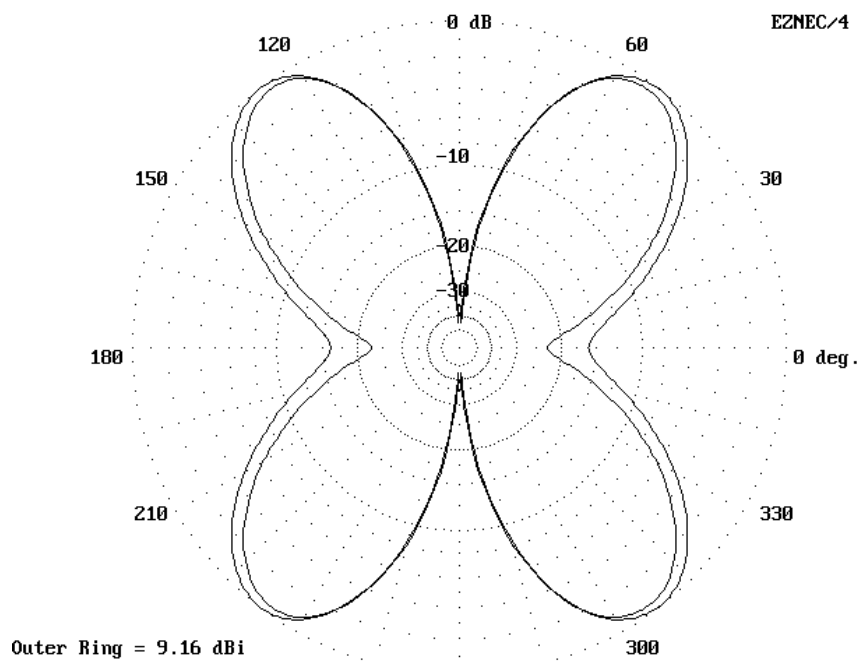
Feedpoint Z ( $R \pm jX$ ): 100 - 50 ohms

TL = 450 ohms; VF = .95

Deg	Feet	Meters	$R \pm jX$ (ohms)
0	0	0	100 - 50
20	3.8	1.1	105 + 100
40	7.3	2.2	140 + 275
60	11.0	3.4	60 - 270
80	14.7	4.5	780 + 930
100	18.3	5.6	1920 - 485
120	22.0	6.7	500 - 790
140	25.7	7.8	200 - 430
160	29.4	9.0	120 - 215
180	33.0	10.1	100 - 50

TL = 300 ohms; VF = .80

Deg	Feet	Meters	$R \pm jX$ (ohms)
0	0	0	100 - 50
20	3.1	0.9	100 + 45
40	6.2	1.9	125 + 145
60	9.3	2.8	200 + 275
80	12.4	3.8	450 + 410
100	15.5	4.7	925 + 25
120	18.5	5.7	475 - 40
140	21.6	6.6	210 - 285
160	24.7	7.5	125 - 155
180	27.8	8.5	100 - 50



17 meters: 18.1 MHz

AZ plots: El. Angle = 21 deg. @ 35';  
15 deg. @ 50'

EL plots: Az. Angles = 54 deg. @ 35'  
54 deg. @ 50'

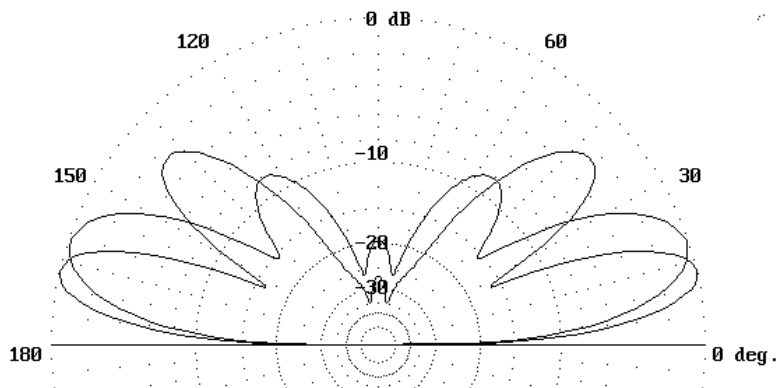
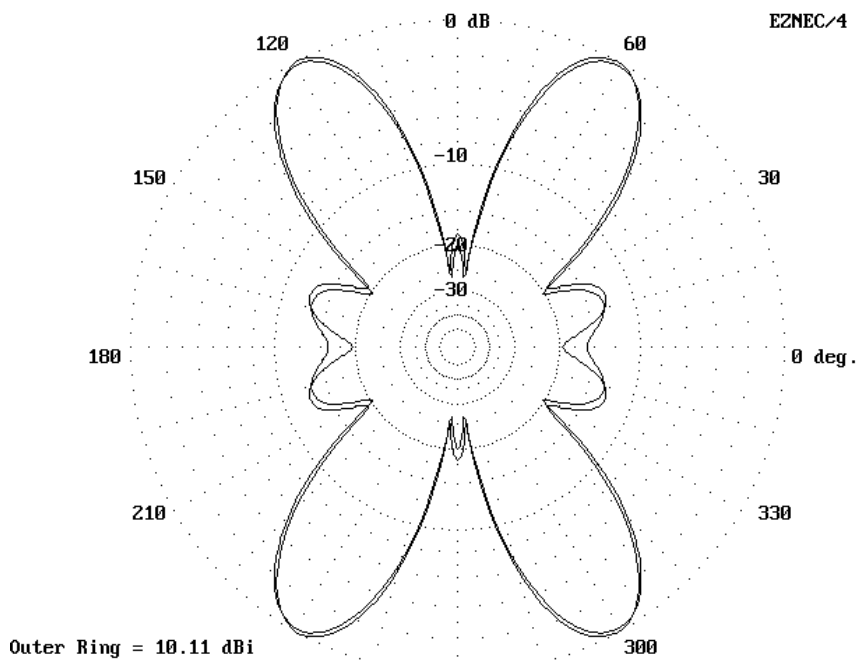
Feedpoint Z (R ± jX): 2040 + 1640 ohms

TL = 450 ohms; VF = .95

Deg	Feet	Meters	R ± jX (ohms)
0	0	0	2040 + 1640
20	2.9	0.9	815 - 1400
40	5.7	1.8	185 - 635
60	8.6	2.6	90 - 320
80	11.5	3.5	65 - 130
100	14.3	4.4	60 + 30
120	17.2	5.2	70 + 195
140	20.1	6.1	110 + 415
160	22.9	7.0	285 + 835
180	25.8	7.9	2040 + 1640

TL = 300 ohms; VF = .80

Deg	Feet	Meters	R ± jX (ohms)
0	0	0	2040 + 1640
20	2.4	0.7	325 - 955
40	4.8	1.5	75 - 405
60	7.3	2.2	40 - 200
80	9.7	2.9	30 - 75
100	12.1	3.7	25 + 30
120	14.5	4.4	30 + 145
140	16.9	5.2	55 + 305
160	19.3	5.9	155 + 640
180	21.7	6.6	2040 + 1640



15 meters: 21.15 MHz

AZ plots: El. Angle = 18 deg. @ 35';  
   13 deg. @ 50'

EL plots: Az. Angles = 60 deg. @ 35'  
   61 deg. @ 50'

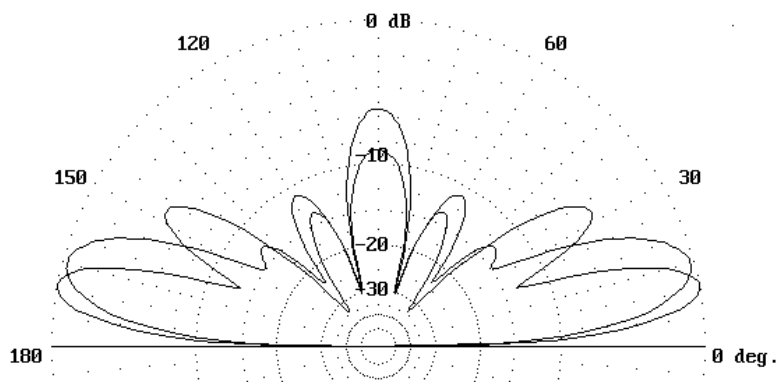
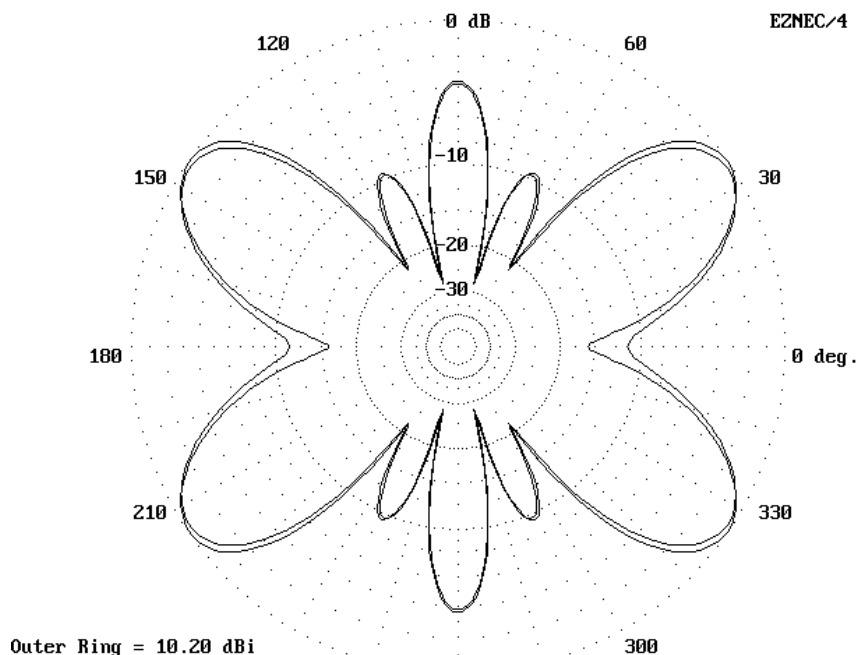
Feedpoint Z ( $R \pm jX$ ): 375 - 1135 ohms

TL = 450 ohms; VF = .95

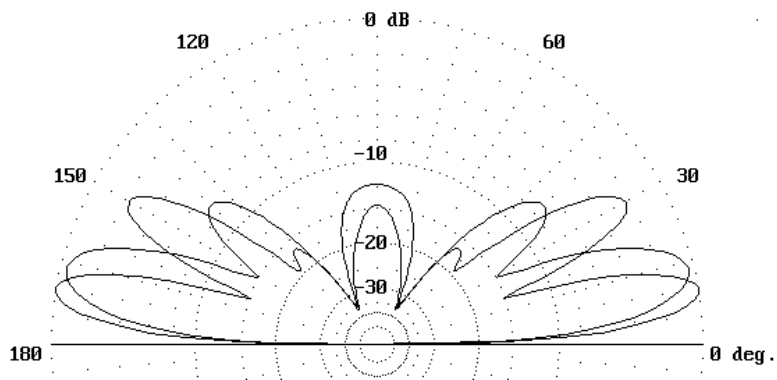
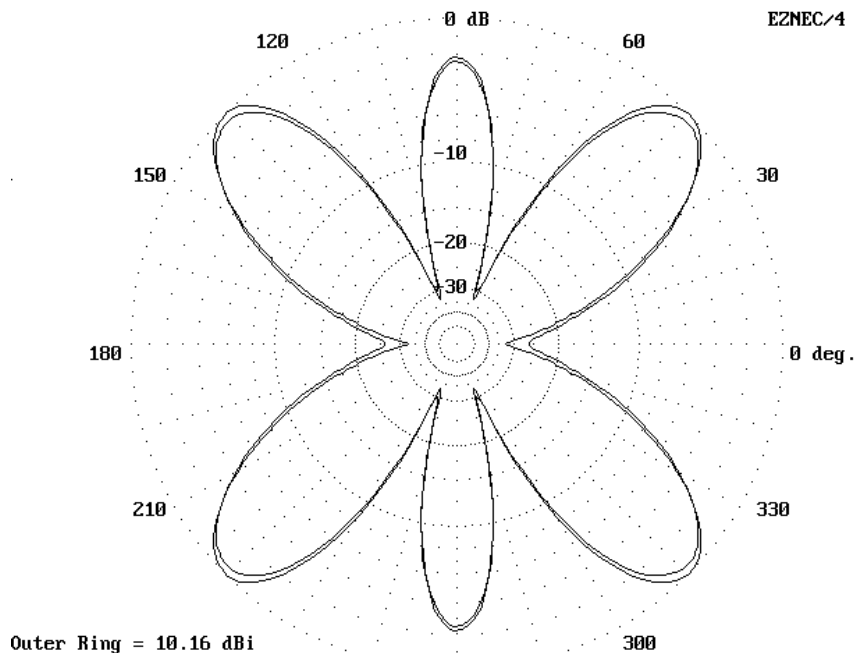
Deg	Feet	Meters	$R \pm jX$ (ohms)
0	0	0	375 - 1135
20	2.5	0.8	115 - 525
40	4.9	1.5	65 - 255
60	7.4	2.2	50 - 80
80	9.8	3.0	50 + 80
100	12.3	3.7	65 + 255
120	14.7	4.5	110 + 520
140	17.2	5.2	370 + 1125
160	19.6	6.0	4300 + 75
180	22.1	6.7	375 - 1135

TL = 300 ohms; VF = .80

Deg	Feet	Meters	$R \pm jX$ (ohms)
0	0	0	375 - 1135
20	2.1	0.6	75 - 445
40	4.1	1.3	35 - 220
60	6.2	1.9	25 - 90
80	8.3	2.5	20 + 20
100	10.3	3.2	25 + 130
120	12.4	3.8	40 + 280
140	14.5	4.4	110 + 585
160	16.5	5.0	1215 + 1830
180	18.6	5.7	375 - 1135









10 meters: 28.5 MHz

AZ plots: El. Angle = 14 deg. @ 35';  
   10 deg. @ 50'

EL plots: Az. Angles = 44 deg. @ 35';  
   44 deg. @ 50'

Feedpoint Z ( $R \pm jX$ ): 3235 - 65 ohms

TL = 450 ohms; VF = .95

Deg	Feet	Meters	$R \pm jX$ (ohms)
0	0	0	3235 - 65
20	1.8	0.6	460 - 1050
40	3.6	1.1	145 - 510
60	5.5	1.7	80 - 250
80	7.3	2.2	65 - 75
100	9.1	2.8	65 + 80
120	10.9	3.3	85 + 255
140	12.8	3.9	150 + 515
160	14.6	4.4	475 + 1065
180	16.4	5.0	3235 - 65

TL = 300 ohms; VF = .80

Deg	Feet	Meters	$R \pm jX$ (ohms)
0	0	0	3235 - 65
20	1.5	0.5	220 - 765
40	3.1	0.9	65 - 350
60	4.6	1.4	35 - 170
80	6.1	1.9	30 - 50
100	7.7	2.3	30 + 55
120	9.2	2.8	35 + 170
140	10.7	3.3	65 + 350
160	12.3	3.7	225 + 770
180	13.8	4.2	3235 - 65

## Chapter 9: The Versatile Sloper for Small Yards

**A** perennial question I receive is about the sloper. This antenna has become very popular for amateurs with limited space under certain conditions. Hence, it seems to deserve some kind of treatment. For reasons that will become clear as we proceed, these notes are about the best I can do in terms of the antenna's basic operating characteristics.

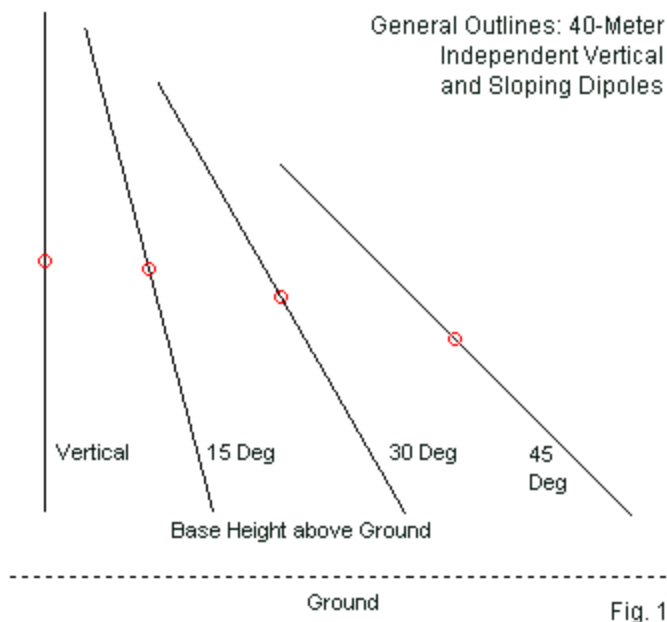
One of the most common sloper installations uses an existing tower that supports a beam at the top as the upper-end support for a sloper. Other amateurs string them from trees or other existing structures. While we can begin by looking at the sloper as if it stood free and clear of everything, reality intrudes its multi-faceted set of interactions that will prevent us from drawing too neat a set of conclusions about sloper performance.

In these notes, we shall work with a sloper made from AWG #12 copper wire. The test frequency will be 7.1 MHz, since the 40-meter band is the lowest band for the common use of a sloping dipole, otherwise known as a full sloper. (A sloper fed at the upper end, nearest the support, has been dubbed a half-sloper.) We shall pose a number of fundamental questions first, such as when a sloper becomes a sloper and not just a vertical with a slight tilt, and what may be the best (rough) angle for a sloper.

Our second set of questions will involve the sloper and its support. We shall begin by contrasting true vertical dipoles and nearby vertical objects with a roughly preferred slope and the vertical object that supports the upper end. Those questions will very quickly become too complex in terms of installation variables for us to give anything like a systematic set of answers. Ultimately, it will become the responsibility of the installer and the user to evaluate whether the sloper is the right antenna for a particular job.

## Vertical and Sloper Basics

Let's begin in the abstract world in which we can construct an antenna that is free and clear of all supports. The world is antenna-modeling software, of course, where we may support an antenna wire simply by specifying its coordinates. This world is limited, but it does offer us the opportunity to contrast true vertical dipoles with slopers having various tilt angles. In all cases, we shall specify a sloper's tilt by its departure from a true vertical orientation. **Fig. 1** shows the range of sloper models that we shall consider.



As the sketch suggests, one of the variables that we can work with within modeling software is the base height of the sloper above ground. Base height

simply means the height of the antenna element's lower end above the surface of the ground. A second variable that we can use in the evaluation of basic performance is the ground quality. We shall use 3 types of ground. At one extreme is very poor ground with a conductivity of 0.001 s/m and a permittivity or dielectric constant of 5. More the norm is the so-called average ground with a conductivity of 0.005 s/m and a permittivity of 13. A few fortunate amateurs live above very good soil with a conductivity of 0.0303 s/m and a permittivity of 20. As we shall see, for any degree of slope from 0 through 45 degrees, both the base height above ground and the ground quality will make a difference in the anticipated performance.

*1. The True Vertical:* A 40-meter vertical dipole is a very useful antenna for amateurs who desire a very low elevation angle and very little radiation at (or reception from) very high angles. **Table 1** catalogs the modeled performance of 7.1-MHz vertical dipoles with base heights from 1' to 20' over each of the three soil types. We can draw a few immediate inferences from the data. First, the greater the base height (up to only the limit of the table), the lower will be the TO angle (take off angle or elevation angle of maximum gain). Second, the better the soil, the higher will be the antenna's gain for any given base height. However, note that over very good soil, the gain peaks with a base height of 10', but over worse soils, the gain continues to increase to the sampled limits. We might also note in passing that the gain variation from the lowest to the highest base level decreases as we improve the soil quality.

Table 1. Vertical dipole at various heights above ground and over different ground qualities

## Very Poor Soil (0.001, 5)

Base Height	Gain dBi	TO Angle degrees	Vert BW degrees	Feedpoint Z R +/- jX $\Omega$
1'	-0.77	21	31	94 + j11
2'	-0.65	21	31	91 + j8
5'	-0.35	20	30	85 + j4
10'	0.05	19	29	78 + j2
15'	0.38	18	28	75 + j3
20'	0.66	18	28	73 + j5

## Average Soil (0.005, 13)

Base Height	Gain dBi	TO Angle degrees	Vert BW degrees	Feedpoint Z R +/- jX $\Omega$
1'	-0.14	18	28	100 + j15
2'	-0.08	18	28	97 + j10
5'	0.05	17	26	89 + j4
10'	0.19	16	24	81 + j1
15'	0.27	15	23	76 + j1
20'	0.29	15	22	73 + j3

## Very Good Soil (0.0303, 20)

Base Height	Gain dBi	TO Angle degrees	Vert BW degrees	Feedpoint Z R +/- jX $\Omega$
1'	1.91	15	27	104 + j19
2'	1.94	14	26	100 + j13
5'	2.02	14	24	93 + j5
10'	2.08	13	22	84 + j0
15'	2.07	12	20	77 - j0
20'	1.97	12	18	73 + j1

Notes: Antenna = AWG #12 copper wire; length = 67.7'

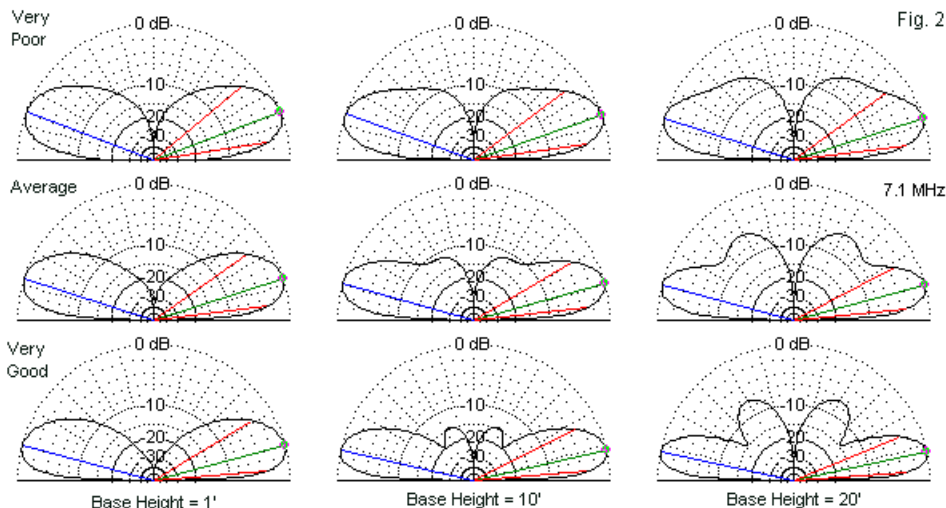
Test Frequency: 7.1 MHz

TO angle = elevation angle of maximum gain

Vert BW = vertical beamwidth in degrees

The feedpoint impedance entries simply give us an idea of how the impedance changes of over each soil type as we change the base height. The model was resonated (approximately) over average soil with a base height of 10'. The data change as a body as we change the soil type. Within each soil type, we find a range of impedance variation that is interesting. The values are always within the range of our ability to prune the dipole length.

The table also lists a vertical beamwidth, the angular distance between the half-power points. To gain a sense of what those values mean to operation, we should examine the gallery of sample patterns in **Fig. 2**. At very low base heights, the pattern shape does not vary much as we change soil types. However, as we increase the base height, we find the emergence of secondary lobes at high elevation angles. At a height of 10', the secondary lobes are not significant, although we should note that as the soil quality improves, the lobes are much more distinct. At a height of 20' at the lower end of the vertical dipole, the secondary high-angle lobes are becoming stronger. This factor may play a role in planning a vertical dipole installation in terms of a compromise between obtaining the lowest TO angle possible and the strength of high-angle noise that we are willing to handle during operation.



Sample Elevation Patterns of a Vertical 40-Meter Dipole  
with Different Base Heights and over Different Ground Qualities

We have reviewed the basic properties of vertical dipoles because these are the antennas against which we measure the potential advantages and disadvantages of a sloper.

**2. The 15-Degree Sloper.** Fortunately, vertical dipole properties do not change rapidly as we tilt the antenna from its initial position. In fact, a 15-degree sloping vertical dipole (using the same base height and ground quality variations) shows very little change in its performance values relative to the vertical dipole. As shown in the data in **Table 2**, the maximum gain and TO-angle values are only marginally higher than those we encountered with the true vertical antenna. The feedpoint impedance values are almost identical.

Table 2. 15° sloping dipole at various heights above ground and over different ground qualities

Very Poor Soil (0.001, 5)

Base Height	Gain dBi	TO Angle degrees	Vert BW degrees	Feedpoint Z R +/- jX $\Omega$
1'	0.35	24	41	94 + j11
2'	0.45	24	41	92 + j8
5'	0.69	23	41	85 + j3
10'	1.01	22	41	79 + j1
15'	1.26	21	43	75 + j2
20'	1.46	20	47	73 + j3

Average Soil (0.005, 13)

Base Height	Gain dBi	TO Angle degrees	Vert BW degrees	Feedpoint Z R +/- jX $\Omega$
1'	0.61	20	36	101 + j16
2'	0.67	20	35	97 + j11
5'	0.79	19	34	90 + j4
10'	0.91	18	32	82 + j0
15'	0.98	17	32	77 + j0
20'	0.99	16	48	74 + j1

Very Good Soil (0.0303, 20)

Base Height	Gain dBi	TO Angle degrees	Vert BW degrees	Feedpoint Z R +/- jX $\Omega$
1'	2.04	16	31	104 + j20
2'	2.07	13	30	101 + j14
5'	2.14	13	28	93 + j5
10'	2.20	13	25	85 + j0
15'	2.19	13	23	79 - j1
20'	1.11	12	21	74 + j0

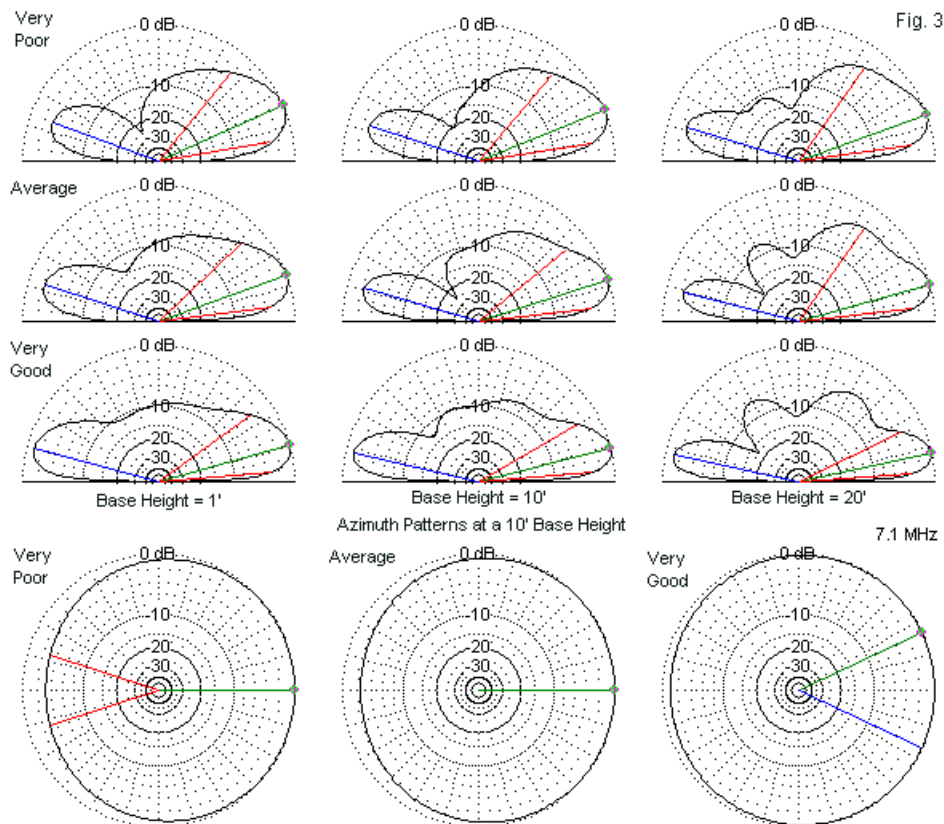
Notes: Antenna = AWG #12 copper wire; length = 67.65'

Test Frequency: 7.1 MHz

TO angle = elevation angle of maximum gain

Vert BW = vertical beamwidth in degrees





Sample Elevation and Azimuth Patterns of a 15-Degree Sloping 40-Meter Dipole with Different Base Heights and over Different Ground Qualities

The most noticeable increases occur in the vertical beamwidth entries. To understand how these values grow, we may examine **Fig. 3**. In all cases, the antenna is set so the its lower end is right of its upper end relative to the elevation patterns. The 15-degree tilt is sufficient to increase the vertical

beamwidth of the lobe away from the angle and to shrink the beamwidth of the lobe included by the antenna. In the direction of maximum gain, the lobe is strong enough to admit considerably more higher angle radiation and noise than we obtain with the true vertical dipole, and we lose a little bit with respect to our desire for a very low TO angle.

The elevation patterns alone might be misleading, since they appear similar to the elevation patterns of 2-element beams with a poor front-to-back ratio. Therefore, I have included a set of representative azimuth patterns--all at the listed TO angles in the table--for 15-degree slopers with a 10' base height. Although the rearward (or left) portion of the pattern has a smaller beamwidth, the overall azimuth pattern is simply a distorted circle. Whether the small changes in pattern shape justify a 15-degree sloper is a question that we shall hold open until we complete our survey.

*3. The 30-Degree Slopers:* 30 degrees is a handy angle for a sloping dipole, since it parallels the angle of typical guy wires or ropes stabilizing typical amateur tower-and-beam installations. As we examine the data on 30-degree slopers in **Table 3**, we can see that the trends started with the 15-degree version continue. The maximum gain and TO angle values continue to rise, at least over very poor and average soil. Over very good soil, the gain values decline. Moreover, the gain values over very poor soil are now systematically higher than the values over average soil. For a home installation, soil quality does make a difference in the final decision on whether to install a true or nearly true vertical or whether to move to a 30-degree tilt angle.

Table 3. 30° sloping dipole at various heights above ground  
and over different ground qualities

Very Poor Soil (0.001, 5)

Base Height	Gain dBi	TO Angle degrees	Vert BW degrees	Feedpoint Z R +/- jX Ω
1'	0.77	30	67	95 + j12
2'	0.86	30	68	92 + j8
5'	1.03	29	69	87 + j3
10'	1.23	28	68	81 + j0
15'	1.37	26	66	77 - j1
20'	1.49	26	64	75 - j1

Average Soil (0.005, 13)

Base Height	Gain dBi	TO Angle degrees	Vert BW degrees	Feedpoint Z R +/- jX Ω
1'	0.77	25	77	101 + j20
2'	0.80	24	79	98 + j11
5'	0.87	23	82	92 + j5
10'	0.91	22	81	85 + j0
15'	0.91	21	76	80 - j2
20'	0.89	20	71	76 - j2

Very Good Soil (0.0303, 20)

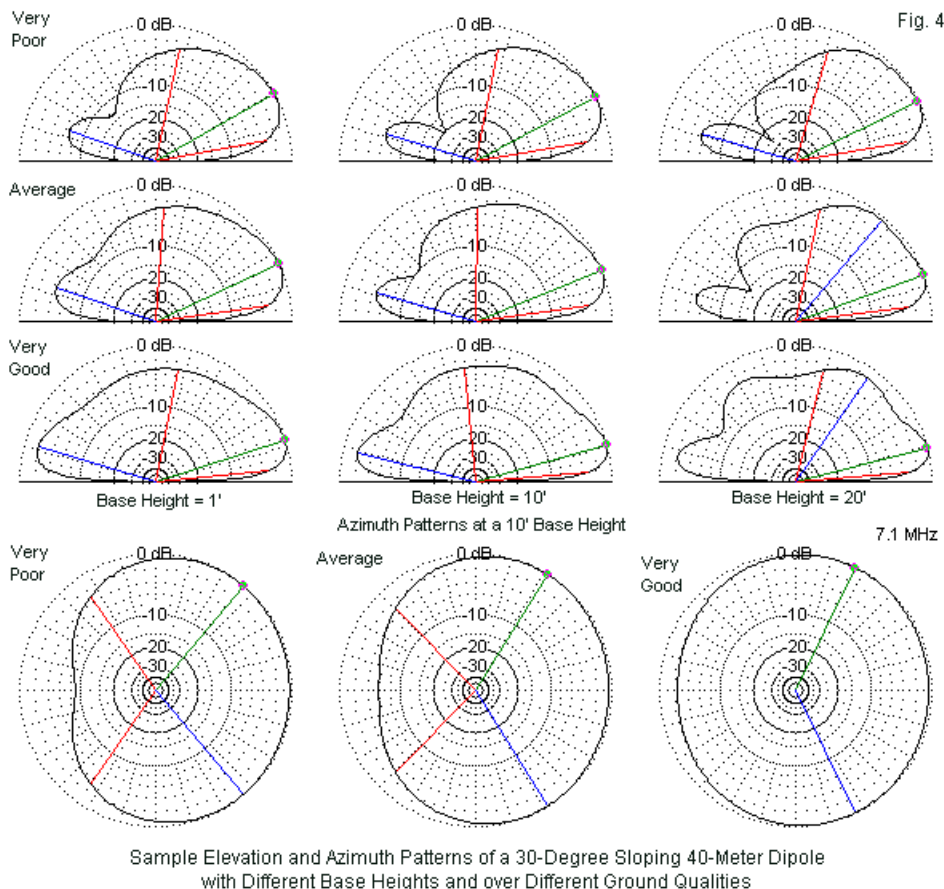
Base Height	Gain dBi	TO Angle degrees	Vert BW degrees	Feedpoint Z R +/- jX Ω
1'	1.62	18	73	103 + j25
2'	1.62	18	80	100 + j19
5'	1.62	17	89	95 + j7
10'	1.58	16	91	88 + j1
15'	1.51	15	78	82 - j2
20'	1.42	14	72	78 + j3

Notes: Antenna = AWG #12 copper wire; length = 67.5'

Test Frequency: 7.1 MHz

TO angle = elevation angle of maximum gain

Vert BW = vertical beamwidth in degrees



The vertical beamwidth angles in the table alert us to the fact that we should expect some very different patterns in the gallery in **Fig. 4**. The additional tilt of the antenna produces strong radiation (and reception sensitivity) at quite high angles. As we improve the soil quality, we begin to see that the very large vertical

beamwidth is a function of 2 elevation lobes that essentially merge at an angle where we might expect to find a null.

With the increased tilt angle, we begin to see a more distinct potential for a usable front-to-back ratio. The sample azimuth patterns for a base height of 10' show that the potential is highest over very poor soil, with an 8-9-dB difference between the forward and rearward directions. The ratio decreases to about 2-dB by the time we use very good soil. Indeed, over very good soil, we find in the elevation patterns very little difference between the forward and the rearward direction, with a consequent decrease in the maximum gain that we can obtain from the antenna.

*The 45-Degree Sloper:* I have included the 45-degree sloping dipole to show that there is a limit to how much we can tilt a dipole from the vertical and still gain some advantage. As shown by the data in **Table 4**, there is very little difference among the maximum gain values for equal base heights over the different soil types. Moreover, the TO angles have increased to values that we normally do not associate with long-distance communications. Indeed, these values resemble more the TO angles we might expect from a horizontal dipole at a relatively low highest (as a fraction of a wavelength).

Table 4. 45° sloping dipole at various heights above ground and over different ground qualities

## Very Poor Soil (0.001, 5)

Base Height	Gain dBi	TO Angle degrees	Vert BW degrees	Feedpoint Z R +/- jX $\Omega$
1'	1.12	50	90	93 + j13
2'	1.23	51	91	91 + j9
5'	1.49	55	92	86 + j2
10'	1.78	60	93	82 - j3
15'	1.92	58	91	79 - j5
20'	1.98	54	84	77 - j6

## Average Soil (0.005, 13)

Base Height	Gain dBi	TO Angle degrees	Vert BW degrees	Feedpoint Z R +/- jX $\Omega$
1'	1.24	66	106	96 + j24
2'	1.40	66	107	94 + j18
5'	1.78	70	106	90 + j8
10'	2.10	68	106	86 + j1
15'	2.17	64	107	83 - j4
20'	2.13	60	107	81 - j6

## Very Good Soil (0.0303, 20)

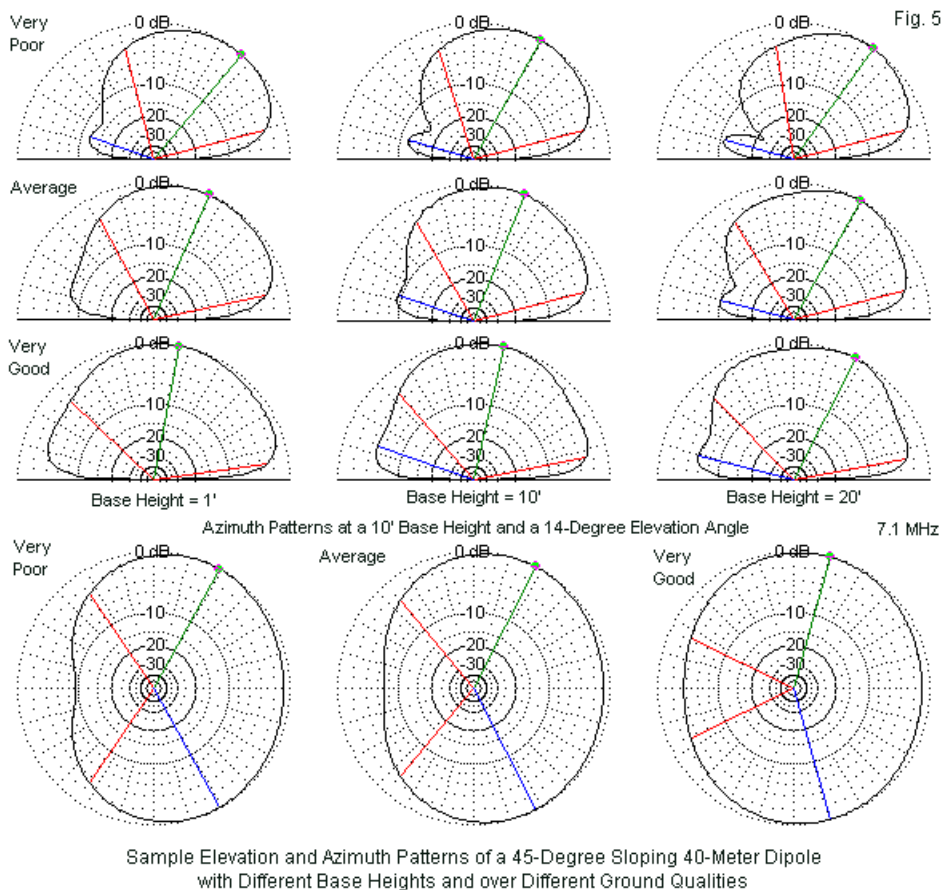
Base Height	Gain dBi	TO Angle degrees	Vert BW degrees	Feedpoint Z R +/- jX $\Omega$
1'	1.78	79	129	95 + j33
2'	1.96	80	126	93 + j26
5'	2.34	80	122	91 + j14
10'	2.60	77	120	89 + j5
15'	2.54	72	122	87 - j2
20'	2.35	63	124	84 - j6

Notes: Antenna = AWG #12 copper wire; length = 67.2'

Test Frequency: 7.1 MHz

TO angle = elevation angle of maximum gain

Vert BW = vertical beamwidth in degrees



A further alert that we may be exceeding the boundaries of good sloper tilt angles appears in the vertical beamwidth column. All of the versions of the 45-degree sloper show strong radiation straight upward, a trait that we normally associate with antenna expressly designed for NVIS operation. The pattern gallery in **Fig. 5**

confirms this suspicion. Over very poor soil, we still obtain a good front-to-back ratio, despite the very high TO angle, but as we improve the soil, the TO angle continues to climb, while the difference in radiation forward and aft disappears.

The 45-degree sloper is, in general, a good NVIS antenna. In fact, many amateurs who do not have ready-made support points for a level dipole make use of this form of sloper, even though they set out to install a horizontal dipole. However, most amateurs who consciously wish to install a sloper are seeking long-distance communications. The 45-degree version of the slope offers perhaps the worst of all options, with the combination of a high TO angle and very strong sensitivity to high-angle radiation and noise.

In the abstract, then, the 30-degree sloper is the best in show. The 15-degree version acts much like a true vertical, while the 45-degree version acts like a horizontal dipole (over most soils). The 30-degree sloper provides some directivity, a little front-to-back ratio, and finally the primary ingredient in sloper installations: convenience. It needs only one high support point and a ground anchor of some sort. Remember that our survey has used 15-degree increments, so all angles are approximations. Plus or minus 5 degrees from a target angle will make little or no difference to performance. In fact, other installation considerations will create much greater performance variations and mess up our seemingly systematic progressions.

## **The Support Question**

The realities of 40-meter true verticals and full slopers is that they often depend upon a nearby structure to support the upper end. We usually acknowledge that a nearby vertically oriented object may have "some" effect on performance without fully appreciating the extent of the effect. Therefore, I ran a series of modeling tests to gauge the general parameters of the effect. Precision is not possible in this realm. Support objects may range from masts to towers to trees. Masts and towers vary in diameter from a little over an inch to towers with faces up to 24", but more normally, 12" or 18", with some crank-up towers using a



graduated face width. Moreover, these supports may be ungrounded, poorly grounded, or well grounded.

Tree supports are even more variable, since they may differ in both diameter and in the resistivity of the material. A single tree may vary its resistivity according to the current weather, the season, and numerous other environmental variables. Trees are not insulators, but at best semi-conductors. Experiments have shown that we can even use trees as antennas, although very lossy ones.

As a consequence, we cannot be as systematic in looking at verticals and slopers plus their supports as we managed to be with slopers in the abstract. However, we can perform a few tests to obtain a general idea of the interaction between verticals and slopers on the one hand and their supports on the other. Let's begin by using a 40-meter antennas with its base 10' above ground. The support will be a vertical object that is 90' tall and 12" in diameter. The 12" diameter is a compromise between the circular equivalent of towers with a face width of 12" and a face width of 18". The AM BC industry uses (and has confirmed by both models and measurements) a simple set of equivalence equations. The diameter of a circular element is 0.74 times the face width of a triangular tower (relevant here) and 1.12 times the face width of a square tower. A 12" 3-sided tower face calls for an 8.88" diameter, while a 12" tower face requires a 13.44" element diameter.

To preserve a reasonable segment length to diameter ratio, the 90' support object uses 31 segments. In raw NEC, I might have used the LD2 or LD3 command to continuously load the tower at various levels to simulate the range (but in no case the specific value) of a lossy support object. Since only spot loads are available within the software used (EZNEC), I simply placed a load on each segment of the support tower or object. The values in the next two tables will show the load value per segment, and the total resistance across the length of the object is that value times 31. There is no magic in the selection of resistance values except for one. I stopped the progression when the performance of the antenna came close to suggesting that the support object was RF transparent.

We shall create two sets of tests using a true vertical antenna, one with the support tower ungrounded (that is, separated from the ground by 0.1'), and the other with the tower grounded by a tower extension of 9' below the ground surface. We shall repeat these tests for the 30-degree sloper.

*1. The True Vertical:* Since we have set up a true vertical dipole as a baseline against which to compare and contrast various sloper angles, we might as well use it in our first test series. Indeed, I often receive the question of how far from an existing structure, such as a tower or a tree, to place a vertical antenna. Assuming that "the next county" is not a usable answer, let's see what the spacing should be between a vertical dipole and a support object that has various levels of resistance. Remember that we are working with only one object height and one configuration (truly vertical with no taper and no branches), so the data can only be suggestive at a first-order level. We shall begin with the ungrounded tower.

**Table 5** shows the results of the initial tests for spacing values of 1, 2, 5, 10, and 17 feet. (The last entry is roughly 1/8 wavelength at 40 meters.) Just above the notes are the modeled performance values of the same vertical dipole when free and clear of all surrounding objects. As the feedpoint impedance entries indicate, the closer the vertical dipole is to a support object, the more profound is the effect on performance. Likewise, as we increase the resistance of the support object, the interaction weakens. With 1000-Ohms per segment, the interaction is minimal with a spacing of at least 5' between the antenna and the object. However, lesser values of resistance show significant interaction across the entire range of spacing values used in the sampling.

Table 5. 40-meter vertical dipole at a 10' base height plus a 12" diameter ungrounded 90' vertical object at various distances and with various resistivities

Spacing: 1'					
Resistance $\Omega$	Gain dBi	TO Angle degrees	Vert BW degrees	Front-Back Ratio dB	Feedpoint Z R +/- jX $\Omega$
0	-0.81	16	24	1.33	6 - j21
1	-3.95	16	24	0.80	13 - j22
5	-6.12	163 (17)	24	0.45	36 - j24
10	-5.17	164 (16)	24	0.56	58 - j20
100	-2.07	164 (16)	24	0.12	124 + j11
1000	-0.49	164 (16)	24	0.02	93 - j6
Spacing: 2'					
0	0.48	16	24	1.64	14 - j12
1	-0.83	16	24	1.33	18 - j14
5	-3.34	16	24	0.28	34 - j19
10	-3.52	164 (16)	24	0.29	49 - j20
100	-1.31	164 (16)	24	0.17	101 - j2
1000	-0.17	164 (16)	24	0.03	86 - j6
Spacing: 5'					
0	1.19	16	24	2.70	31 + j4
1	0.73	16	24	2.49	32 + j2
5	-0.70	16	24	1.50	39 - j5
10	-1.55	16	24	0.55	48 - j10
100	-0.53	164 (16)	24	0.24	83 - j8
1000	0.06	164 (16)	24	0.04	82 - j6
Spacing: 10'					
0	1.77	16	24	3.99	50 + j17
1	1.56	16	24	3.81	50 + j15
5	0.78	16	24	2.92	51 + j8
10	0.08	16	24	1.86	55 + j2
100	-0.17	164 (16)	24	0.17	77 - j6
1000	0.14	164 (16)	24	0.03	80 - j5
Spacing: 17' (1/8- $\lambda$ )					
0	2.13	16	24	5.02	70 + j21
1	2.03	16	24	4.87	69 + j20
5	1.62	16	24	4.13	67 + j15
10	1.15	16	24	3.15	67 + j11
100	0.03	16	24	0.10	76 - j3
1000	0.17	164 (16)	24	0.01	80 - j4

Reference: Vertical only with 10' base height

Gain	TO Angle	Vert BW	Feedpoint Z
dBi	degrees	degrees	R +/- jX $\Omega$
0.19	16	24	81 + j1

Notes: Antenna = AWG #12 copper wire; length = 67.65'

Vertical object: 0.1' to 90', 12" diameter

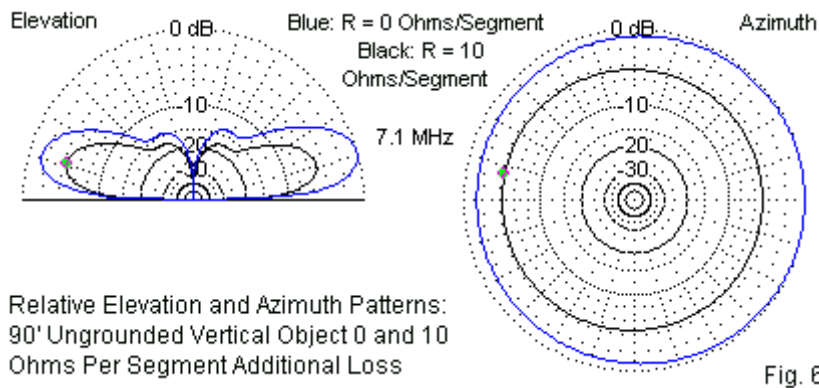
Test Frequency: 7.1 MHz

TO angle = elevation angle of maximum gain; values above 90° indicate a main lobe toward object; values below 90° indicate a main lobe away from object

Vert BW = vertical beamwidth in degrees of main lobe

Resistance: resistance per segment, for 31 segments total vertical object resistance = listed value times 31

With very low resistance values, the interaction can be significant at least up to 1/8-wavelength and possibly farther. A resistance value of zero in these tests does not indicate a perfect conductor. The load value is in addition to the material loss assigned to the antenna element and its support object. Increasing the resistance in the object, especially at relatively close spacing values (for example, 2' or 5' at 40 meters) results in power absorption and dissipation by the support object. The table shows a consistent reduction in the elevation lobe strengths as we move from zero Ohms to about 10 Ohms or more. These are values that we might expect from trees or uncoated wooden structures used to support a vertical dipole. The numbers in the table do not hide the emergence of strong lobes at 90 degrees to the elevation pattern, which is in a line from the tower to the dipole. **Fig. 6** overlays elevation and azimuth patterns for a spacing of 1' using zero and 10 Ohms added resistance per segment. As the patterns show, when we use the 10-Ohm value, some energy is simply missing from the far-field radiation patterns, relative to zero Ohms. Also note that as we exceed 100 Ohms per segment and move toward 1000 Ohms per segment, the support object becomes virtually RF transparent.



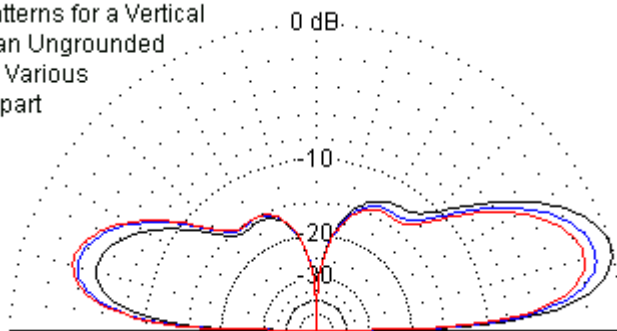
For spacing values less than 10' and depending upon the lossiness of the support, the vertical dipole gain can be significantly lower than when the antenna is free and clear. Moreover, some combinations of tower height and spacing between the tower and the dipole can result in parasitic element effects from the tower. **Fig. 7** overlays elevation patterns for a tower and a dipole at various spacing values, ranging from 2' to 17'. Note that the 17' spacing--about 1/8-wavelength at 40 meters--results in a directional pattern with about 2-dB forward gain and 5-dB front-to-back ratio relative to a freestanding vertical dipole. Not all combinations of support tower and dipole spacing will yield this result.

Elevation Patterns for a Vertical  
Dipole and an Ungrounded  
90' Tower at Various  
Distances Apart

Fig. 7

No Additional  
Resistance

7.1 MHz



To use this effect, the individual installer must establish that the right relationship exists between the support tower and the dipole element, a task that might be difficult if the tower also supports a beam for the upper HF region. To preserve omni-directional coverage, one suggested vertical dipole support system seems to have merit, assuming that the antenna builder wishes to preserve the omni-directional pattern. That system uses two supports at a considerable distance from each other, with a non-conductive support rope between them. The wire dipole extends downward from a point midway between the distant support objects. The alternative to this method of support is to create a wire dipole that is freestanding.

The numbers, of course, apply only to a 90' support object with a 1' diameter. Other support lengths will yield different results using the same tests. As well, the tests used only a single base height and did not account for any other possible objects near to either modeled object. Therefore, the results are in no way exhaustive or definitive. However, they do show the potential for interaction between a vertical dipole and one kind of support object.

Before we leave the true vertical and its nearby support tower, let's consider an additional factor: how well the tower is grounded. I repeated the same series of tests that we found in **Table 5**, but extended the tower 9' below ground. We may

compare the modeled performance values by examining **Table 6**. For the particular tower that we are using for the tests, improved grounding results in lower gain values, less directionality, and higher TO angles, as a general rule. However, with high values of resistance per segment, the support object becomes just about as RF transparent as the ungrounded tower. Generally, the region of about 10-Ohms per segment shows the greatest absorption and dissipation of energy.

Table 6. 40-meter vertical dipole at a 10' base height plus a 12" diameter grounded 90' vertical object at various distances and with various resistivities

Spacing: 1'					
Resistance $\Omega$	Gain dBi	TO Angle degrees	Vert BW degrees	Front-Back Ratio dB	Feedpoint Z R +/- jX $\Omega$
0	-1.19	18	28	0.63	6 - j22
1	-4.24	17	25	0.63	13 - j22
5	-7.58	14	20	0.32	35 - j26
10	-7.78	166 (14)	19	0.04	56 - j28
100	-3.02	164 (16)	23	0.12	129 + j9
1000	-0.49	164 (16)	24	0.02	92 - j6
Spacing: 2'					
0	0.55	18	28	0.77	13 - j14
1	-0.56	17	27	0.75	19 - j15
5	-2.84	16	23	0.58	33 - j19
10	-3.79	15	22	0.27	47 - j22
100	-1.91	164 (16)	23	0.16	102 - j13
1000	-0.18	164 (16)	24	0.02	86 - j6
Spacing: 5'					
0	1.03	17	27	1.26	33 - j1
1	0.70	17	27	1.26	33 - j2
5	-0.24	16	25	1.15	40 - j5
10	-0.91	16	24	0.85	47 - j9
100	-0.80	164 (16)	24	0.18	83 - j12
1000	0.06	164 (16)	24	0.04	82 - j6
Spacing: 10'					
0	1.32	17	27	1.86	50 + j10
1	1.19	17	26	1.86	51 + j9
5	0.80	16	25	1.82	53 + j6
10	0.45	16	25	1.59	56 + j3
100	-0.27	164 (16)	24	0.06	76 - j7
1000	0.14	164 (16)	24	0.03	80 - j5
Spacing: 17' (1/8- $\lambda$ )					
0	1.42	16	26	2.31	68 + j13
1	1.38	16	26	2.34	68 + j13
5	1.23	16	25	2.37	68 + j11
10	1.08	16	25	2.25	69 + j9
100	0.12	16	24	0.25	76 - j3
1000	0.16	16	24	0.00	80 - j4



Reference: Vertical only with 10' base height

Gain	TO Angle	Vert BW	Feedpoint Z
dBi	degrees	degrees	$R + jX \Omega$
0.19	16	24	$81 + j1$

Notes: Antenna = AWG #12 copper wire; length = 67.65'

Vertical object: 0' to 90', 12" diameter, plus 9' below ground

Test Frequency: 7.1 MHz

TO angle = elevation angle of maximum gain; values above 90° indicate a main lobe toward object; values below 90° indicate a main lobe away from object

Vert BW = vertical beamwidth in degrees of main lobe

Resistance: resistance per segment, for 31 segments total vertical object resistance = listed value times 31

How well a supporting tower (or simply a nearby tower) is grounded suffices to significantly alter the vertical's pattern. Thus it adds one more variable to our growing collection. We shall see this variable at work again as we turn to the 30-degree sloper.

*The 30-Degree Sloper:* The most usual form of full-sloper installation supports the upper end of the antenna near a tower or other tall vertical object. The wire then extends away from the support object toward its base. With a 10' base height (to be roughly comparable to the vertical dipole tests), the remaining distance to the ground is normally a non-conductive line to a ground anchor of some sort. Because the sloper has a 30-degree tilt angle, the lower end is about 35' from the support object, and the dipole feedpoint is about 17' from the support. Since the dipole is slightly less than 70' long, the upper end will be about 0.75' (or about 9") away from the surface of the 12" diameter support object.

One consequence of the necessary conditions of installing a 30-degree 40-meter sloper is that we need only one test sequence to test the effects of varying the support object resistance. However, we shall run two tests, one with a support object that is 70' tall, and the other with a 90' tall object. These heights correspond to two heights of towers in wide amateur use. Our goal is to see whether support-object height makes a difference to the sloper's performance.

We shall again use ungrounded and grounded support objects for each tower height. **Table 7** provides some interesting tabular data for the 70' support object.

Table 7. 40-meter 30° sloping dipole with a base height of 10' plus a 12" diameter, 70' vertical object 0.75' (surface-to-surface) distant from upper end of sloper with various resistivities

Ungrounded Resistance $\Omega$	Gain dBi	TO Angle degrees	Vert BW degrees	Front-Back Ratio dB	Feedpoint Z R +/- jX $\Omega$
0	3.12	21	47	14.26	103 + j39
1	2.93	21	49	14.78	99 + j36
5	2.31	23	58	13.36	91 + j28
10	1.83	23	67	10.67	87 + j22
100	0.93	22	81	5.42	85 + j4
1000	0.90	22	82	4.80	85 + j0
Grounded Resistance $\Omega$	Gain dBi	TO Angle degrees	Vert BW degrees	Front-Back Ratio dB	Feedpoint Z R +/- jX $\Omega$
0	1.91	23	68	7.53	90 + j15
1	1.88	23	68	7.58	90 + j15
5	1.78	23	69	7.69	88 + j15
10	1.64	23	71	7.63	87 + j14
100	0.98	22	81	5.52	85 + j4
1000	0.90	22	82	4.80	85 + j0
Reference: 30° sloper only with 10' base height					
	Gain dBi	TO Angle degrees	Vert BW degrees	Front-Back Ratio dB	Feedpoint Z R +/- jX $\Omega$
	0.91	22	81	5.82	85 + j0

Notes: Antenna = AWG #12 copper wire; length = 67.5'

Test Frequency: 7.1 MHz

TO angle = elevation angle of maximum gain

Vert BW = vertical beamwidth in degrees of main lobe

Resistance: resistance per segment, for 31 segments total vertical  
object resistance = listed value times 31

The 70' support object shows significant directionality in the sloper pattern with both ungrounded and grounded supports up to loss levels of 10 Ohms per

segment. The ungrounded tower acts more like a parasitic reflector than the grounded version, but the data show that both versions increase the front-to-back ratio over the natural values of an independent full sloper with the same 10' base height. The relatively high front-to-back ratios for the ungrounded tower also accompany more radical changes in the sloper feedpoint impedance and lower values of vertical beamwidth until the tower loss approaches RF transparency.

If we replace the 70' tower with a 90' tower, the numbers change, as shown in **Table 8**. There is little difference in the gain values between the two grounding states for the 90' support, although the ungrounded tower yields higher front-to-back ratios. We do find a differential effect on the feedpoint impedance values, with the ungrounded support (at low-loss assignments) yielding impedances that are lower than a free-standing sloper and the grounded version providing impedance values that are higher.

Table 8. 40-meter 30° sloper dipole with a base height of 10' plus a 12" diameter, 90' vertical object 0.75' (surface-to-surface) distant from upper end of sloper with various resistivities

Ungrounded Resistance $\Omega$	Gain dBi	TO Angle degrees	Vert BW degrees	Front-Back Ratio dB	Feedpoint Z R +/- jX $\Omega$
0	2.52	20	59	12.04	83 + j33
1	2.45	21	60	11.94	83 + j33
5	2.16	22	65	11.18	82 + j30
10	1.87	22	70	9.97	82 + j27
100	0.77	24	81	5.20	89 + j7
1000	0.82	22	82	4.74	86 + j0
Grounded Resistance $\Omega$	Gain dBi	TO Angle degrees	Vert BW degrees	Front-Back Ratio dB	Feedpoint Z R +/- jX $\Omega$
0	2.33	26	69	7.24	98 + j23
1	2.27	26	69	7.22	97 + j22
5	2.04	27	70	7.18	95 + j20
10	1.82	26	71	7.13	92 + j19
100	0.83	24	80	5.29	89 + j7
1000	0.83	23	82	4.75	86 + j0
Reference: 30° sloper only with 10' base height					
	Gain dBi	TO Angle degrees	Vert BW degrees	Front-Back Ratio dB	Feedpoint Z R +/- jX $\Omega$
	0.91	22	81	5.82	85 + j0

Notes: Antenna = AWG #12 copper wire; length = 67.5'

Test Frequency: 7.1 MHz

TO angle = elevation angle of maximum gain

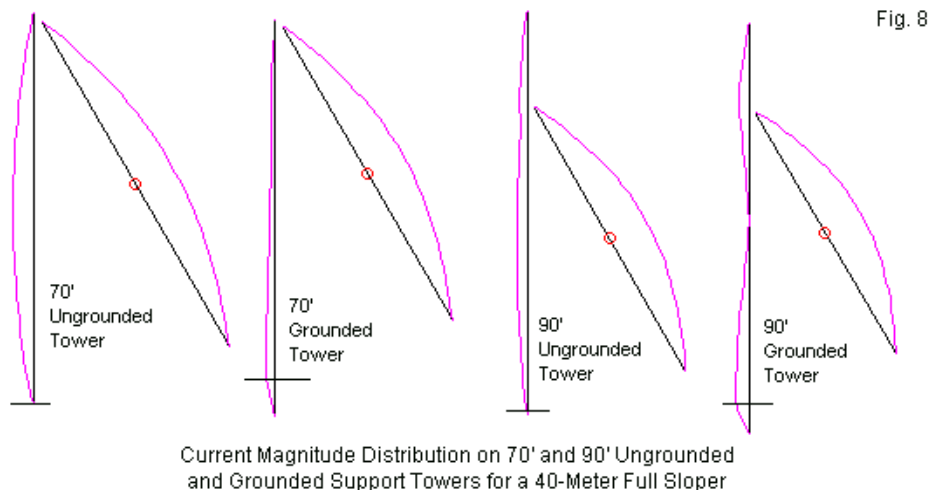
Vert BW = vertical beamwidth in degrees of main lobe

Resistance: resistance per segment, for 31 segments total vertical

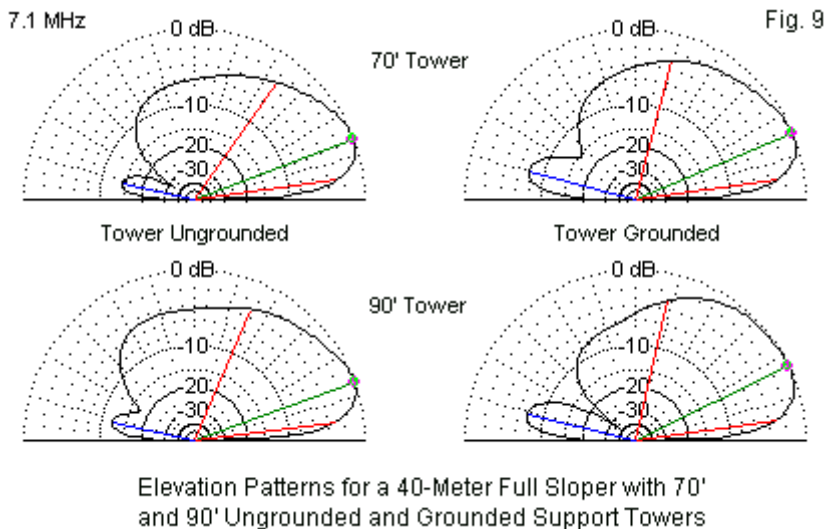
object resistance = listed value times 31

**Fig. 8** reveals part of the reason for the numerical differences by showing the current magnitude distribution along each of the tower situations (with zero additional loss). Grounded and ungrounded towers show different points along the height at which the current is maximum. As well the peak current on all four tower models shows different values. (The curves for the sloper itself have been

equalized to the degree possible within the graphical system used by EZNEC. These same limits also do not allow the 4 model outlines to be in exact scale with each other.)



Some of the far-field radiation pattern differences among the 4 variations of a support tower do not become evident from the tabular data alone. **Fig. 9** shows the elevation patterns that accompany the current magnitude distribution curves in **Fig. 8**. The shape of the main forward lobe is one significant area of interest, since it largely determines the vertical beamwidth. Both ungrounded towers yield smaller vertical beamwidth values with less sensitivity to very high-angle radiation and noise. Unfortunately, failing to ground a tower tends to raise serious safety issues.



Although our survey so far has introduced us to a number of variables that have consequences for full sloper performance, we need to add a final variable that generally affects only highly conductive towers.

*The Tower Support with a Beam on Top:* Many slopers use an existing tower as the support for the top of a 30-degree full sloper. Normally, the tower has an appurtenance at the top, namely, an upper-HF beam. The beam may be simple or complex. At the small end, we might find a 10-meter 2-element Yagi. At the large end of the scale might be a 16-element tri-band array on a 30' boom--or something even larger.

The beam at the tower top usually has an electrical connection to the tower, although that connection may or may not include the driven element. If we treat the tower as a vertical element, the beam becomes a form of "top" or end loading, that is, an irregularly shaped extension of the element with its structure

at right angles to the tower. Normally, such structures on active elements lower the resonant frequency of the element without altering the current distribution along the element. Essentially, the beam-hat plays little or no role in the radiation from the tower itself. However, the sloper antenna to which we supply energy has both a vertical and a horizontal component to its radiation, and the horizontal component is more than incidental. Therefore, the top section of the beam-hatted tower may interact directly with the sloper antenna.

In this space, we cannot sample every possible combination of beam and tower. We can look at two simple cases: a 3-element 20-meter Yagi with a 24' boom and a 6-element 20-meter Yagi on a 48' boom. We can place each antenna on either a 70' or a 90' tower to which we have attached our 7.1-MHz AWG #12 copper-wire 30-degree sloper. Of course, given our recent modeling, we can have each tower in an ungrounded condition or a well-grounded condition. As well, we can align the Yagi boom with the tower-sloper line or set the beam cross-wise to that line (or at any intermediate angle). Since our variations are already numerous, we shall set the sloper with a base height of 10' above average soil as fixed values, even though we might easily vary both the base height and the soil quality. Even within these restrictions, we end up with the 2-column data set on **Table 9**. For reference, the table includes values for each tower with no beam on top.

Table 9. 40-meter 30° sloping dipole with a 10' base height plus 12" diameter vertical mast and a 20-meter beam at the top with touching and well-grounded towers

Tower Ungrounded					Tower Well Grounded				
Gain dBi	TO Angle degrees	Vert BW degrees	Front-Back Ratio dB	Feedpoint Z R +/- jX Ω	Gain dBi	TO Angle degrees	Vert BW degrees	Front-Back Ratio dB	Feedpoint Z R +/- jX Ω
70' mast + no beam									
3.12	21	47	14.26	103 + j39	1.91	23	68	7.53	90 – j15
70' mast + 3-element Yagi aligned with sloper									
1.30	26	123	2.34	95 + j16	2.45	42	70	7.81	123 + j17
70' mast + 3-element Yagi cross-wise to sloper									
1.99	22	72	9.44	78 + j30	2.60	42	67	8.46	110 + j29
70' mast + 6-element Yagi aligned with sloper									
1.91	24	101	6.84	59 + j46	1.02	24	72	6.58	103 + j6
70' mast + 6-element Yagi cross-wise to sloper									
1.79	26	111	9.01	67 + j51	1.38	29	69	7.61	111 – j4
90' mast + no beam									
2.52	20	59	12.04	83 + j33	2.33	26	69	7.24	98 + j23
90' mast + 3-element Yagi aligned with sloper									
3.27	49	123	17.37	69 + j68	0.94	70	98	6.19	87 + j1
90' mast + 3-element Yagi cross-wise to sloper									
3.52	36	66	18.13	72 + j66	1.27	27	77	6.24	89 + j0
90' mast + 6-element Yagi aligned with sloper									
3.74	35	59	7.32	124 + j94	1.43	23	60	6.86	89 + j4
90' mast + 6-element Yagi cross-wise to sloper									
4.22	31	54	7.78	125 + j89	1.41	23	80	6.87	87 + j4

Notes: Antenna = AWG #12 copper wire; length = 67.65'

Test Frequency: 7.1 MHz

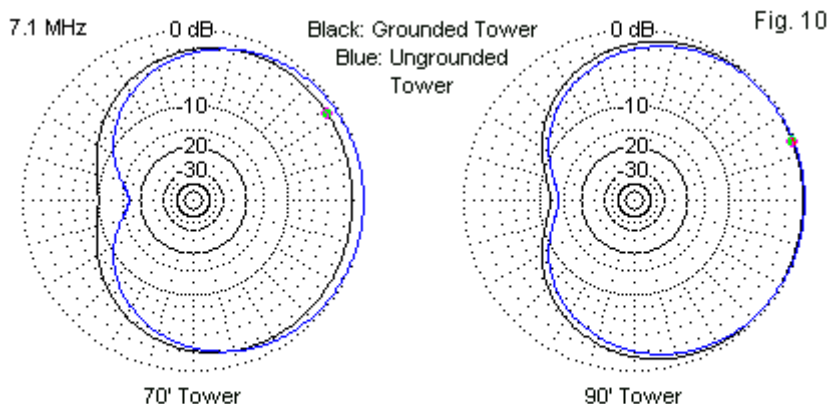
TO angle = elevation angle of maximum gain

Vert BW = vertical beamwidth in degrees of main lobe

Beam structure contains elements and boom with direct connection to tower

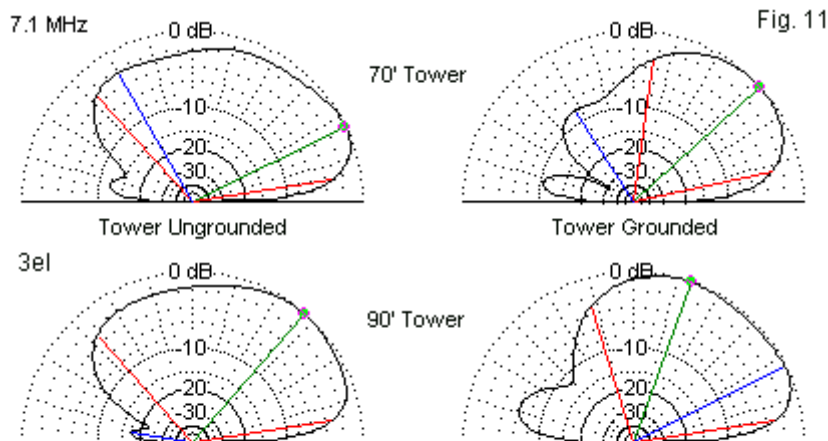
The tabulated data show no clear trends in the numbers. Changing the beam orientation does affect the values, as does changing the beam size. It is likely the even changing the beam design with the same general boom length and the same number of elements might occasion changes in the modeled values. For the 3-element beam, at least, we do find a greater difference in pattern shapes between ungrounded and grounded 70' towers than for the same grounding states for 90' towers. **Fig. 10** shows the overlaid azimuth patterns for the two tower heights.





Affect on Sloper Azimuth Pattern of  
Tower Height and Grounding

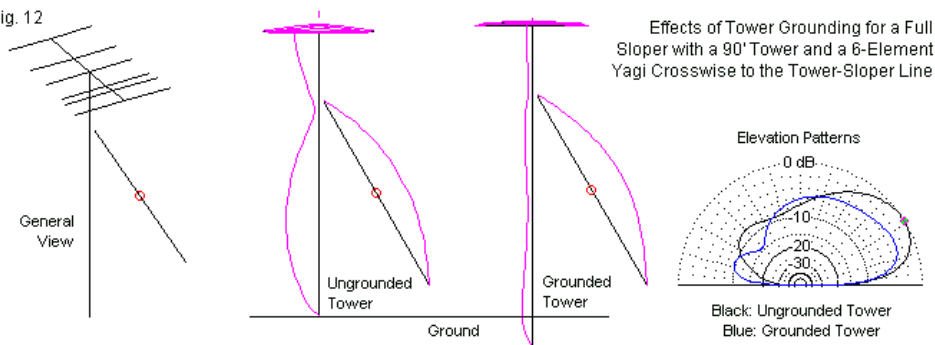
Nevertheless, the 4 variations on the 3-element aligned Yagi do have significant consequences that appear in the elevation patterns shown in **Fig. 11**. Grounding either tower reduces the vertical beamwidth dramatically, but perhaps more radically with a 70' tower than with a 90' version. Both models of the 70' tower show the appearance of a secondary lobe (which most NEC software implementations would identify by a definite reversal in the progression of gain values in the trace progression, regardless of the size of that variation). At least three of the sloper installations modeled would be useful for NVIS communications.



Elevation Patterns for a 3-Element Yagi Aligned with Sloper  
Supported by 70' and 90' Ungrounded and Grounded Towers

Our graphic sampling so far has used the 3-element Yagi aligned with the tower-sloper line. **Fig. 12** provides a sample using the 6-element beam crosswise to the tower-sloper line. If we contrast grounded and ungrounded 90' support towers, we find very different current distribution curves. Not only do the current magnitude values on the tower differ in placement and value, but as well we find differences in the current magnitudes on the beam elements. The result is a set of quite different elevation patterns for the two situations, with the ungrounded tower and beam yielding the greatest change from the pattern we would expect of a free-standing full 30-degree sloper.

Fig. 12



We cannot extrapolate from these cases any general conclusions. Even monoband beams for 20 meters come in different element configurations, and--of course--the beam on top of the tower might be of any design that has appeared commercially or been developed as strictly a personal project. All that our simple demonstration can show is that a top beam can and often does make a difference to the performance of the sloper attached at its upper end to the tower supporting the beam.

## Conclusion

As soon as we pass from the abstractions of independent element performance to the realm of actual installations, both the true vertical antenna and the 30-degree sloper fall into a realm of almost innumerable variables for which no set of calculations or models can provide much usable guidance. The utility of the exercise has been to show that any one or more of these variables can alter the actual performance of the sloper. Moreover, we saw that even true vertical antennas are subject to interaction with both highly conductive and lossy nearby objects, whether or not they play an active role in support the antenna. In the case of the sloper, such objects are unavoidable in a real installation.

The performance of a sloper results from the totality of the property variables, including the sloper position, the diameters of the materials, the lengths of the elements (sloper and tower), the base height of the sloper above ground, the ground quality, the quality of support tower grounding, and the loading effects of an indefinitely large variety of beams that might be on top of the tower. This list does not include other nearby objects that may also affect especially the vertical component of the sloper's radiation and potential interactions.

For most antennas, we can work with the basic antenna design in isolation and then make adjustments for the installation environment. The sloper differs in having a necessary upper support point in proximity to an existing structure. Under these conditions, the data about the antenna in isolation holds far less guidance than it does for most other types of antennas. In the end, no sloper is a textbook case. Rather, each one is an experiment that combines differing values for each of the many variables. The sloper builder can only make his best estimate and then proceed by operating tests and measurements to find, within the real limitations of the installation site and available materials, the adjustments that yield as close as possible to optimal operation.

## Chapter 10: The G5RV on 20 meters

Louis Varney's "G5RV" *was* and *is not* an antenna, that is, an array of elements. It is an antenna system including a radiating element and a length of transmission line designed to present "correct" impedance at a design frequency.

### The 1984 *RADCOM* Version of the Antenna System

The most familiar part of the system is the wire: a center-fed doublet 102' long. Actually, Varney calculated the length to be 3/2 wavelengths long at 14.15 MHz using a long standing equation:

$$L_{\text{feet}} = \frac{492(n - 0.05)}{f_{\text{MHz}}} \quad (1)$$

The letter 'n' is the number of half wavelengths in the antenna. The result is 102.57' or 31.27 m. It is interesting that Varney notes in his 1984 article in *RADCOM* that he can shorten the wire to 102' or 31.1 m, since the entire system will be handled by an antenna tuning unit (or ASTU--antenna system tuning unit--as Varney preferred).

(The entire 1984 article has been reprinted in Erwin David, G4LQI, *HF Antenna Collection*, published by RSGB in 1991. In the G5RV article, the author makes reference to his initial 1966 presentation of the basic idea. An adapted version appears in *The ARRL Antenna Compendium*, Vol. 1, 1985.)

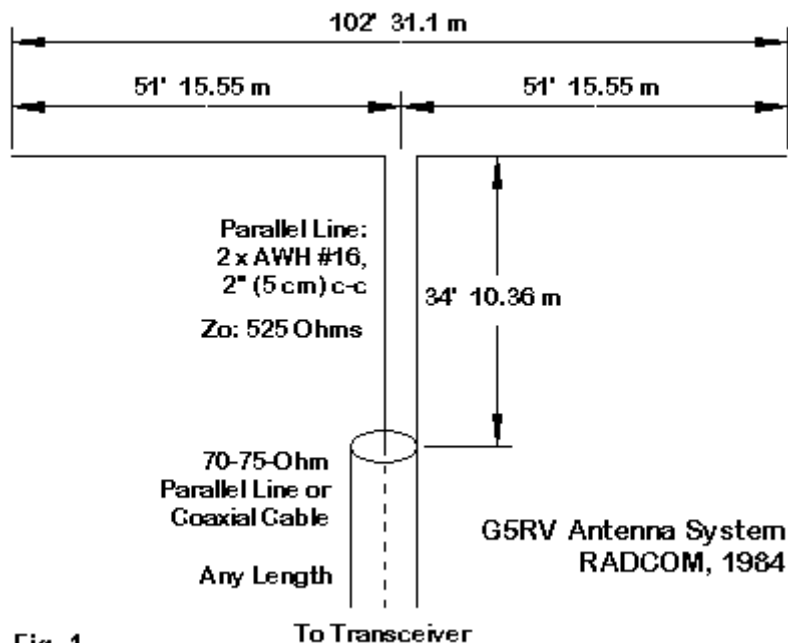


Fig. 1

However, we conventionally sketch the G5RV antenna system as in **Fig. 1**. The center-fed doublet has a section of parallel transmission line extending from the radiating wire feedpoint to a junction with the "main" feedline.

Curiously, Varney specifies the length of the matching section as 34.0' or 10.36 m. Using the same constant for a half-wavelength (492), the section is a half wavelength at 14.47 MHz. The prescribed length assumed a velocity factor (VF) in the line section of 0.98--hence the final length.

Many folks presume that the original impedance of the matching section line used in the G5RV is 450 Ohms. However, Varney specifies home-made open wire feeder composed of AWG #16 copper wire spaced 2" (5 cm) apart. The characteristic impedance of such line by standard calculations is closer to 525 Ohms. At 14.15 MHz, the line is 1/2-wavelength long, thus replicating the feedpoint impedance. Hence, the line  $Z_0$  is--at 20 meters--of little consequence.

A 3/2-wavelength wire--if properly cut--should present a feedpoint impedance slightly higher than a 1/2-wavelength resonant dipole: about 90 Ohms. Hence, the impedance at 14.15 MHz at the base of the matching section should also be about 90 Ohms. Thus did Varney design the G5RV antenna system for a 75-Ohm "twinlead" or coaxial feeder?

There seemed to be an instant misunderstanding of the 1/2-wavelength line used by Varney in his antenna system, since recommendations immediately began to appear for the use of twinleads other than the home-made open-wire feeder used in the original. At 14.15 MHz, 300-Ohm solid ribbon twinlead with a VF of 0.82 (using numbers from the *RADCOM* article) requires 28.5' or 8.69 m of line for the matching section. However, the recommended length is 28' or 8.5 m. This latter value is closer to but not identical with applying the ribbon VF value to Varney's 34' length--which already has a VF of 0.98 built into its length. Likewise 300-Ohm ribbon with windows has a VF (in the article) of 0.90. Calculating its length using the 492 constant yields 31.29' or 9.54 m. However, the recommended length of such line is 30.6' or 9.3 m, the values one would arrive at by applying the 0.90 VF value to Varney's 34' length.

With so much confusion built into the basic accounts of the G5RV, there can be little wonder that the antenna has become the subject of endless variations, some being serious attempts to arrive at an ideal antenna of its type, others being generated simply to sell commercial versions of the antenna.

We have not yet tried to place the antenna on bands other than 20 meters. It is in pursuit of this goal that the G5RV has been taken well past its original intent. Remember that, even though Varney thought the G5RV would provide a good

match on 20 meters for a 75-Ohm main feedline, he believed in using an ATU at the rig end of the line.

### **Some Small Facts about Wire Antennas**

Before we take the plunge into other bands, we should pause to review the methods by which the G5RV antenna system emerged and how well they play in the 21st century. The review will not be simple, because many of the notes are partially accounted for by the developer of the system. However, those same notes may be at odds with common but erroneous interpretations of the antenna. This feature will hold true without ever leaving 20 meters or straying very far from the design frequency, 14.15 MHz.

The equation for calculating the length of an antenna consisting of multiple half-wavelengths has a long and honored history when well used. In fact, it is very well used when calculating non-resonant antennas or antennas for which resonance is not at all crucial. Where we require some degree of precision in determining the length of a resonant antenna, the equation turns out to be quite off the mark.

Since Louis Varney stated that he intended to use the antenna system with an antenna tuner, he effectively implied that the equation used to determine the 102' length was sufficiently accurate for that method of operation. As well, his estimate of the feedpoint impedance, repeated at the end of the 34' matching section of parallel transmission line, was also within the limits of accuracy necessary for using the system with an ATU. However, 102' is not a resonant length of wire at 14.15 MHz, and its resistive impedance component is not 90 Ohms.

These latter facts, which we shall embellish shortly, would not be a problem if the general conception of the G5RV antenna system included the use of an antenna tuner. However, the antenna has acquired a reputation for being able to provide under 2:1 SWR on more than one band--without qualifications needed to confine the claim to a reasonably clear arena of truth. So the following notes are more



applicable to understanding why the general conception--rather than Varney's--is off base.

We should note two facts about wire antennas. First, in the HF region, we have tended to blithely ignore the fact that changes of wire diameter have an effect upon the resonant length of a wire antenna and upon the feedpoint impedance. We tend to use "cutting" formulas as if they were wholly unrestricted in scope and always accurate, regardless of the wire we select. For HF wire antennas in the U.S., we tend to use wires as small as AWG #18 (0.0403" diameter)--such as copperweld--and as large as AWG #12 (0.0808" diameter) hard drawn copper, not to mention the common sizes in between. The wire diameter is small compared to a wavelength (about 834.5" at 14.15 MHz); nevertheless, a 2:1 change of wire diameter will have a recordable affect on the wire's resonant length and feedpoint impedance.

Second, as we move a horizontal wire antenna to varying heights below about 1 wavelength, we shall find a second source of variation in the resonant length and feedpoint impedance of a wire antenna. Unlike variations due to wire diameter, which are quite regular, the variations due to height tend to follow cyclical patterns that repeat every half-wavelength.

We can sample some of these variations from the tables that follow. In each case, I modeled 102' copper wires from AWG #18 through AWG #12, using NEC-4, which is more than adequate to provide accurate data. The models used 101 segments with a source centered on the wire. The test models were initially modeled in free space and then at two different heights above average ground (conductivity: 0.005 s/m; permittivity: 13). The upper height was 65.62' or 20 m, close to 1 wavelength above ground. The lower height was 32.81' or 10 m above ground. Let's see what the models report.

.....  
 Source Impedance of a 102' Wire at 14.15 MHz

## Free Space

Wire Dia.	Feedpoint Impedance	75-Ohm
AWG	R +/- j X Ohms	SWR
#12	102 - j 48	1.869
#14	103 - j 51	1.914
#16	104 - j 53	1.958
#18	105 - j 55	1.999

## 65.62' / 20m

Wire Dia.	Feedpoint Impedance	75-Ohm
AWG	R +/- j X Ohms	SWR
#12	104 - j 49	1.883
#14	104 - j 51	1.928
#16	105 - j 54	1.972
#18	106 - j 56	2.012

## 32.81' / 10m

Wire Dia.	Feedpoint Impedance	75-Ohm
AWG	R +/- j X Ohms	SWR
#12	111 - j 56	2.048
#14	112 - j 59	2.093
#16	112 - j 61	2.136
#18	113 - j 63	2.177

.....

The SWR numbers are overly precise relative to the rounded impedance values. The intent is to show clearly the general trends. The thinner the copper wire, the higher the resistive component of the impedance, despite the fact that the wire is ever shorter of resonance. As well, although the impedance values at a 1-wavelength antenna height are very close to the free-space values, the impedance figures at a 1/2-wavelength height show some departure from the free-space values.

Finally, the wire is well short of resonance at the design frequency. Otherwise put, for precision of resonant length, the traditional equation simply will not do.

I replicated the exercise when I added in a 34' or 10.36-m length of 525-Ohm feedline with a velocity factor of 0.98. This provides an electrical half-wavelength of line, that is, the equivalent of 34.77' or 10.60 m at 14.15 MHz. Remember that the intent of this line section on the design frequency is to replicate the wire feedpoint impedance at the end of the so-called matching section.

For this exercise, it is unnecessary to model the parallel transmission line with physical wires. One may use the TL facility within NEC-4 software to provide a non-radiating mathematical model of a perfect (lossless) transmission line. Since Varney's writings anticipate that the antenna builder will respect the requirement of parallel transmission line to sustain its balance, the non-radiating aspect of the NEC TL facility is within the bounds of the exercise. Because the line is relatively short, the difference between a lossless line and a real line constructed according to Varney's specifications will almost too small to notice. On the other hand, because we are using a physical length that is only close to but not exactly a half-wavelength at the design frequency, we should expect to see small variations in the resulting impedance and SWR values. The following table records the results of this exercise.

Source Impedance of a 102' Wire and 34' Line at 14.15 MHz			
Free Space			
Wire Dia.	Feedpoint Impedance	75-Ohm	
AWG	R +/- j X Ohms	SWR	
#12	102 - j 52	1.933	
#14	103 - j 54	1.979	
#16	104 - j 57	2.024	
#18	105 - j 59	2.066	
65.62' / 20m			
Wire Dia.	Feedpoint Impedance	75-Ohm	
AWG	R +/- j X Ohms	SWR	
#12	104 - j 52	1.946	
#14	104 - j 55	1.993	
#16	105 - j 57	2.037	
#18	106 - j 59	2.079	
32.81' / 10m			
Wire Dia.	Feedpoint Impedance	75-Ohm	
AWG	R +/- j X Ohms	SWR	
#12	111 - j 60	2.111	
#14	111 - j 62	2.158	
#16	112 - j 64	2.203	
#18	113 - j 66	2.245	

There are only slight differences between the two tables and the bulk of those differences result from the fact of choosing a physical approximation of a 1/2-wavelength line rather than using an exact 1/2-wavelength line. However, it is

likely that the modeled line is closer to  $1/2$  wavelength than will be most lines cut for a physical implementation of the G5RV antenna system.

At the design frequency, we need not explore the consequences of using something other than the line specified for the antenna. The use of 300-, 400-, and 450-Ohm lines--if each is an electrical half-wavelength--will result in virtually identical tables for 14.15 MHz.

A more important question concerns the antenna length. As initially specified, the wire is too short to be resonant at 14.15 MHz. But what length might seem more resonant? The spread of impedance figures suggests that we might use a compromise between the resonance at a 20-m height and resonance at a 10-m height. In fact, I used this compromise to arrive at a length of 103.35' or 31.5 m.

The compromise does not represent an ideal situation, only a convenient one. The change of impedance and resonant length does not follow a simple progression with decreases in height. Instead, the values change cyclically in half-wavelength increments (ignoring height below about 0.2 wavelengths above ground). The sample heights used here do not necessarily represent the extremes that might appear at other heights.

With these qualifications, we can examine the data reported by NEC-4 for the revised wire length with the 34' line attached. Since the free-space values and the 20-m height values are so similar, I have omitted the free-space portion of the exercise.

Source Impedance of a 103.35' Wire and 34' Line at 14.15 MHz

65.62' / 20m

Wire Dia.	Feedpoint Impedance	75-Ohm
AWG	R +/- j X Ohms	SWR
#12	111 + j 7	1.494
#14	112 + j 7	1.497
#16	112 + j 6	1.504
#18	113 + j 6	1.515

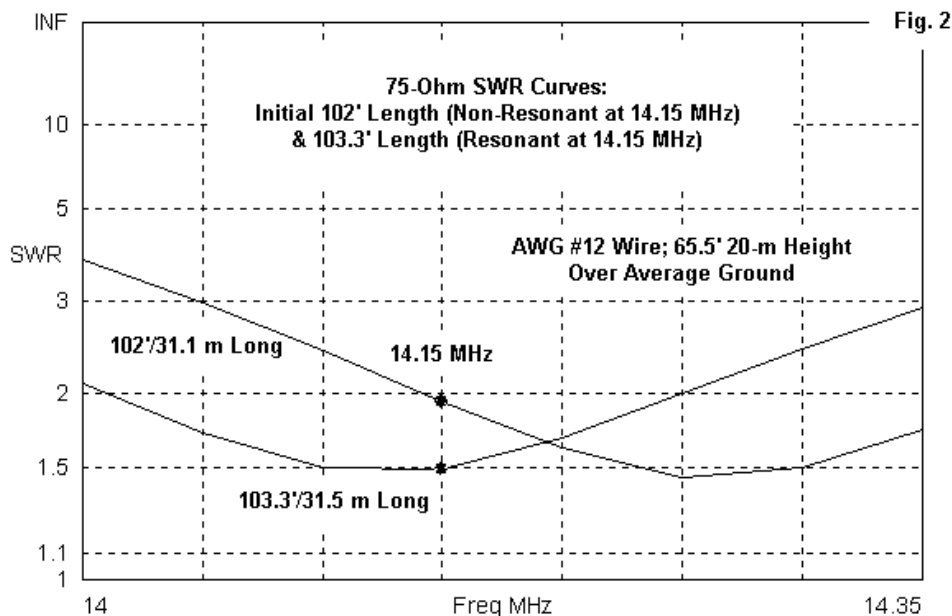
32.81' / 10m

Wire Dia.	Feedpoint Impedance	75-Ohm
AWG	R +/- j X Ohms	SWR
#12	119 - j 1	1.586
#14	119 - j 2	1.592
#16	120 - j 2	1.601
#18	120 - j 3	1.613

Increasing the length of the wire toward resonance, of course, increases the resistive component of the source impedance. Hence, there is a limit as to how low the 75-Ohm SWR can go by this strategy. As well, as the wire thins, the resistive component goes up.

We seem to have gained a usable 75-Ohm SWR at the design frequency, but obviously the 50-Ohm SWR would be well above 2:1. In the days before fixed-tuned output circuits in transmitters, the old pi-network amplifier output circuits--with variable "tune" and "load" controls--would have easily provided a match to these impedance values in 20 meters. As well, they fall well within the range of almost any ATU, even the limited range versions incorporated into some modern transceivers.

However, an SWR value at a spot frequency does not tell the entire story about antenna performance. We are as interested in the SWR bandwidth as we are in the particular value at some given frequency. So I ran frequency sweeps of the two versions of the G5RV antenna, both with the 34' line attached.



**Fig. 2** shows the curves for the short and the long antennas. Clearly, the longer length favors the lower end of 20 meters, while the 102' length favors the upper end of the band. The impedance level of a G5RV is high enough that we cannot obtain full band coverage from the wire and line combinations. In addition, the 1/2-wavelength line section is 1/2 wavelength only at the design frequency. Hence, it contributes to a narrowing of the SWR bandwidth.

We may note in passing that a common resonant 1/2-wavelength dipole of any of the wire sizes sampled in this exercise would easily cover the 20-meter band with under 2:1 SWR. Moreover, an ATU would free us from concern about the 2:1 SWR that marks the limit of full output from most modern transceiver designs. Nonetheless, it is interesting to note that the 3/2-wavelength wire tends to show a

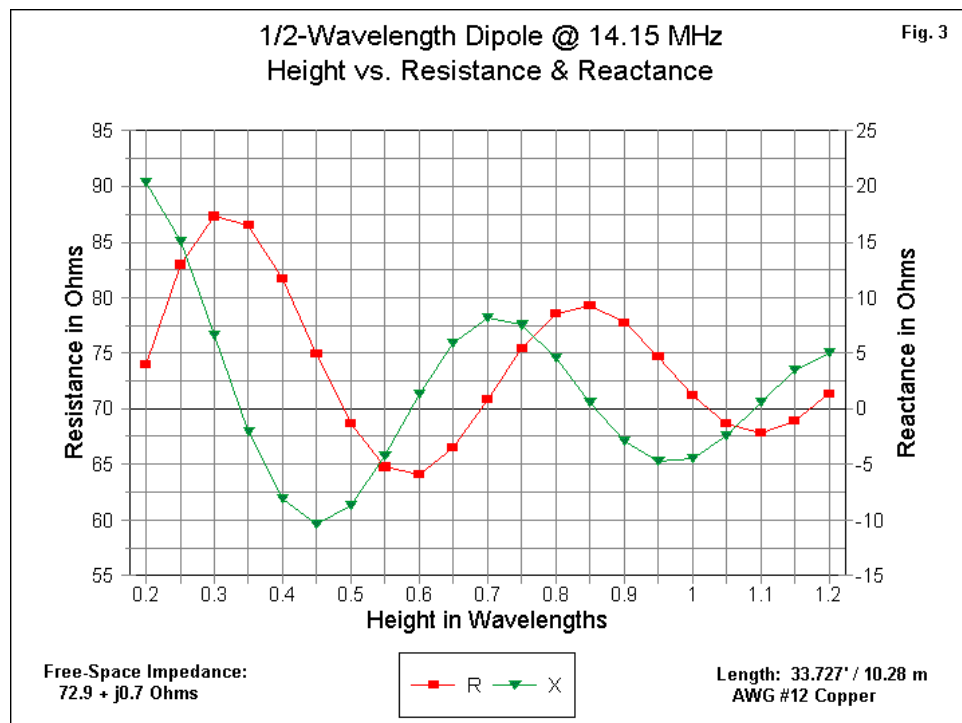
narrower SWR bandwidth than the shorter half-wavelength dipole. The narrower operating bandwidth will, of course, be a matter of concern for anyone who tries to use a G5RV antenna system without an intervening ATU. Unfortunately, this latter mode of operation seems to be the rule rather than the exception--at least until one experiences firsthand the limitations of the system.

### **A Side-Note on Height vs. Feedpoint Impedance**

I have noted that for any single-wire doublet, the source impedance varies with the height above ground. The variation is most significant in the region below a 1-wavelength height. The differences in the G5RV feedpoint impedance reflected this variation, but perhaps not as convincingly as it ought to do.

Let's begin with a common center-fed dipole at 14.15 MHz. We shall make it from AWG #12 copper wire. Our model will be resonant in free-space. A length of 33.727' or 10.28 m satisfies this requirement within  $\pm j 1$  Ohm reactance. The wire's impedance in free space is  $72.9 + j 0.7$  Ohms.

I then set the antenna over real average ground, beginning at 0.2 wavelengths and continuing in 0.05-wavelength increments to 1.2 wavelengths. The effects of the height changes on the feedpoint resistance and reactance appear in **Fig. 3**.

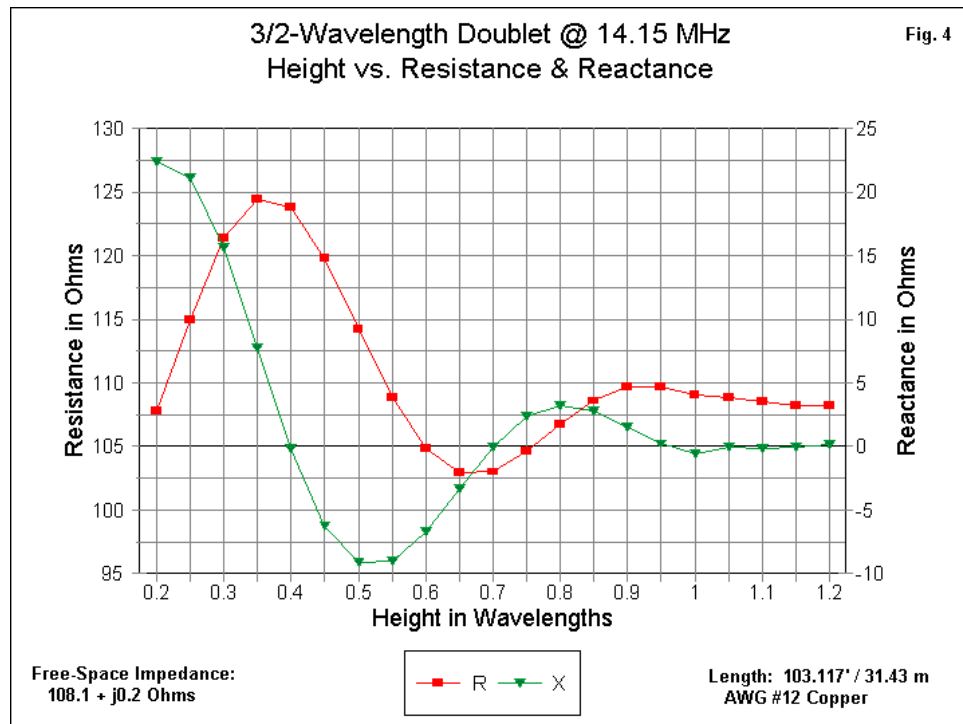


As noted earlier, the resistance and reactance cycles peak at 0.5-wavelength intervals of height. However, the resistance and reactance curves are not synchronized. The reactance peaks occur about 0.15-wavelength higher than their closest resistance peaks.

The reactance swings allow us to re-interpret the data in this way: The resonant length of a 1/2-wavelength dipole changes with height, especially within the range of heights shown in **Fig. 3**. But, even if we resonate the dipole at each height, the feedpoint impedance will still show cyclical changes as we increase the height throughout the range that we have sampled.



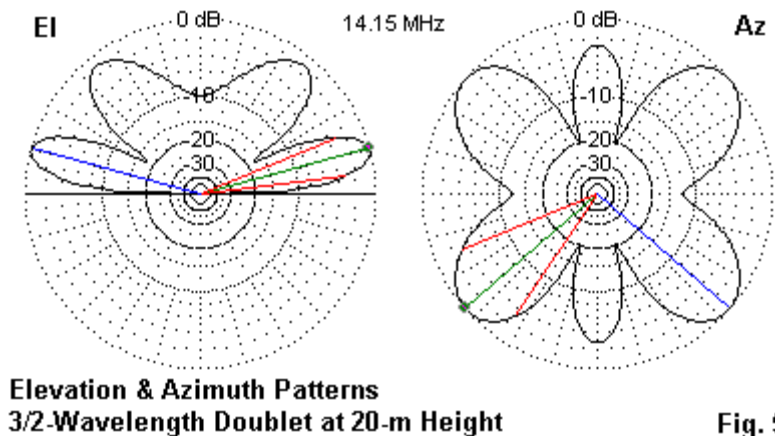
A 3/2-wavelength doublet exhibits the same sort of impedance swing. Let's construct a 14.15-MHz resonant 3/2-wavelength doublet from the same AWG #12 copper wire. If we resonate it in free space, it will be 103.117' or 31.43-m long. Its free-space feedpoint impedance will be  $108.1 + j 0.2$  Ohms. Now we are ready to perform the same set of exercises that we performed on the dipole.



**Fig. 4** shows the results of our test runs. Once more, the resistance and reactance vary considerably as we change heights. The reactance reaches its peaks about 0.15-wavelength higher than height at which the resistance values peak. Perhaps the most notable differences between the dipole and doublet

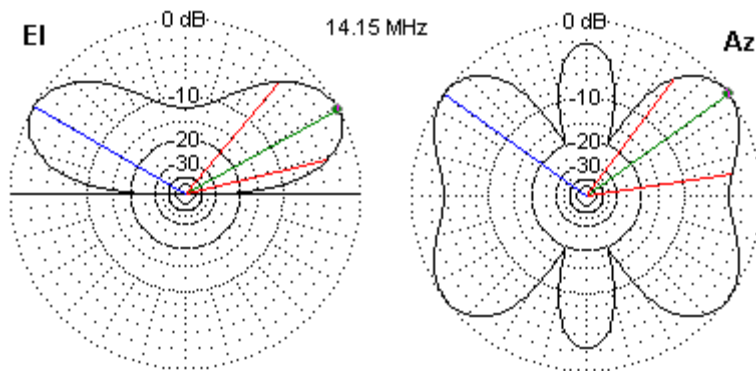
graphs are two: First, the doublet peaks and dipole peaks do not occur at the same heights above ground, although the impedance components for both antennas show 1/2-wavelength cycles. Second, the feedpoint impedance of the longer doublet smooths out rapidly above 1 wavelength, while the 1/2-wavelength dipole impedance components continue to show noticeable cycles.

Not only does the impedance show differences with height, but so too do the elevation and azimuth patterns. Here, we may illustrate by taking the elevation and azimuth patterns of the 3/2-wavelength doublet at 20-m and at 10-m heights above ground.



The elevation pattern in **Fig. 5** shows the typical double lobe structure of any horizontal antenna just below 1-wavelength above ground. The azimuth pattern presumes that the antenna wire is stretched horizontally across the graphic and is taken at the antenna's take-off (TO) angle (the elevation angle of maximum radiation), namely, 14 degrees. It shows 6 lobes, just as we would expect of any wire antenna half-way between 1- and 2-wavelengths long. Note the distinctness

of the angular lobes; that is, note the depth of the null off the ends of the antenna.



**Elevation & Azimuth Patterns  
3/2-Wavelength Doublet at 10-m Height**

**Fig. 6**

**Fig. 6** shows the equivalent patterns when the antenna is half the height of the first model. At just below a half-wavelength in height, we have only a single elevation lobe, just as would any horizontal single-wire antenna at the same height. The azimuth pattern uses a TO angle of 28 degrees and is clearly kin to the one taken at 20 m above ground. However, note the shallower null off the ends of the antenna wire. Radiation off the ends of the wire is down only about 4 dB compared to radiation at the maximum gain angles, compared to a 12-dB differential for the higher version of the antenna.

Like any other wire antenna, the 3/2-wavelength doublet--the heart of the G5RV antenna system at 20 meters--requires reasonable careful orientation if the user has in mind any particular target areas for communications. Likewise, height will always benefit a single-wire antenna, at least to the point where the vertical beamwidth matches as best possible the typical variations in the skip angles on 20 meters.

## **Conclusion to Part 1**

We have reviewed some of the design elements that went into the G5RV antenna system at its design frequency of 14.15 MHz, including some apparent confusion surrounding alternative "matching section" lengths when using different parallel transmission lines. As well, we have shown some of the limitations within the simplified design procedure used to develop the basic G5RV length.

Perhaps of equal or greater significance has been our foray into understanding some of the factors that influence the operation of wire doublets that are usually absent from simplified cutting formulas. Every change that we make from a design that we use as a starting point has consequences for how well the antenna performs compared to the original. The importance of these changes can range from negligible to monumental, depending upon our operating circumstances and our expectations.

Louis Varney expected to use his G5RV antenna system with an ATU on many bands without much regard for where on each band his strongest lobes were pointed. Consequently, the antenna worked very well for him. However, much of the indirect reputation of the G5RV has to do with operating on at least some bands without an ATU. As well, expectations of lobe direction have largely been silent, leaving each user to bring his or her own expectations to the table. As a result, many users have been overjoyed, while many other have been disappointed.

Since we have extracted about as much useful data as we can for the basic design frequency--the 20-meter band--we may next turn to trying to use the G5RV on other bands.

## Chapter 11: The G5RV on all HF Bands

The original G5RV antenna system consists of a center-fed horizontal 102' wire plus a 34' length of open-wire 525-Ohm feeder. Louis Varney, the antenna system's developer, intended two other features. First, the main feeder that we connect to the base of the open-wire section should be 75-Ohm twinlead or coaxial cable. Second, the main feeder should go to an antenna tuning unit (ATU) and not directly to a transceiver.

In Part 1 (Chapter 5), we examined some of the basic properties of the G5RV antenna system at its basic design frequency, 14.15 MHz. We explored some of the variations created by varying the height of the antenna above ground and by using different wire diameters. While none of these variations has much of an effect if we use an ATU between the main feeder and the transceiver, they become important if we attempt to use the antenna system without a tuner. With the physical dimension selected by Varney, the system provides only a partial coverage of 20 meters with a 75-Ohm SWR under 2:1, although a tuner would easily permit full band coverage.

Somewhere along the line of time, the G5RV antenna system has acquired a false aura: namely, that it can cover many amateur bands in the HF region without the use of an antenna tuner. Since almost any rudimentary analysis of the antenna system can show this reputation to be false--and not consistent with what Varney wrote about his antenna system--we shall not dwell on that matter. We shall, of course, present some modeling data that confirms the inaccuracy of the reputation. However, there is a much more interesting question to investigate.

If the antenna system will not provide the desired coverage without an antenna tuner, why use the matching section at all? Why not simply run a feedline of one impedance all the way from the antenna wire to an antenna tuner? Varney recognized that this mode of operation is quite feasible. Nevertheless, he believed that his matching section offered some advantages on most amateur bands. Let's see if we can uncover them.

## The 102' Wire Doublet

In Varney's 1984 *RADCOM* article, he noted that whatever feed system the user might provide, the patterns on each of the HF amateur bands depended solely on the radiation from the antenna wire itself. Over the years, I have discovered that many multi-band wire-antenna users remain unaware of the patterns produced by their antennas on different bands. Therefore, it may be useful to review the pattern situation for the 102' wire that is the radiating portion of the G5RV.

A single center-fed linear element (regardless of the element diameter) will have a pattern that is broadside to the element from a length of about  $1/3$ -wavelength (about the shortest practical doublet length) to a length that is a bit over 1 wavelength. The electrical length of a fixed length physical doublet will increase as we increase the operating frequency. A  $3/2$ -wavelength doublet at 14.15 MHz is  $1/2$ -wavelength at one third that frequency, or about 4.7 MHz. Obviously, the 102' wire is well under  $1/2$ -wavelength in the 80-meter band. At 3.75 MHz, the wire is about 0.39-wavelength.

As we increase the operating frequency, the wire becomes electrically longer. When it is about 1.25 wavelengths, we obtain the typical extended double Zepp pattern with the strongest broadside main lobes that we can achieve from a single element, but with "ears." The ears are emerging new lobes that are part of the natural process of pattern evolution. As we increase frequency--that is, as we make the wire electrically longer--the lobes will evolve in a regular fashion.

At 1 wavelength, we have 2 lobes--one on each broadside to the wire. At 2 wavelengths, we have 4 lobes, each at quartering angles relative to the wire orientation. At 3 wavelengths, we obtain 6 lobes. In fact, the total number of lobes for any wire that is an integral number of wavelengths will simply be twice the length as measured in wavelengths.

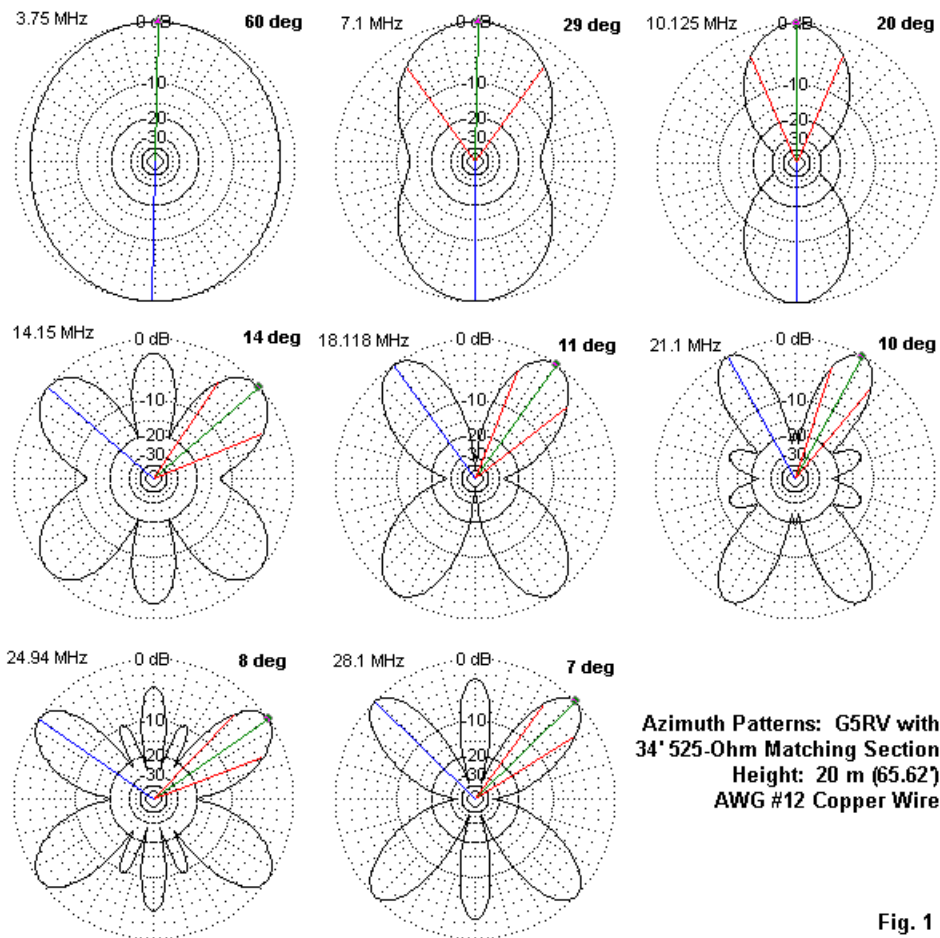
However, lobes do not simply pop into and out of existence. As we pass any integral wavelength marker in making our wire electrically longer, the old lobes will gradually diminish and the new lobes associated with the next integral

wavelength marker will emerge and increase in size. At the 1.25-wavelength point of the extended double Zepp, the 1-wavelength broadside lobe have reached their peak and are ready to diminish, while the new lobes--associated with a 2-wavelength wire--have made their appearance. As we move the wire closer to 1.5 wavelengths, the lobes reach a point of roughly equal strength. Since we have both the 1-wavelength and the 2-wavelength lobes, our lobe total is 6. We can apply similar counting methods to any wire that is  $x.5$  wavelengths, where  $x$  is any integer.

So for any wire of any electrical length, we can predict the lobe structure. With that fact in mind, let's survey the patterns that we can obtain from a 102' wire. For the sake of brevity, I shall select only one of the 102' wires and one of the heights that we examined in Part 1. Let's use AWG #12 copper wire and place it 20 m or 65.62' above average ground.

The fixed physical height above ground, of course, will have a bearing upon the pattern by changing the take-off (TO) angle, or the elevation angle of maximum radiation as we change frequency. As we increase frequency and shorten the length of a wave, the antenna will be electrically higher. Hence, the TO angle will be lower. As a rule of thumb--although calculation equations exist in the handbooks--the TO angle of an antenna at  $1/2$  wavelength height is about 25-26 degrees. At 1 wavelength, the TO angle is 14 degrees. At 2 wavelengths, the angle drops to the 7-8-degree mark. One of the benefits of using a single multi-band wire antennas is that the TO angle tends to correlate with skip properties. As we increase frequency, the dominant skip angles decrease, matching our wire antenna TO angles, if we have it high enough in the first place.

**Fig. 1** shows the anticipated azimuth patterns of the 102' wire at a height of 20 m above ground--about 1 wavelength high at 20 meters. Unlike the patterns for a long-boom Yagi, which might change across the span of a single amateur band, the patterns of a single wire antenna are stable and change slowly. Hence, there will be no significant difference in the 15-meter patterns from one end to the other of this 450-kHz wide band.



Each pattern in **Fig. 1** shows the frequency at which it was taken, along with the TO angle. 102' represent a little over 1 wavelength at 10.125 MHz, and so we



see two broadside lobes. The antenna is about 2 wavelengths long at 17 meters, revealing a 4-lobe pattern. At 10 meters, the antenna is close to 3-wavelengths long and shows 6 distinct lobes.

At 20 meters, where the wire is  $3\frac{1}{2}$ -wavelengths, we also find 6 lobes, but these are the product of the 1-wavelength and the 2-wavelength lobes, one set enlarging and the other set diminishing. The other bands shows lobes in various states of emergence or disappearance because the 102' wire is somewhere between the convenient marker lengths that we have designated.

With any multi-band single-wire antenna, the user has some decisions to make. If he has some latitude in orienting the antenna, he can choose a favorite band and orient the wire so that a major lobe points in the direction or directions of favored target communications areas. Or he can spend nights of pencil and paper planning trying to figure out the best orientation that will yield the best possible results on all favored bands.

Before we try to feed this wire, let's examine one other feature of the lobe structure of the 102' wire. The following table provides the maximum gain and TO angle of the 102' wire as we installed it at 20 m above ground. Maximum gain is the strength of the most major lobe (of which there may be more than one).

.....  
1. 102' AWG #12 Copper Wire Gain and TO Angles

Band Meters	Freq. MHz	Max Gain dBi	TO Angle degrees
80	3.75	6.00	60
40	7.1	7.94	29
30	10.125	9.68	20
20	14.15	8.37	14
17	18.118	9.37	11
15	21.1	10.05	10
12	24.94	10.57	8
10	28.1	10.12	7

Note: Antenna height = 20 m. Maximum gain = gain of the strongest lobe.  
TO angle = elevation angle of maximum radiation.

There is a general trend toward higher gains in the major lobes as we increase the electrical length of the wire by increasing frequency. This property applies to any horizontal wire antenna, regardless of any special name we might give it. However, increase major lobe gain is accompanied by a disadvantage: the width of the major lobes decreases as we electrically lengthen the antenna wire and place more lobes into the pattern. Hence, the higher the frequency of our 102' wire, the more finicky becomes the aim at a target area.

You may also note another trend in the number, most clearly revealed by examining the numbers of 30, 20, and 17 meters. Note that the maximum gain on 20 meters is less than the values for 30 and 17 meters. One of the phenomena of lobe emergence is that, in general, when we are at the x.5-wavelength region, the emerging and diminishing lobes will have a bit less strength, because we are combining two lobe structures.

The final feature that we want to notice is the feedpoint impedance of the 102' wire as taken at the center point of the wire itself. These values will give us some clue as to the rationale behind the G5RV antenna system.

.....  
2. 102' AWG #12 Copper Wire Feedpoint Impedances

Band Meters	Freq. MHz	Feedpoint Impedance R +/- j X Ohms	Notes
80	3.75	46 - j 339	High relative X
40	7.1	397 + j 1037	High relative X
30	10.125	1220 - j 2522	High Z and relative X
20	14.15	104 - j 49	Low X
17	18.118	2281 + j 1624	High Z
15	21.1	337 - j 1038	High relative X
12	24.94	203 + j 328	Moderate relative X
10	28.1	2669 + j 678	High Z

Note: Antenna height = 20 m  
.....

Notice the large range of the resistive components of the impedances on the HF bands--all the way from 46 to 2600 Ohms. (The resistive component at 3.5 MHz

would be even lower than 46 Ohms.) As well, note how many of the bands present relatively high values of reactance--some inductive, others capacitive.

To feed this antenna with a single transmission line, we would normally select a characteristic impedance somewhere in the vicinity of the geometric mean between the extremes. Something in the 400-600-Ohm vicinity should prove usable. However, the impedance at the antenna tuner terminals depends upon three general factors--ignoring line losses for the moment: the feedpoint impedance, the characteristic impedance of the feedline, and the electrical length of the feedline. Unless there is a perfect match between the antenna feedpoint impedance and the characteristic impedance of the transmission line, the line itself will continuously transform the impedance components along each half-wavelength of line at the frequency of operation. It is not at all unusual to encounter values of resistance and/or reactance at the tuner terminals that fall outside the matching range of the tuner. The most ready cure is often to insert an additional length of line to see if we cannot arrive at resistance and reactance values within the tuner's range. If we are lucky, the insertion may allow matching at all used frequencies. If we are not so lucky, then we may need to develop a switching system to insert the added line length on the bands for which we need it.

Now we are ready to understand part of the rationale behind the G5RV antenna system, with its 34' of 525-Ohm transmission line.

### **The G5RV Antenna System and Some Variants on All HF Bands**

Varney performed a rudimentary standing wave analysis for his antenna system in his 1984 article. Let's begin by reviewing his results in tabular form. Remember that he is analyzing the likely impedance that will appear at the lower terminals of the matching section.

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### 3. G5RV's analysis of the system at all HF frequencies

Note: Load Impedance is the impedance at the end of the "matching section."

Band	Analysis	Load Impedance
80 meters	Wire + Section = shortened Dipole	Reactive ( $R+/-jX$ )
40	Wire + Section = partially folded	
	2-half-waves in phase	Reactive ( $R+/-jX$ )
30	Wire + Section = partially folded	
	2-half-waves in phase	Reactive ( $R+/-jX$ )
20	3-half-waves	Resistive (ca. 90 Ohms)
17	2-full-waves in phase	High Z, slight X
15	5-half-waves	High Z, resistive
12	5-half-waves	Resistive (90-100 Ohms)
10	2 x 3-half-waves in phase	High Z, slight X

.....

This sort of information style makes it difficult for us to directly compare the results with the matching section with the modeled results that we obtained without the matching section. Therefore, let's do some NEC-4 modeling, using the same TL facility matching section construct that we used in Part 1. As we did initially, we shall confine ourselves to a 20-m height for the 102' AWG #12 copper wire.

While we are at the task, we can also examine some slight variations in the G5RV antenna system. All of the variations represent slight modifications in the matching section transmission line.

Version 1: the original G5RV with 34' of 525-Ohm 0.98 VF open wire line.

Version 2: the common U.S. implementation of the G5RV using 34' of 450-Ohm 0.91 VF vinyl-covered window line.

Version 3: a second common implementation using 28' of 300-Ohm 0.82 VF TV-type ribbon or solid vinyl covered line, noted in the 1984 article.

Version 4: 300-Ohm 0.9 VF windowed vinyl-covered TV-type ribbon line (in the U.S., available from The Wireman in SC, but check his specification for the VF).

Allowing for the possible confusion of the VF attached to the original open-wire line by those who suggest alternative line for the matching section, the sections are all cut to be about 1/2-wavelength at 14.15 MHz. Hence, we should see about the same impedance values in all versions as we obtained for the wire alone.

The following table shows the modeled impedance values at the base of the matching section for each version on each of the test frequencies spread across the HF region. As well, for reference, the tables also provide the 75-Ohm SWR values in keeping with Varney's intent that the remaining transmission line to the ATU be 75-Ohm twinlead or coaxial cable.

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4. Impedances at the base of the "Matching Section" for 4 Variations on the G5RV Antenna System

All Versions use a 102' AWG #12 copper wire at 20 m above average ground. differences appear in the "Matching Section."

Version 1: 34' (10.36 m) 525-Ohm, VF 0.98 open wire system (G5RV recommendation)

Version 2: 34' (10,36 m) 450-Ohm, VF 0.91 windowed parallel line (common implementation)

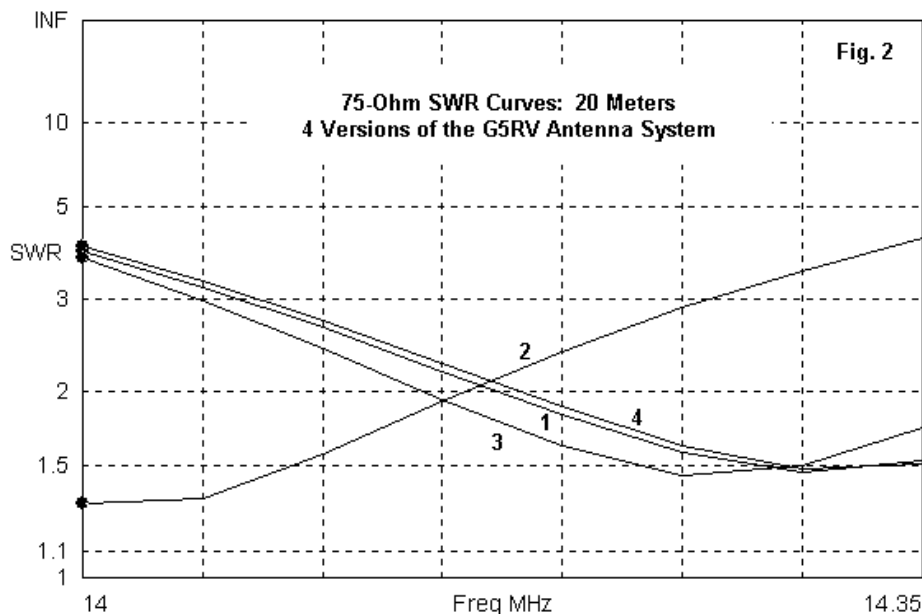
Version 3: 28.0' (8.53 m) 300-Ohm, VF 0.82 solid TV-type parallel line

Version 4: 30.6' (9.33 m) 300-Ohm, Vf 0.90 windowed TV-type parallel line

Band meters	Freq MHz	Version 1		Version 2	
		Impedance R+/-jX	75-Ohm SWR	Impedance R+/-jX	75-Ohm SWR
80	3.75	35 + j 136	9.6	31 + j 112	8.0
40	7.1	88 - j 230	9.9	60 - j 110	4.5
30	10.125	95 + j 584	50.0	103 + j 682	62.0
20	14.15	104 - j 52	1.9	104 + j 51	1.9
17	18.118	157 - j 517	25.2	73 - j 230	11.6
15	21.1	77 + j 219	10.2	86 + j 376	23.9
12	24.94	144 - j 73	2.5	145 + j 156	4.5
10	28.1	2398 + j 1002	37.6	409 - j 917	33.0

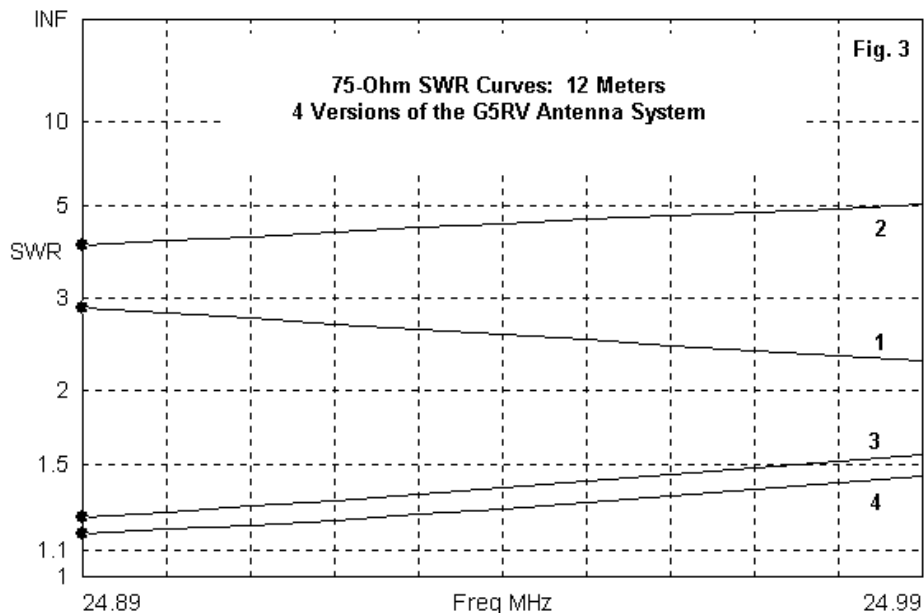
Band meters	Freq MHz	Version 3 Impedance		75-Ohm SWR	Version 4 Impedance		75-Ohm SWR
		R+/-jX			R+/-jX		
80	3.75	20 - j	10	3.8	20 - j	11	3.8
40	7.1	29 - j	83	5.9	29 - j	85	6.1
30	10.125	25 + j	270	41.9	25 + j	266	41.1
20	14.15	106 - j	64	2.2	106 - j	68	2.3
17	18.118	55 - j	315	26.2	57 - j	326	26.9
15	21.1	24 + j	44	4.2	24 + j	38	4.0
12	24.94	83 + j	24	1.4	83 + j	18	1.3
10	28.1	825 + j	1261	36.8	666 + j	1171	36.4
.....							

Let's initially look at a couple of bands in the whole range. Although all of the matching sections show similar impedances at 14.15 MHz, we cannot be assured that the 20 meter SWR curves will be identical for all 4 versions. Therefore, **Fig. 2** shows the 75-Ohm curves for the 4 versions.



Versions 1, 3, and 4 show similar curves, since they were cut close to a half wavelength for the line used. However, the common US implementation of the G5RV simply replaces one line with another without allowing for the difference in velocity factor. Hence, the impedance transformation undergoes more than 1/2 wavelength, and the resulting impedance away from the design frequency differs from the other versions. The lesson is that if one wishes to replicate the G5RV system at 20 meters with a different matching section line, one must use some care in accounting for differences in the velocity factor.

Of all the bands, 12 meters shows the greatest promise for avoiding the need for an ATU. **Fig. 3** presents the SWR curves for this narrow ham band.



As may be evident, the two 300-Ohm systems provide a good 75-Ohm SWR, while the two higher-impedance matching sections do not. The unsuspecting novice builder of a G5RV may wonder why.

The matching section is 1/2-wavelength long at 14.15 MHz. However, it has a different electrical length at every other frequency across the amateur bands. Lines having different characteristic impedances will yield different impedance transformations.

We are likely familiar with the fact by now that a transmission line of any characteristic impedance will replicate the wire feedpoint impedance if the line is electrically 1/2 wavelength. We may also be familiar with the fact that if a line is



electrically an odd number of quarter-wavelengths, then the impedance at the base or "sending" end will be the square of the line's characteristic impedance divided by the load impedance--in this case the wire feedpoint impedance.

However, these simplified relationships derive from a much more complex equation describing the transformation of the load impedance for any length of line whatsoever. The following equation shows the transformation, but still simplified by omitting the calculation of line losses. As noted in Part 1, the modeling software uses a lossless-line model for its calculations, and the losses in the short parallel line composing the matching section are almost small enough to be negligible.

$$Z_s = Z_o \frac{\frac{Z_L}{Z_o} \cos\left(2\pi \frac{l}{\lambda}\right) + j \sin\left(2\pi \frac{l}{\lambda}\right)}{\cos\left(2\pi \frac{l}{\lambda}\right) + j \frac{Z_L}{Z_o} \sin\left(2\pi \frac{l}{\lambda}\right)} \quad (1)$$

The terms  $l$  and  $\lambda$  are in the same units, where  $l$  is the electrical length of the transmission line, while  $\lambda$  is a wave length.  $Z_o$  is the characteristic impedance of the line;  $Z_L$  is the load impedance, and  $Z_s$  equals the impedance at the sending end of the line. This particular version of the impedance transformation equation comes from page 186 of Terman's *Radio Engineers' Handbook*. Of course,  $Z_L$  may be complex ( $R \pm jX$ ), and so, too, may be  $Z_s$ . There are a number of utility computer programs that will calculate the impedance transformation--with or without losses--including the resistive and reactive components.

The message of the equation for this context is that the complex transformation of impedance along a transmission line, when the load impedance and the line's characteristic impedance are not a perfect match, depends on the line length and

the line's characteristic impedance. The transformation on all bands for which the line is not a nearly exact multiple of a half wavelength will differ as we change the characteristic impedance of the line. Therefore, as we develop alternative types of transmission line for the matching section of a G5RV, we should not expect to replicate the impedance values of Varney's original version on bands other than 20 meters.

We can see the effect of moving from the 450-to-525-Ohm region down to 300 Ohms by looking at the impedance values for the bands below 20 meters. The higher impedance lines yield resistive components between 35 and 95 Ohms, while the 300-Ohm lines produce values in the 20-30-Ohm range. These values are also a good reason not to run the feedline to the 4:1 balun that inhabits so many network tuners in common use today. We do not need an already low resistive component further reduced.

However, the 300-Ohm line has a small advantage. It yields impedance values on more bands with 75-Ohm SWR values under 10:1. Although there is no guarantee, given the very wide variety of components used in today's tuners, the lower the overall SWR value, the more likely it is that the feedline from the matching section to the tuner will provide values within the tuning range of the ATU.

Indeed, it is now time to perform one more comparison: between the overall impedance values in the table for the 4 versions of the G5RV and the impedance values for the feedpoint of the 102' wire alone. In general, the matching section yields lower values of both resistance and reactance. Therefore, with a 75-Ohm line from the matching section to the ATU, we are likely to be able to effect a match. We would only be able to achieve this goal with parallel transmission line all the way from the wire to the ATU--and might have to insert some line on some bands.

The final question in this series of inquiries is simple: why do the job in the G5RV manner?

## Setting Up a G5RV Antenna System

For a G5RV antenna system--at least as indicated by both Varney himself and by the modeling results--we shall need several components:

102' of strong copper or copperweld wire--along with sundry end rope, insulators, and a center-junction piece.

A length of parallel transmission line cut to 1/2-wavelength at about 14.15 MHz, accounting for the line's velocity factor.

A length of feedline from the matching section to the ATU. For network tuners, we might as well use 75-Ohm or even 50-Ohm cable. However, since the line will be subject to considerable SWR and hence voltage and current excursions along its length, we should use the shortest possible length to minimize losses. As well, we should use the fattest, lowest loss line that we can obtain (RG-213 or better). Because 75-Ohm transmitting twinlead is no longer made in the U.S., we can only implement the G5RV using coaxial cable, unless we are willing to build our own low-impedance parallel line.

A choke to place at the junction of the matching section and the coaxial cable, as noted in the 1984 *RADCOM* article.

A wide-range network tuner.

**Fig. 4** sketches the essential ingredients of the antenna from the wire down to the network tuner.

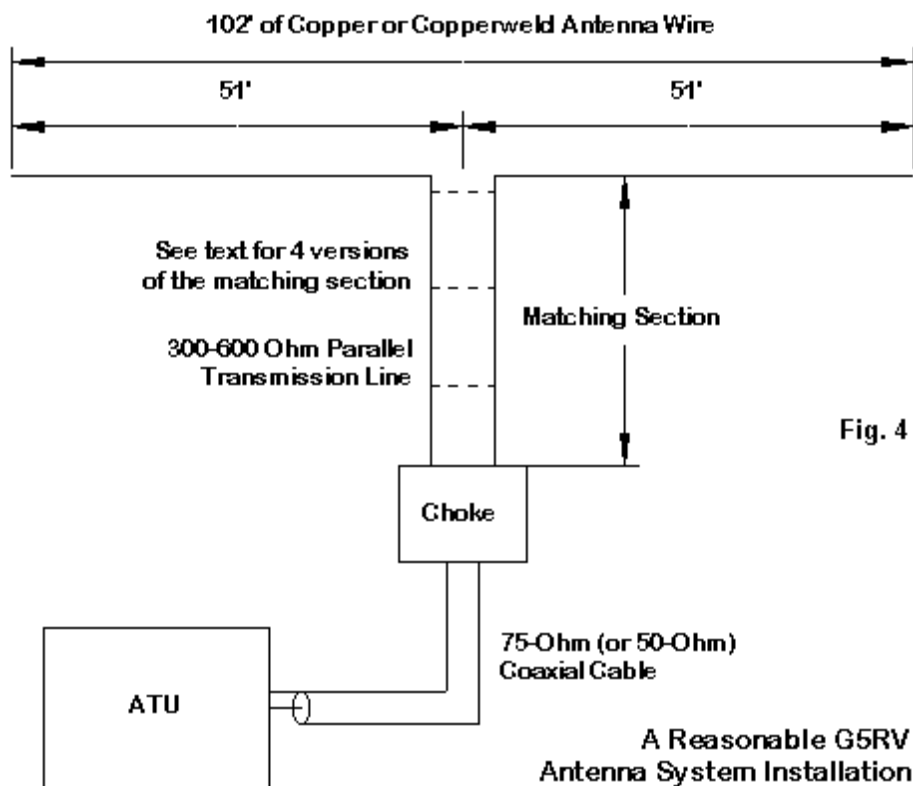


Fig. 4

When used with a wide-range tuner, there is little to choose among the versions of the matching section illustrated in these notes--or among a large lot of other potential sections. Each should be 1/2-wavelength at about 14.15 MHz. Perhaps the only general rule involved is that the higher the characteristic impedance of the matching section transmission line, the higher the impedance that is likely on the bands below 20 meters. However, 300-Ohm line (the transmitting variety, for

lowest losses) offers fewer bands with very high SWR values relative to either 50- or 75-Ohm cable.

Perhaps the only other component of the system calling for comment is the choke. Very often we hear such devices being called choke-baluns or simply 1:1 baluns. Such devices have two functions that are inter-related. They provide a transition between balanced line on the one side and unbalanced line on the other. They also tend to attenuate common-mode currents on the braid of the coax. In fact, these two functions are one and the same, for the only reason for needing a transition device where we effect no impedance transformation is to suppress common-mode currents.

Newcomers to antenna work are sometimes confused by calling these current common-mode currents and also saying that they appear on the coax braid. Normal transmission line currents are ideally equal in magnitude but opposite in phase anywhere along a transmission line. Common-mode currents have the same phase on both conductors. On parallel line, such currents are of equal magnitude on each line. However, on coaxial cable, due to the skin effect which tends to cancel currents at the center of a conductor and place all current at the surface, the current is most measurable on the braid.

Louis Varney warned against the use of transformer-wound 1:1 baluns because many designs show considerable losses when the load reactance is significant. Indeed, Jerry Sevick, W2FMI, who has published the most material on transmission-line transformers, recommends that all reactance compensation occur on the load side of the balun.

In place of such baluns to suppress common-mode currents, Varney recommends a 6" diameter coil of about 8 to 10 turns of the feedline coaxial cable at the junction of the matching section and the main feedline. I have found that W2DU-type ferrite bead chokes also perform well in this function.

One recommendation that I have seen from vendors of commercially prepared G5RV kits is to use as long a run of coaxial cable as possible. Coaxial cable is

inherently lossier than parallel transmission line. Any SWR factor acts as a multiplier on the basic matched-line loss of a cable at a given frequency. Hence, the only reason that I can think of for using a very long run of coaxial cable--other than one of necessity for extending from the shack to the antenna--is to use the line losses to mask the SWR at the shack end of the line. If the measured SWR at the shack end of the line is very significantly lower than the sorts of figures produced by these models--or models customized to the system proposed by a user--then they result from line losses. And the only purpose for accepting such losses would be to operate the system without a tuner.

With a wide-range tuner, one achieves the lowest feasible loss level with the shortest possible coaxial cable run.

## **Conclusion to Part 2**

From Louis Varney's own writings, we can derive and confirm with NEC-4 models the fact that the G5RV antenna system is suitable for multi-band operation, just as any wire from about 88 to 140 feet might be. The matching system comes into play, not to do away with the need for an ATU, but to permit the use of a coaxial cable as the main feedline with SWR values that are considerably lower than they would be without the matching section on most HF bands. Nevertheless, the ATU remains an essential part of the G5RV antenna system.

The use of coaxial cable for the main feedline has some advantages in the modern home. Contemporary homes have walls, ceilings, and floors that are rampant with wiring and other metallic conductors associated with heating and air conditioning systems. Hence, indoors, the chances of a parallel line encountering environments that would disrupt the line balance have multiplied with time. A coaxial cable main feedline properly immunized from common-mode currents with a suitable choke offers some isolation from the conductive contents of the modern home with only small losses as the cost.

50-Ohm cable has come to rule the field of amateur feedlines. As well, the ATU remains among many folks a suspect device, since it adds to the number of

boxes on the operating desk. As a result, after the appearance of the G5RV antenna system, a search ensued for a combination of antenna wire length and matching section that would yield the highest number of amateur bands offering ATU-less operation on a 50-Ohm cable. We shall devote a final part to this series to explore a G5RV variant, perhaps the most successful effort to reach the 50-Ohm cable goal.

## Chapter 12: The Almost-No-ATU G5RV-Type Antenna

In the mid-1980s, Brian Austin (then ZS6BKW, now G0GSF) addressed the quest left as a nearly mythical heritage of the G5RV antenna system: to develop an antenna system that, for the maximum number of HF bands possible, would permit no-ATU operation of the system with a 50-Ohm coaxial cable as the main feedline. There had been other cousins of the G5RV, such as the W5ANB transmission-line translation featured in *QST* for November, 1981 (pp. 26-27). Serious researchers traced the overall design concept to the 300-Ohm based Collins version of the 1930s. However, virtually all of these cousins satisfied themselves--as did Varney--with moderate impedances that would fall easily in the range of the average antenna tuner. They did not seek to free the user completely from the ATU in multi-band operation.

### The ZS6BKW/G0GSF Antenna System

Austin's amateur developments appear in *RADCOM* for August, 1985, and in *Radio ZS* for June 1985, with professional efforts reported in *Elektron* for June/July, 1986, and the *Journal of IERE (UK)* for July/August, 1987. G3BDQ's *Practical Wire Antennas* volume reports on the amateur version of Austin's antenna on p. 22. Essentially, his task was to find a length and characteristic impedance for a matching section that will transform the impedance at the center of a wire of a given length to something close to 50 Ohms. So we have several variables (using Austin's notation) in combination:

L1: the length of the horizontal wire;

L2: the length of the matching section;

Z2: the characteristic impedance ( $Z_0$ ) of the matching section; and

Z4: the characteristic impedance of the main feedline, which is 50 Ohms for most amateur applications.



By computer calculation, Austin arrived at a workable set of relationships that permitted the largest number of bands to arrive at a direct 50-Ohm feed with an acceptable SWR value. Let  $L_1$  approximately equal  $204/\text{Flow}$  meters or  $669.3/\text{Flow}$  feet, where Flow is the lowest frequency to be used. For a  $Z_o$  of 400 Ohms, let  $L_2$  approximately equal  $92/\text{Flow}$  meters or  $301.8/\text{Flow}$  feet. Of course,  $L_2$  must be adjusted according to the velocity factor of the actual parallel transmission line used. (A 400-Ohm Window line is available from The Wireman of SC).

It is interesting that the sum of the two lengths is about 1% under 1 wavelength. More significant than this accidental result is the fact that the combination of  $L_1$  and  $L_2$  provides a good 50-Ohm match in the following progression of ratios: 1 : 2.02 : 2.57 : 3.54 : 4.14, etc. If we let the lowest used frequency be about 7 MHz, then we may have acceptable matches on 20, 17, 12, and 10 meters. 5 bands with one doublet and no ATU is no mean feat.

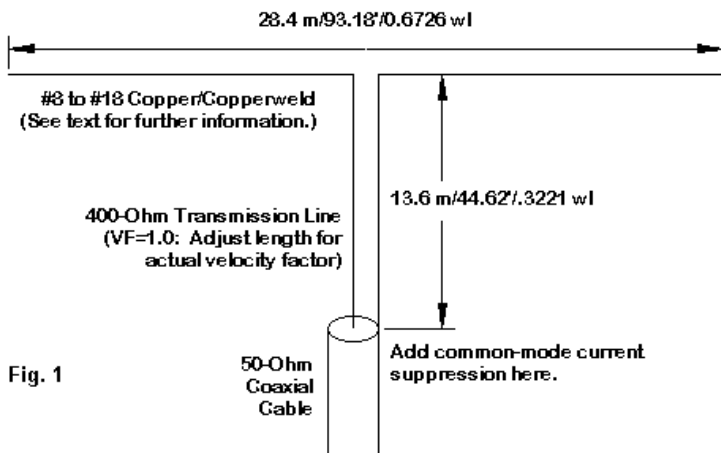


Fig. 1

The ZS6BKW/G0GSG Multi-Band Antenna System

**Fig. 1** shows the outline for a ZS6BKW/G0GSF antenna system for 40 through 10 meters. The wire length is 28.4 m or 93.18'. The matching section uses 400-Ohm parallel line and a length of 13.6 m or 44.62'. We shall examine various wire sizes for L1 later, but for the moment we may note the following small table of values for constructing 400-Ohm open wire transmission line using common copper wire sizes.

400-Ohm Open-Wire Transmission Line			
Wire Size	Center-to-Center	Wire Size	Center-to-Center
AWG	Spacing (inches)	AWG	Spacing (inches)
12	1.137	16	0.715
14	0.901	18	0.567

There are some commercially available vinyl-covered windowed lines that are closer to 400 Ohms than our expected 450-Ohm value. Therefore, if you do not wish to make up the 45' of 400-Ohm line, you may wish to check with vendors. Obtain the velocity factor to determine how much to physically shorten the line to achieve the required electrical length in **Fig. 1**. However, do not rely on the report. Whether you build or buy the match-section line, measure its velocity factor.

The Hayes volume reports the Austin results in the following manner with respect to SWR at the junction of L2 and the main 50-Ohm feedline.

50-Ohm SWR Values for the ZS6BKW Antenna System		
Freq.	50-Ohm	Notes
MHz	SWR	
3.65	11.8:1	poor
7	1.8:1	good
10	88:1	very poor
14	1.3:1	good
18	1.6:1	good
21.2	67:1	very poor
24	1.9:1	fairly good
29	1.8:1	good

Austin used a free-space calculation of the impedance of L1 as the basis for his matching section calculations. It is not clear that the equations factor in either the effects of height or wire size on the quality of 50-Ohm match. As well, the spot checks of the match do not provide us with a good portrait of the operating bandwidth potential for each band.

Consequently, it may be useful to subject the ZS6BKW/G0GSF antenna system to the same sorts of NEC-4 modeling that we used for the G5RV. We shall begin with a basic model using AWG #12 copper wire, placing it in free space and then at heights of 20 m and 10 m (65.62' and 32.81') above average ground. The models produce the following results.

Modelled Results for the ZS6BKW/G0GSF Antenna System

Free Space

Band	Freq.	Feedpoint Impedance	50-Ohm
Meters	MHz	R +/- j X Ohms	SWR
80	3.75	13 + j 79	13.23
40	7.15	55 + j 6	1.15
30	10.125	502 + j 1506	>100
20	14.175	42 + j 16	1.47
17	18.118	68 + j 37	1.99
15	21.2	1333 + j 1783	74.36
12	24.94	65 + j 28	1.74
10	28.8	77 + j 7	1.56

20 m/65.62' Above Average Ground

Band	Freq.	Feedpoint Impedance	50-Ohm
Meters	MHz	R +/- j X Ohms	SWR
80	3.75	16 + j 82	11.68
40	7.15	56 - j 4	1.14
30	10.125	490 + j 1576	>100
20	14.175	43 + j 13	1.37
17	18.118	67 + j 35	1.94
15	21.2	1381 + j 1783	73.69
12	24.94	64 + j 26	1.68
10	28.8	78 + j 6	1.57

10 m/32.81' Above Average Ground

Band	Freq.	Feedpoint Impedance	50-Ohm
Meters	MHz	R +/- j X Ohms	SWR
80	3.75	11 + j 84	18.03
40	7.15	57 + j 19	1.47

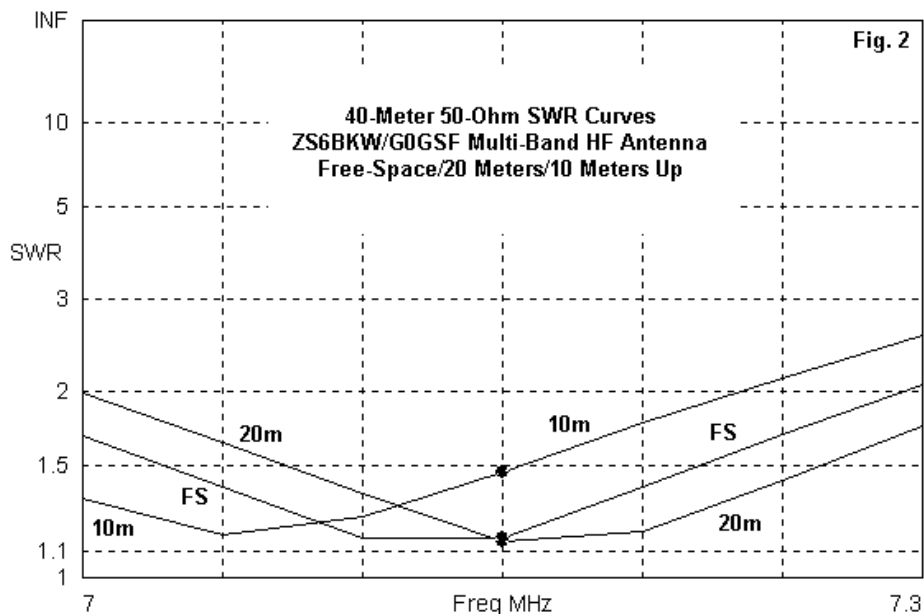
30	10.125	598 + j 1460	83.33
20	14.175	43 + j 11	1.31
17	18.118	67 + j 30	1.81
15	21.2	1305 + j 1920	82.61
12	24.94	67 + j 31	1.83
10	28.8	75 + j 7	1.53

. . . . .

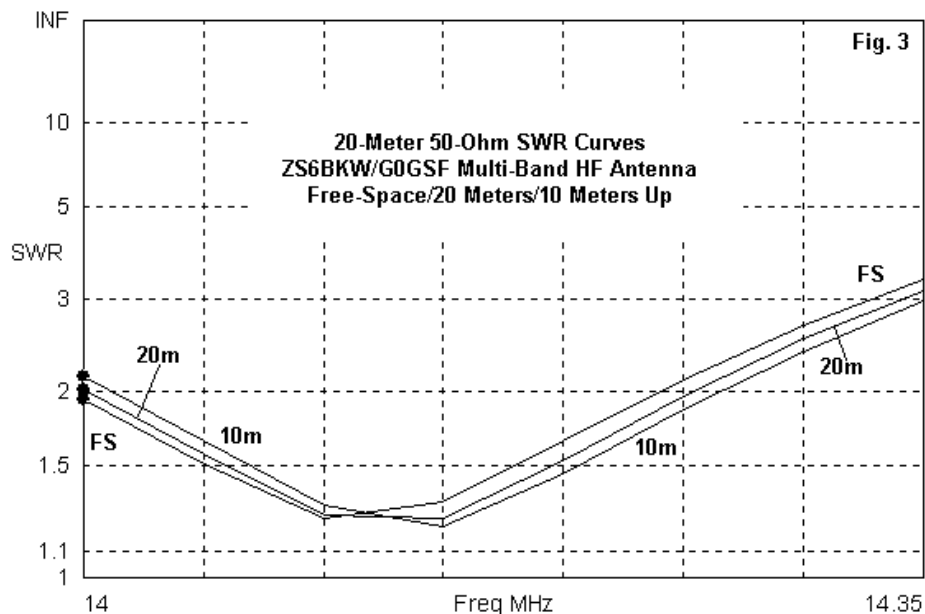
The modeled values for the spot frequencies coincide quite closely with Austin's initially charted SWR reports. 80, 30, and 15 meters are essentially non-usable. 17 and 12 meters show 50-Ohm SWR values near the limits of where modern transceivers begin to reduce power. However, with most coax runs, the SWR values shown at the transceiver will be reduced as a function of line losses on these bands. The SWR values for 40, 20, and 10 meters are highly promising.

Side note: Examine the SWR values for the free-space and the 20-m models. In both cases, the reactance is identical and high. However, the free-space resistive component is lower than the 20-m value, but the SWR is higher. Newcomers often believe that higher impedance values automatically produce higher SWR values and fail to appreciate the role played in the complex SWR calculation equations of the ratio of reactance to resistance in yielding the final result.

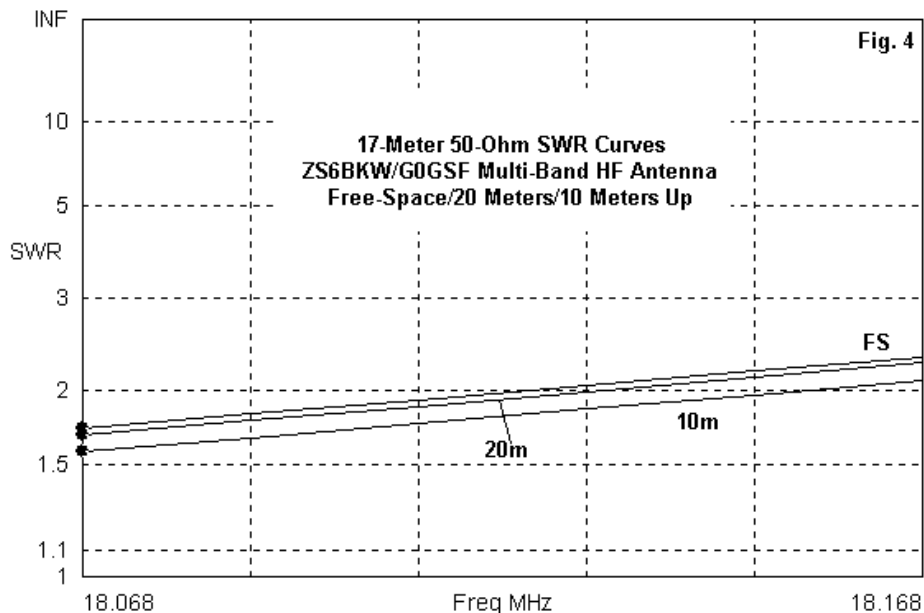
Let's look a bit further into the usable bands by taking 50-Ohm sweeps at each height across the bands. This exercise will give us a bit of insight into the operating bandwidth for the antenna system.



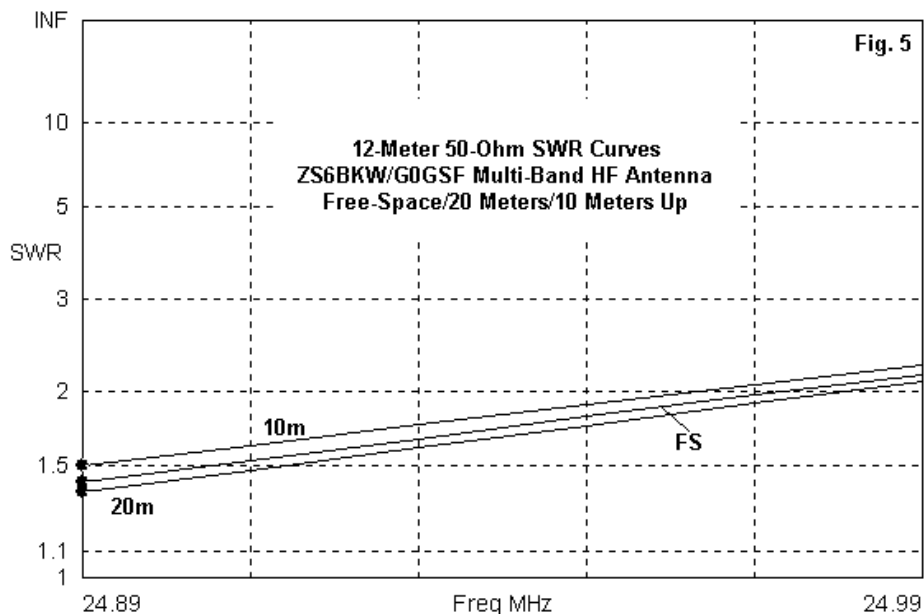
**Fig. 2** provides us with a triple sweep of 40 meters. Only the curve for the 20-m height covers the entire band with an acceptable (less than 2:1) 50-Ohm SWR. On 40 meters, that height is about 1/2 wavelength up, while the lower 10-m height is only a quarter wavelength.



The 20-meter curves, shown in **Fig. 3**, coincide more closely, since the heights are 1/2 and 1 wavelength. The SWR bandwidth favors the low end of the band and is narrower than would be the SWR curve for an AWG #12 copper dipole resonated somewhere in the middle of the band.

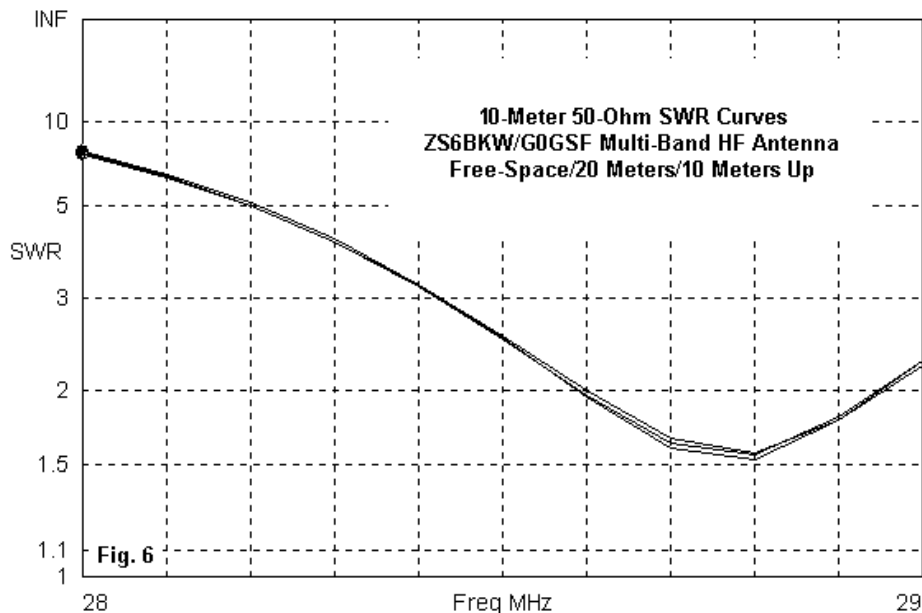


The 17-meter band is marginal with respect to a 2:1 SWR bandwidth, as shown in **Fig. 4**. With a length of 50-Ohm coax between the matching section and the rig, the measured SWR near the transmitter would be a bit less, allowing the use of this band without triggering most power-reduction features associated with solid-state final amplifiers.



12 meters (**Fig. 5**) shows a similar phenomenon where the 50-Ohm SWR passes the 2:1 mark within the band. However, for most heights, the SWR is a bit lower than on 17, and the same length of coax would show a bit more loss and hence a bit lower SWR at the transmitter end of the line. Hence, the 12-meter band might prove a bit less problematical relative to triggering power reduction circuitry.





Because the "good-match" frequency ratios are not harmonically related, the ZS6BKW/G0GSF antenna system favors the upper end of the first MHz of 10 meters, as shown in **Fig. 6**. The window is small, but quite usable. If the transceiver has a built-in narrow range tuner, of course, the entire band would be usable, and the marginal and narrow band conditions on other bands would no longer be a problem.

The ZS6BKW/G0GSF antenna system is also somewhat sensitive to the wire diameter. To show this fact, I modeled the antenna using AWG #8, #12, and #18 wire. The #8 selection is fatter than almost all amateurs would use, but-in conjunction with the other wires--it provides a reasonably graphic illustration of the effects of wire diameter on the performance of the antenna system. The

following tables provide the spot frequency data for the runs. For this set of models, the height is 20 m above average ground. The unusable bands have been omitted.

. . . . . ZS6BKW Performance Data with AWG #8, #12, and #18 Wire . . . . .

**AWG #82**

Band	Freq.	Feedpoint	Impedance	50-Ohm
Meters	MHz	R +/- j X	Ohms	SWR
40	7.15	61 - j	11	1.31
20	14.175	46 + j	26	1.73
17	18.118	73 + j	30	1.86
12	24.94	67 + j	41	2.11
10	28.8	86 + j	2	1.72

**AWG #12**

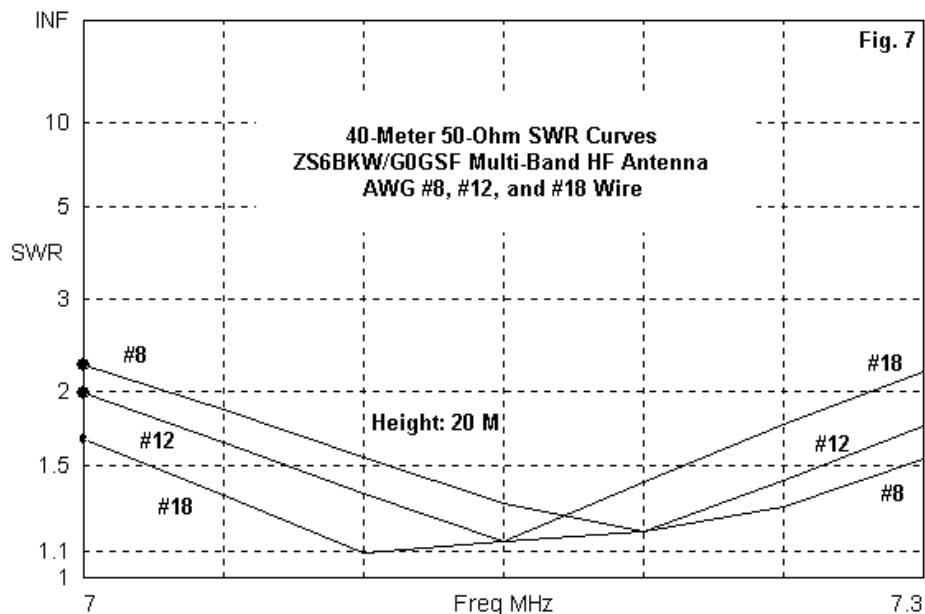
Band	Freq.	Feedpoint	Impedance	50-Ohm
Meters	MHz	R +/- j X	Ohms	SWR
40	7.15	56 - j	4	1.14
20	14.175	43 + j	13	1.37
17	18.118	67 + j	35	1.94
12	24.94	64 + j	26	1.68
10	28.8	78 + j	6	1.57

**AWG #18**

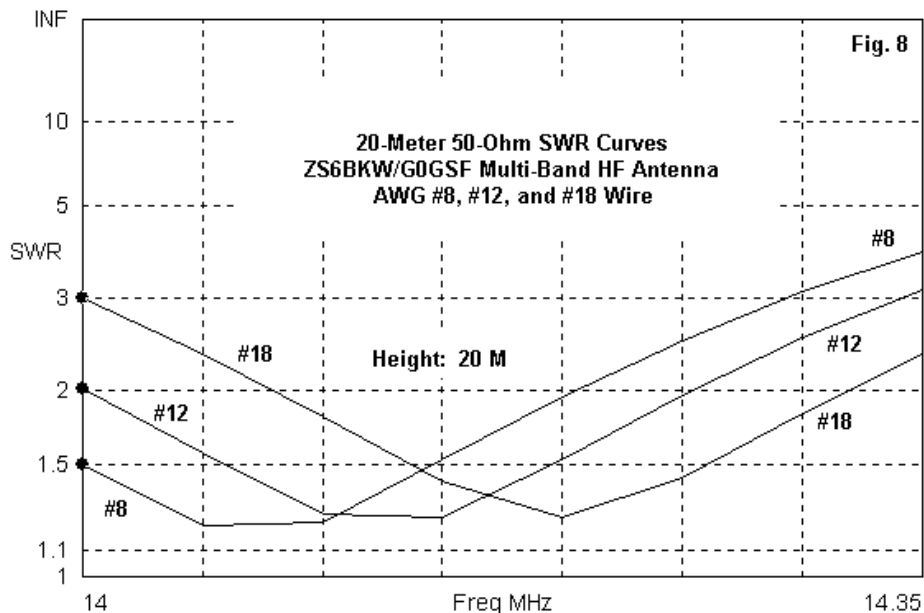
Band	Freq.	Feedpoint	Impedance	50-Ohm
Meters	MHz	R +/- j X	Ohms	SWR
40	7.15	50 + j	7	1.14
20	14.175	40 - j	5	1.29
17	18.118	59 + j	42	2.18
12	24.94	60 + j	7	1.25
10	28.8	68 + j	13	1.46

Like all other small adjustments to the ZS6BKW/G0GSF antenna system, including changes of wire length, match section length, and match section  $Z_0$ , the 17-meter match and the 12-meter match tend to show opposite effects. An improvement to one is accompanied by a degradation of the other.

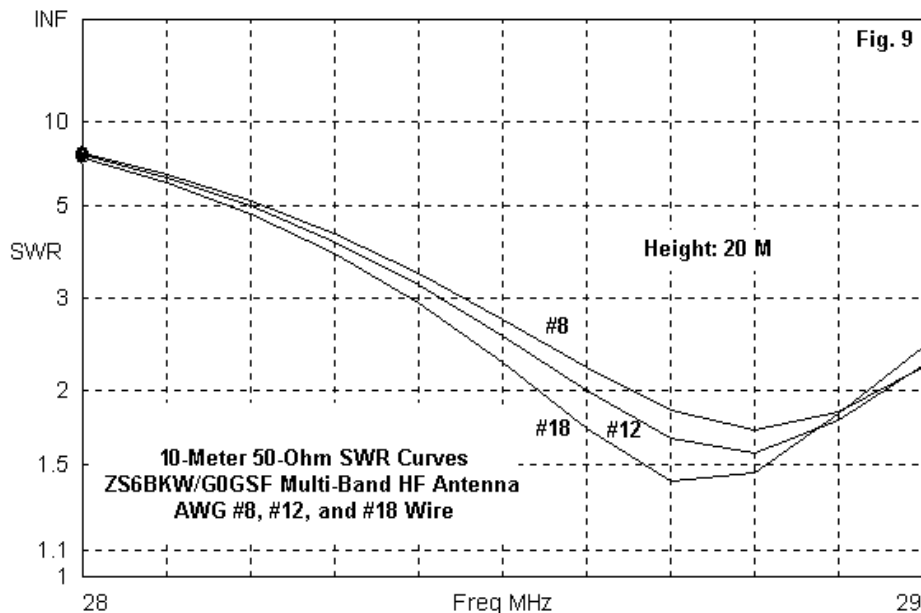
For the wider usable bands, we might again look at comparative 50-Ohm SWR sweeps using the three wire sizes for an antenna wire at 20 m above average ground.



**Fig. 7** shows the effects of changing wire diameter across the 40-meter band. #18 through #12 wire seem to show the best promise of full band coverage, although a wire as large as #8 is usable with an in-rig tuner.



See **Fig. 8**: on 20 meters, as the operating bandwidth narrows, the thinner end of the wire scale offer fuller band coverage, with the #18 wire favoring the upper end of the band. Those who use only the low end of the band for CW or digital work might prefer a larger diameter wire for the antenna.



On 10 meters, thinner is definitely better in terms of total operating bandwidth, as demonstrated by **Fig. 9**. However, all three curves miss the popular 28.3 to 28.5 MHz window of major 10-meter activity, along with the "CW" end of the band. In these regions, there is little to choose among the wire sizes, and an in-rig tuner would likely provide the necessary match.

Of the unusable bands--80, 30, and 15 meters--a wide range external ATU would likely provide a usable match on 80 and 75 meters. Since the losses of coaxial cable are low in this band and the SWR loss multiplier for the 10:1 to 13:1 range is moderate, the band might prove to be feasible. The higher losses at 30 and 15 meters, accompanied by very high SWR values, do not bode well for effective use of these bands with the ZS6BKW/G0GSF antenna system. Cable losses

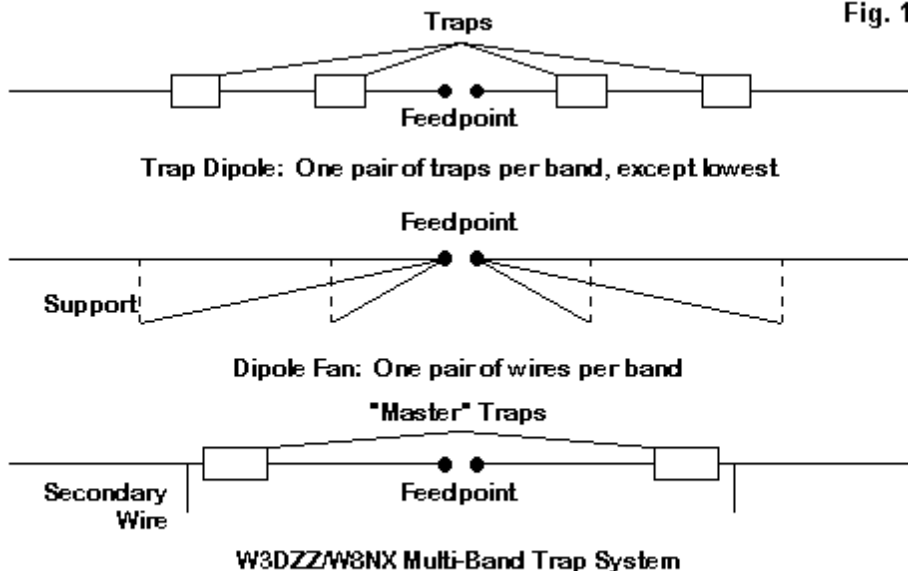
may show a lower measured SWR at the transceiver end of the line, and a tuner may effect a match of some sort, but the losses in the cable will remain. As well, the tuner network may operate in a high-loaded-Q condition, further adding to overall losses.

I have not shown azimuth patterns for Austin's antenna system, since those patterns are a function of the radiating wire length. Patterns for a 93' wire and a 102' wire are too similar to need repetition. So you may refer to the patterns in Part 2 for a good idea of where the lobes will go on each usable band with the ZS6BKW/G0GSF system.

### **Conclusion to Part 3**

Of all the G5RV antenna system cousins, the ZS6BKW/G0GSF antenna system has come closest to achieving the goal that is part of the G5RV mythology: a multi-band HF antenna consisting of a single wire and simple matching system to cover as many of the amateur HF bands as possible. From 80 to 10 meters, Austin's system provides an acceptable match on 5 out of the 8 bands under most conditions without an antenna tuner. This is the best result that has been achieved of any of the systems that has come to my attention.

Fig. 10



### 3 Alternative Multi-Band Doublet Systems for Coaxial Cable Feed

There are at least three other classic horizontal wire antenna designs that are proven performers in terms of using a coaxial cable as the feedline and in requiring no ATU. They are illustrated in **Fig. 10**. One is the trap doublet. One can make a dipole for as many bands as one wishes by using traps to terminate the wire at the desired length for a given band. Of course, the traps between the feedpoint and the termination for the band in use provide loads, so the antenna would be shorter than full size on the lowest band in use. How short it would be depends on the number of bands for which the builder installs traps.

Since the trap dipole or doublet is a semi-true dipole for each band used, it provides a resonant feedpoint impedance close to optimal for 50- or 75-Ohm

cable. The exact feedpoint impedance depends in part on a. the terminating trap design and b. the amount of element loading provided by the interior traps relative to the band in use. The patterns will be broadside oval, peanut, or figure-8 shapes--depending upon antenna height in wavelengths above ground. However, when the ratio of the highest to lowest frequencies is greater than 3:1, there may be significant radiation from the outer portion of the antenna at the higher frequencies, resulting in odd lobes relative to dipole expectations.

The advantages that accrue to the trap dipole or doublet are a 50-75-Ohm feedpoint impedance and mostly true dipole patterns. However, the loading of interior traps creates user worries about losses. As well, the L-C traps are weighty and complex compared to the simple light structure of a single-wire doublet. As well, the bandwidth tends to be narrower than for a simple dipole using the same diameter wire.

The second classic design for direct coax feed on multiple bands is the fan of dipoles. One can support in the normal way a dipole for the lowest band to be used. Then, from the same feedpoint, one can run other dipoles suspended beneath the longest one. The more one allows the higher-band dipoles to droop beneath the longest one, the less the interaction of elements and the greater the ease of trimming each dipole to resonance.

As one adds bands to a single fan structure, the heavier it becomes, with more area to intercept the wind. Hence, durability becomes a significant issue relative to a simple doublet. As well, the initial trimming of the dipole lengths tends to become more finicky, and the operating bandwidth narrows relative to a single dipole for the same band.

A third system, pioneered by C. L. Buchanan, W3DZZ, uses a single trap each side of the feedpoint to provide multi-band coverage. Al Buxton, W8NX, extended the technique. The required traps demand careful construction and placement, and band coverage is not complete. Moreover, the patterns on all bands are not completely predictable by reference to the wire length, since interactions may exist between the inner and outer sections of the wire. Nevertheless, such



antennas are capable of covering several bands with acceptable SWR levels on a single coaxial cable feedline.

These classic one-coax-feedline antennas provide part of the rationale for pursuing the G5RV myth of a single doublet for many bands with a single coax feedline and no ATU. A single doublet is mechanically simple for good durability. Operation without an ATU removes one box from the operating desk or field table. The belief that the G5RV antenna system itself could attain these goals--which it could not--literally invented the demand for an antenna that could. And that created the pursuit of techniques that would find a combination of wire length and matching section characteristic impedance and length to come closet to the goal.

These notes are not designed to recommend a particular multi-band wire antenna system to the potential user. There are too many situational variables for me to do much more than mislead someone. Instead, these notes are designed to clarify to some degree the capabilities of the G5RV and the ZS6BKW/G0GSF antenna systems so that you can have reasonable expectations of them. Understanding an antenna system is one way of overcoming the mythology that spreads itself in truncated conversational claims and in advertising.

The G5RV antenna system comes in many commercial packages, simply because it is cheap and easy to produce in a kit. A length of wire, a length of parallel feedline, a few insulators, and a couple of junctions form a low vendor cost high profit item. If all vendors were both honest and knowledgeable, they would label such kits with a warning to use with an ATU. If they wish to sell kits for use without an ATU, they might well consider packaging the ZS6BKW/G0GSF system instead. But even then, they should clearly identify the non-usable bands. (A commercial version of the ZS6BKW/G0GSF antenna system is available from The Wireman of SC.)

Antenna systems using a wire and matching system are but one route to HF all-band antenna service. A simple doublet, parallel transmission line, and an ATU is still an effective system, although truly balanced ATUs are difficult to find. For

coaxial feedlines, we have briefly noted three alternative systems that move the complexity of a tuner to the antenna end of the line in the form of traps or multiple dipoles. Selecting the all-band wire antenna system, in the end, depends on the user's careful definition of his needs, limitations, and desires. Some understanding of the requirements of each competing system also goes a long way to assisting the decision-making process. These notes hope to have added a bit to understanding the single-wire-and-matching-section system of achieving multi-band HF operation.

## Chapter 13: A G5RV or a ZEPP?

If we had unlimited money and space, we could ask the following question sensibly: What is the best 10-meter antenna? The answer might be about 4 stacked long-boom, many-element Yagis from about 70' on up on a rotatable tower on a one-hill island surrounded by ocean. Even that answer might get an argument. However, for most of us, the simple question of what the best 10-meter antenna might be is an exercise in irrelevancy.

A more sensible question is usually this one: which of two alternatives is the better antenna? Each alternative might fit our yard and bank account. However, no general answer is possible. Even if one antenna does outperform another, there are always a number of other factors that affect the final decision. Can I maintain this antenna? What will my neighbors say when they see it? Is it compatible with the rose garden?

With those qualifications in mind, let's compare two antennas on performance alone just because people have asked a certain question: which is better: a multiband wire antenna like a G5RV or a center-fed Zepp on the one hand, or a dipole cut for 10 meters on the other hand? And let's presume you have the room and supports for both antennas to make this a real comparison.

If you like to work all of the HF ham bands and are limited to a single antenna, then the multiband wire is certainly an antenna to consider. An "80-meter" 135' center-fed Zepp, a G5RV 102' dipole, and a "40-meter" 67' center-fed Zepp are all long doublets, center-fed with parallel transmission lines and differ only in length. All require an antenna tuner, although some antennas show a low impedance on some bands. The 135' Zepp obviously works better on 80, although the 102' center-fed antenna does quite well there, and all three antennas can show respectable performance from 40-10.

In fact, some folks praise these longer antennas because they show some gain over a 10-meter dipole on 10-10's favorite band. Unfortunately, that kind of claim

is like preferring \$10 bills over \$5 dollar bills. I'll take the \$5s if you give me enough more of them than the \$10s. The bill size is not relevant until you know how many of each are at stake.

When comparing any of the longer multiband wires with a 10-meter dipole, the extra gain is not relevant until we answer the question of where it goes and, equally, where it does not go. A lot of variables go into the answer to the "where" question, but we can give a glimpse into the answer with Figures 1, 2, and 3. Each shows the azimuth pattern of 3 antennas (2 dipoles and one multiband antenna) modeled at a height of 35' (a typical amateur backyard installation) over real ground at a 14-degree angle of maximum radiation at 28.5 MHz.

Think of these patterns as looking down on the antenna from overhead. The dipoles are the simple figure-8 double loops. For the loops reaching out to 0 and 180 degrees, the antenna runs up and down the page through the center of the diagram. For the loops reaching maximum at the top and bottom of the diagram, the antenna runs left and right across the page. Each multiband antenna also runs left and right across the page.

Figure 1

EZNEC/4

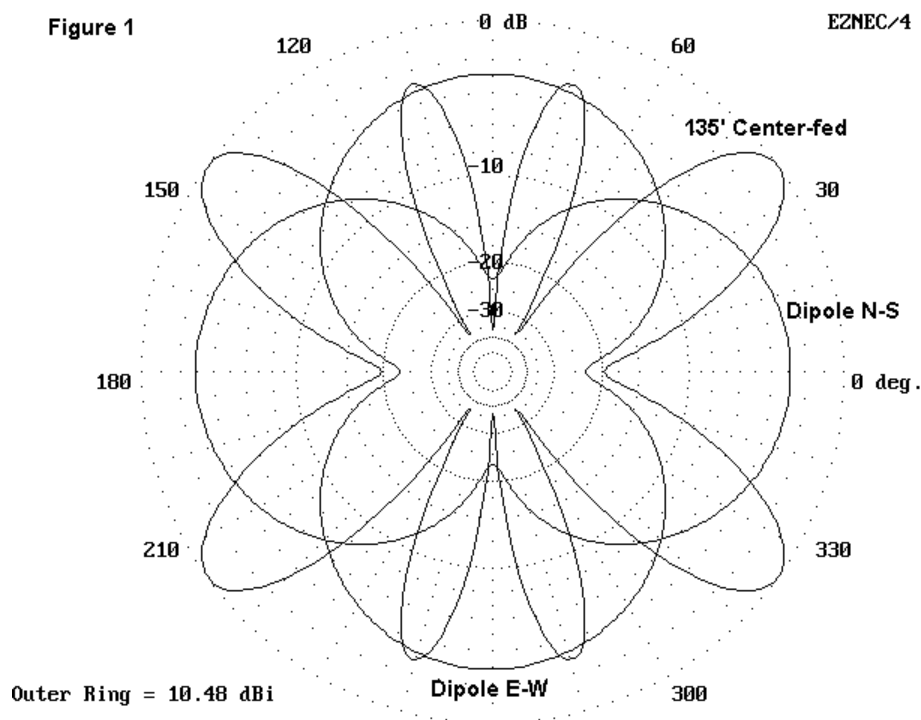


Figure 1 shows the 135' Zepp. It has four lobes that exceed the dipole limit by a good bit. However, notice how narrow they are. Notice also the nulls in the pattern. with some careful planning and some good luck in where your yard trees go, you might align the antenna so that one or more of the lobes points right where you find the stations you like to work most. Then again, you might end up aligning the antenna so that nulls point at your second and third favorite spots.

Figure 2

EZNEC/4

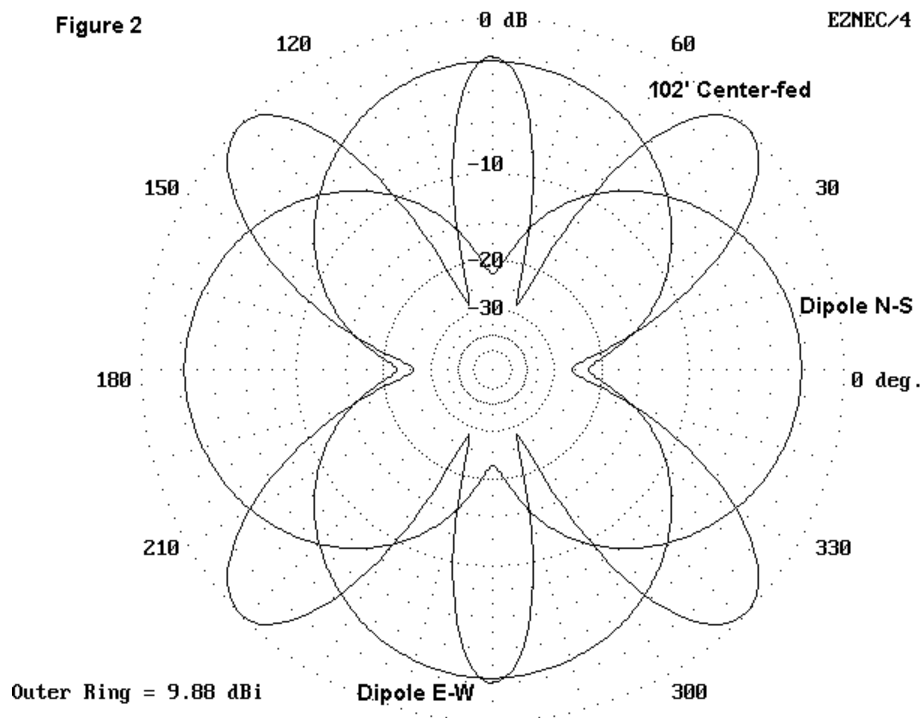


Figure 2 shows the dipoles with a G5RV. Again, there are higher-gain narrow lobes, but aimed more at the 45-degree point on the pattern. The shorter antenna creates fewer lobes. Again, you might use this information to hit one or more of your targets, and possibly miss a few desirable targets.

Figure 3

EZNEC/4

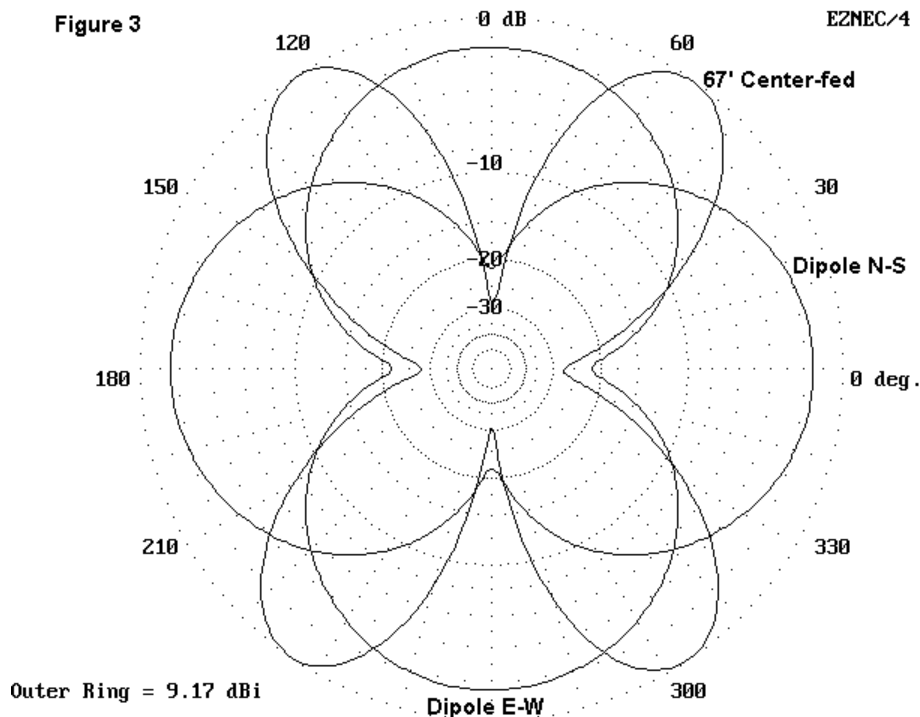


Figure 3 shows the same data for the 67' Zepp, about the length of a 40-meter dipole. There are only 4 lobes for this shorter antenna, but, of course, 4 nulls as well.

Each of these antennas has its place in some ham's yard, especially for working the lower HF bands (and each antenna will show a different pattern on each band). But is any really significantly better than a dipole on 10 meters? Gain is nice, but those nulls can drive you crazy.

Well, the dipole also has nulls off each side, so it too is limited. However, with an overall length of between 16' and 16.5' (depending on the element diameter), it is not too difficult to put up a rotatable dipole. You can hand-rotate the antenna mast or use a TV rotator. Then the nulls disappear. More correctly, they go where you put them, as you broadside the antenna to the desired signal. Hence, you only have to rotate a dipole less than 180 degrees to get full 360-degree coverage.

A stack of TV masting with a house clamp only roughly tight or guys in guy rings would permit you to hand turn the mast. You can attach a short level rod to the mast to make turning easier. Except in odd late afternoon shorter skip conditions, where signals seem to come from every direction, you will likely only have to change the antenna's orientation every few hours.

Am I "pushing" the rotatable dipole? Not really. Part of my point is that gain is not everything, especially if it does not point anywhere useful. Part of my point is that pointing is more simply done on 10 meters than many people believe, especially if they only look at monster 20-meter beams. Part of my point is that a multiband wire antenna is a very useful antenna for working all the bands. And part of my point is that, with a little ingenuity, a 10-meter dipole can do a lot of useful work for us without being unduly noticeable or expensive. Even if you already have that long wire, you might also consider adding a rotatable dipole to the antenna "farm." Now, if it is simple enough, you might even take it apart, toss it in the truck or trunk, and go portable with it--and put it back up when you get home.



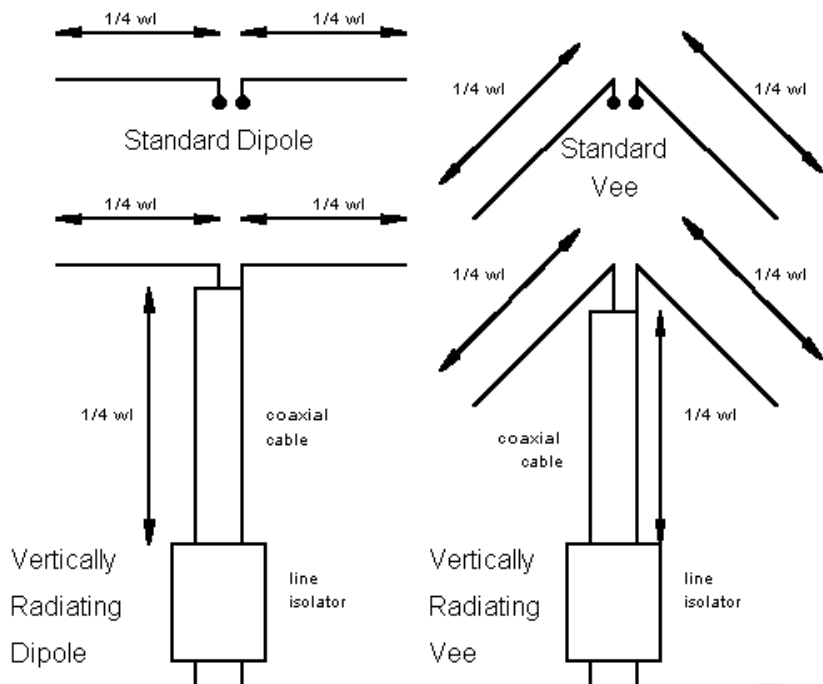
## Chapter 14: Vertically Radiating Horizontal Antennas

**H**orizontal antennas include such old friends as the center-fed resonant half-wavelength dipole, the inverted Vee variant, and a host of similar antennas. Recently, it was discovered that we could use versions of MININEC and NEC-2 to model what might happen if, in addition to the horizontal wire, a portion of the feedline also radiated. The general modeling procedure was to drop a quarter-wavelength vertical wire down from the normal feedpoint (braid side) to simulate radiation from the outer surface of the braid. The physical analog to this model has been the installation of a line isolator  $\frac{1}{4}$  wl down the coax.

Unfortunately, the model wire antennas emerging from these exercises appear to have gathered more acronyms and call-sign labels than careful analysis. Full modeling details have rarely been given, and results are hardly replicable. However, even if the models can be replicated, there remain strong questions about whether the models are adequate representations of the realities of antenna construction and installation. In short, it is dubious whether anything near the modeled performance can be achieved with real wire antennas. It may be instructive to examine some of the modeling techniques involved in promoting vertical radiation concepts.

### Bad Models Make Bad Antenna Theory

Let's begin with dipoles and inverted Vees. **Figure 1** illustrates the supposed difference between standard and vertically radiating dipoles and Vees. The standard horizontal antenna consists of a half-wavelength of horizontally or sloped wire fed by a coaxial transmission line. An isolating balun installed at the feedpoint is optional, although many experts recommend one as a means of preventing the outer surface of the coaxial cable from carrying antenna currents and consequently radiating in unpredictable ways. Many users of these antennas have found no balun to be necessary.

**Figure 1**

Vertically radiating horizontal antennas presume that the current originating on the inner surface of the coaxial cable braid will divide between the antenna wire attached to the braid and the outer surface of the braid. Also presumed is the idea that this outer surface is somehow floating, being too distant from an earth or system ground to be considered grounded, but having no other currents on it other than those developed as a result of the antenna-feedline junction. This permits the outer surface of the braid to act as another antenna wire. A line isolator--usually a device similar in principle to a W2DU ferrite-cores-over-a-length-of-coax--is installed  $1/4 \text{ } \lambda$  down the coax braid and terminates the radiating

section of braid. The result is a current of full strength along the antenna wire connected to the coaxial cable center conductor and a divided current from the inner surface of the braid, part traveling along the antenna wire and part along the outer surface of the braid.

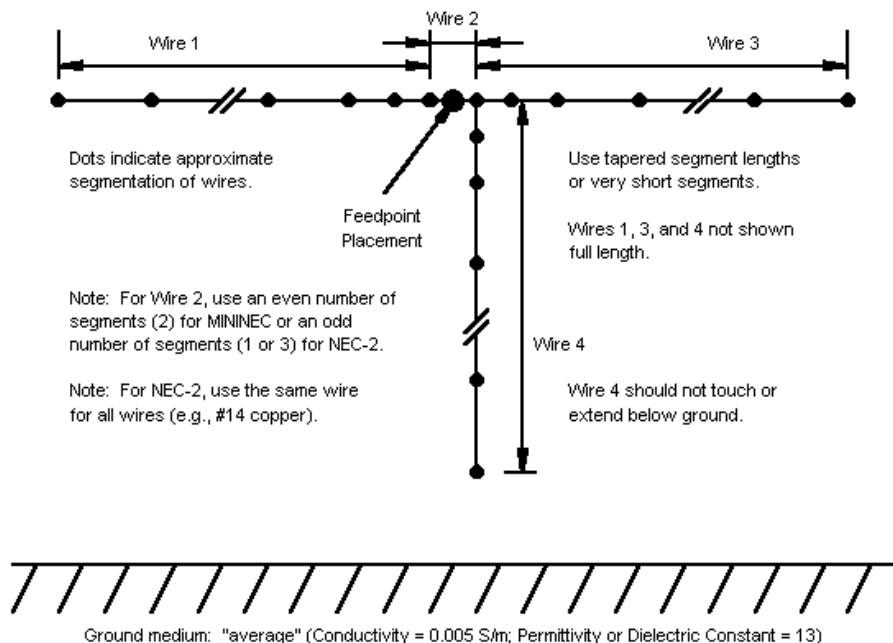
Since the outer surface of the braid is vertically oriented, the dominant polarization of its radiated field is vertical, with a consequential lowering of the overall radiation angle of the antenna's total pattern and a reduction in the front-to-side ratio of the antenna. If a wire dipole or inverted Vee exhibits something like a figure-8 or a peanut-shaped pattern, the vertically radiating versions of the same antennas are reported to exhibit oval or nearly round azimuth patterns.

If we accept all the premises of this scenario for the moment, it is possible to model both standard and vertically radiating dipoles and Vees using common materials and conditions, and to make a comparison between the resultant antennas patterns taken under identical modeling conditions. Let us choose copper wire, perhaps #14 as a commonly used size. Let us also select average earth as the soil under the antenna with a conductivity of 0.005 Siemens/meter and a dielectric constant of 13. These initial choices reflect how such antennas will actually be used, since few, in any, hams have access to lossless wire and perfect ground beneath the antenna.

In constructing our models, we may choose either MININEC or NEC-2 (since NEC-4 is just now becoming available, but at a price beyond the means of most amateurs). NEC-2 has some limitations in this exercise, since it requires a separate wire to which one applies the source, which is centered in the added segment. This short segment must meet adjacent segment length requirements of the program, which enlarges the number of segments in the total model if the feed wire is to be kept short. However, to reduce the number of segments, one may taper the segment lengths shorter toward the feed wire to maintain recommended ratios of adjacent wires. Additionally, the vertical wire must be about the same diameter as the antenna wire, since NEC-2 outputs become unreliable when wires of different diameter are joined in many modeling situations. However, NEC-2 includes a higher quality ground analysis system.

MININEC can handle wires of different diameter, but it is not without its own restrictions. First, for reasonable accuracy, segment lengths should be tapered when wires join at tight angles, and a right angle qualifies. Second, one must be careful with the placement of the source. MININEC sources are applied at one or the other end of a segment, which end must attach to another segment or wire. The end of the first wire is not a permitted source point if multiple junctions are present. Likewise, the junction end of the down wire is not a permitted source point, since it does not reflect the series connection of the coaxial cable to the horizontal wire, but instead treats the down wire as one side of the antenna and both sides of the horizontal portion as the other side of the antenna. One solution is to add a 2-segment wire as a feed point, placing the feed at the end of one segment within the wire. Additionally, one may also taper segment lengths within the wires as they approach the feed wire to ensure that adjacent wires meet program rules. Since MININEC has only a limited accuracy ground system, dropping the vertical wire below 0.2  $\lambda$  above ground without creating a true ground-mounted vertical antenna may strain MININEC limits.

**Figure 2** illustrates some of the salient points of NEC-2 and MININEC models of a vertically radiating dipole.

**Figure 2**

The next question concerns the frequency of operation, which has implications for wire length and the height of the assembly above ground. With a quarter wavelength of vertically oriented coaxial cable setting a minimum height, I decided against 80 meters. The antenna would have to be a minimum of 68-70' above ground. More typical amateur heights range from 35 to 50' above ground. Therefore, the test frequency selected was 7.15 MHz. Antenna heights for models could then range from 35' to 50' for the horizontal section, with the bottom of the vertical section ranging from about 1' to 15' above ground.

Elevation patterns provide a general indicator of an antenna's gain when directed in the azimuth bearing of maximum radiation. Since low angle radiation has been one of the claimed hallmarks of the vertically radiating horizontal antenna, an elevation angle of 20 degrees has been chosen for the azimuth patterns. **Figure 3** shows comparative patterns between a standard dipole and a vertically radiating version at a 35' height. These patterns happen to be taken with NEC-2, but are not significantly dissimilar to patterns taken with MININEC.

Figure 3

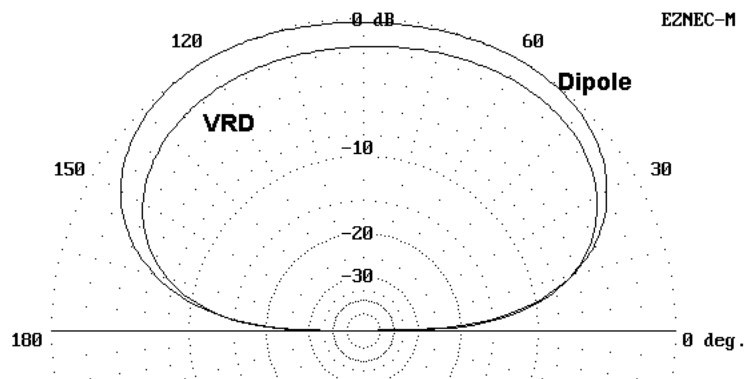
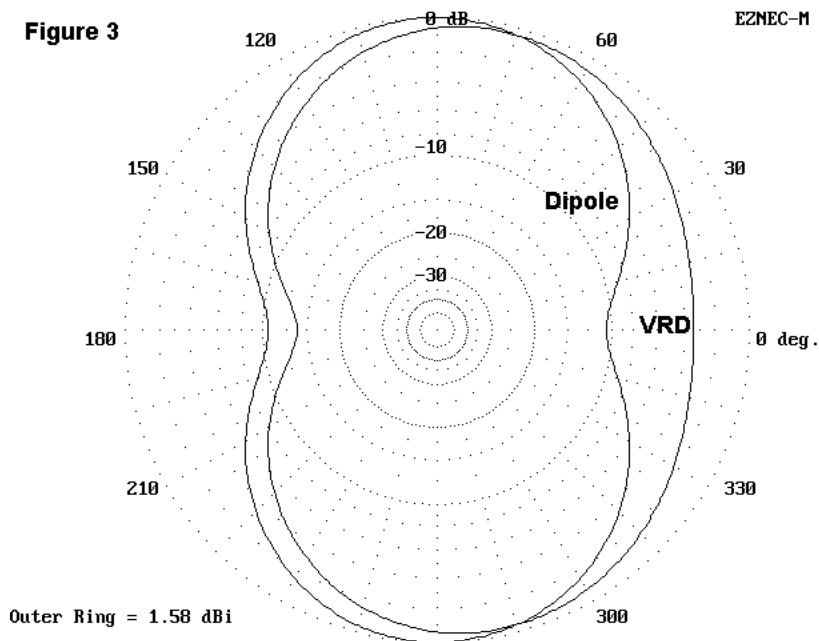


Table 1 below compares three models at heights of 35', 40', 45', and 50': one is a NEC-2 model with #14 copper wire as the vertical element; the second is a MININEC model using the same constraint; and the third is a MININEC model using a 0.5" copper vertical element in combination with the #14 horizontal wire. Although gain, elevation angle of maximum radiation, and feedpoint impedance vary, there is no significant change in the overall antenna pattern among any of the models or heights.

#### A Comparison of Three Modeled Vertically Radiating Dipoles

MININEC model: all #14 copper wire over average MININEC ground; with tapered segments to a short 2-segment feed wire. Horizontal length: 67'; vertical length: 33.5'

Height (feet)	Gain at 20° in dBi	Azimuth angle of maximum radiation	Maximum gain-dBi	Take-off angle	Feedpoint Impedance (R +/- jX)
50'	3.05	79°	4.98	38°	63 - j14
45'	2.35	78°	4.75	42°	66 - j8
40'	1.73	76°	4.66	48°	67 + j1
35'	1.17	75°	4.57	55°	61 + j13

MININEC model: #14 horizontal copper wire with 0.5" vertical copper wire over average MININEC ground; with tapered segments to a short 2-segment feed wire. Horizontal length: 67'; vertical length: 33'

Height (feet)	Gain at 20° in dBi	Azimuth angle of maximum radiation	Maximum gain-dBi	Take-off angle	Feedpoint Impedance (R +/- jX)
50'	3.11	79°	5.07	38°	64 - j15
45'	2.41	78°	4.85	42°	67 - j9
40'	1.79	76°	4.76	48°	68 - j1
35'	1.24	75°	4.70	55°	62 + j11



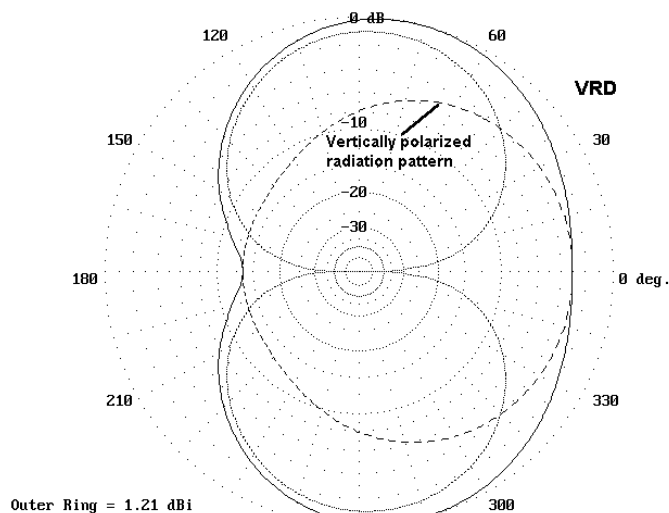
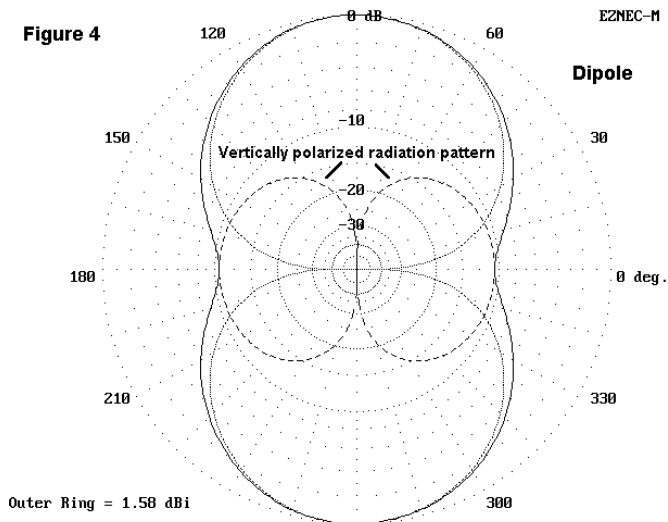
NEC-2 model: all #14 copper wire over average Sommerfeld ground; with tapered segments to a short feed wire. Horizontal length: 67'; vertical length: 33.5'

Height (feet)	Gain at 20° in dBi	Azimuth angle of maximum radiation	Maximum gain-dBi	Take-off angle	Feedpoint Impedance (R +/- jX)
50'	3.51	79°	5.42	38°	57 - j11
45'	2.76	78°	5.15	42°	60 - j7
40'	2.02	77°	4.94	48°	61 - j1
35'	1.19	77°	4.66	56°	59 + j9

Note: NEC-2 and MININEC models using short segments rather than tapered segment lengths do not differ significantly from the figures presented for these models. All models at all heights exhibit the same kidney-shaped azimuth pattern.

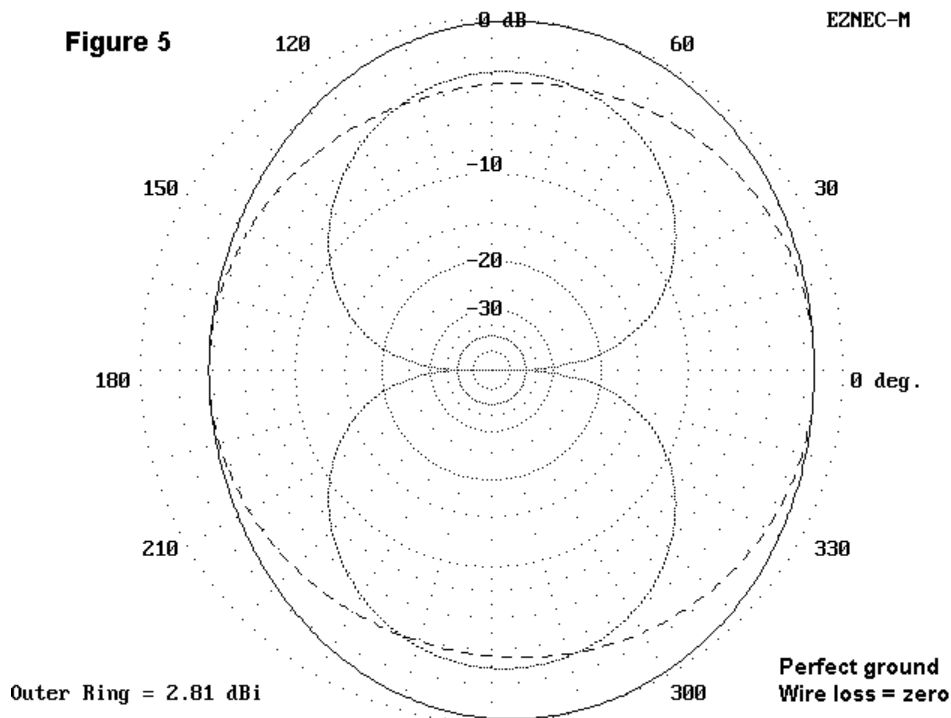
**Table 1. A comparison of three modeled vertically radiating dipoles.**

Obvious in **Figure 3** is the displacement of the narrowed portion of the azimuth pattern toward the horizontal arm connected to the braid, relative to the overlaid pattern for a dipole. Overall gain in the most favored direction of the antennas is similar to that of a dipole, as is the overall gain to the sides (off the antenna ends). The latter is simply displaced. Nowhere does there appear the grand ovals and circles of omnidirectionality advertised for the vertically radiating antennas. Indeed, there seems to be a misconception about low standard dipoles, to the effect that they are exclusively horizontally polarized antennas. To dispel this misconception, **Figure 4** compares the field components of a standard and a vertically radiating dipole azimuth pattern. Although the vertically radiating version shows naturally significantly greater vertically polarized radiation, the standard dipole has a significant amount that contributes to the broadening of the free space Figure 8 into the mere shell of a peanut.



Within these modeling strictures, which attempt to use modeling program features to replicate reality to the degree to which the programs are capable, there appears little to choose between the standard and the vertically radiating versions of the dipole. The displacement differential off the ends of the antenna would be difficult to detect in actual operation, even using antenna range A-B testing techniques. However, that differential might prove marginally useful to someone with certain QRM problems.

Why do these patterns differ so radically from some which claim oval or nearly circular radiation patterns for vertically radiating antennas? The answer lies in certain dubious modeling practices. One of these is the assumption of perfect ground under the antennas. (Some claims for 80-meter VRDs use the almost as rare very good or excellent ground.) This assumption permits the vertical portion of the antenna to seemingly radiate with much greater efficiency in models than a user is ever likely to achieve, even with a radial system under the antenna. Another is the use of lossless wire. A third is the selection of some precise distance of the vertical wire above ground, thereby optimizing conditions as no real user is likely to be able to replicate. These factors do not include obvious violations of the modeling constraints of the available programs, as noted earlier. **Figure 5** shows what illusions may be wrought from unrealistic modeling.

**Figure 5**

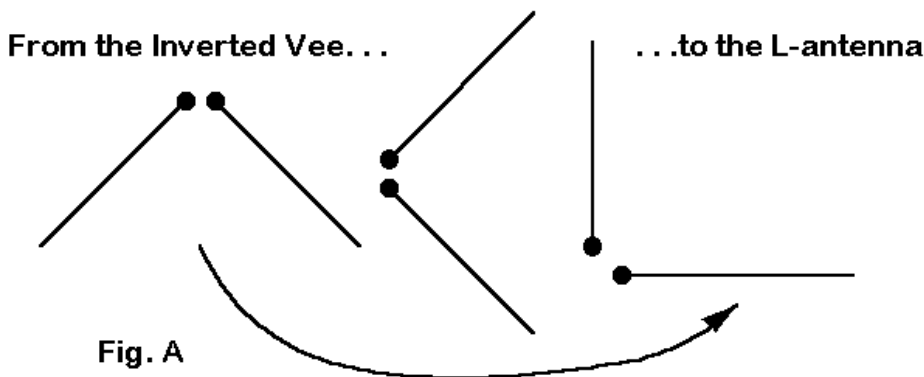
When modeled as close to reality as MININEC and NEC-2 will permit and within program constraints, vertically radiating dipoles and Vees do not constitute radical departures from standard versions of these antennas. Rather, they represent predictable pattern distortions that may be of some use to some operators under some conditions. However, questions about modeling adequacy are only one aspect of the inquiry. There are some significant questions to be raised about the physical means by which a vertically radiating dipole or Vee is to be implemented.

I fear that many an investigator pursuing vertically radiating horizontal antennas has been fooled by antenna modeling possibilities into accepting uncritically the reality, regularity, and reliability of what adding an extra wire to a dipole seems to show under tenuous modeling assumptions. Until there emerges a more adequate analysis of the reported and modeled phenomenon, the vertically radiating horizontal antenna likely deserves to be set aside as an interesting example of unsatisfactory antenna modeling.

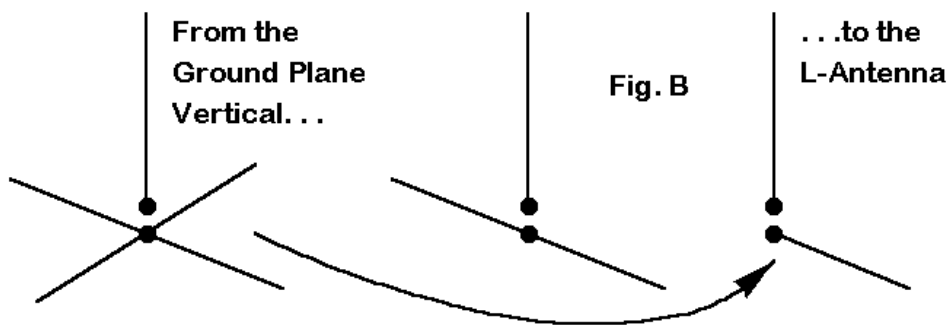
## Chapter 15: The L Antenna

**D**iversity-polarization reception is often handy, especially on 10 meters. We use the same antenna for both horizontally polarized SSB locals and vertically polarized FM repeaters and whip-equipped mobiles. And when the band is really open, we can work distant stations about as well as we might with a vertical or horizontal dipole. All we need is the right antenna.

Actually, the antenna itself is simplicity personified. Let's design it from two different angles.

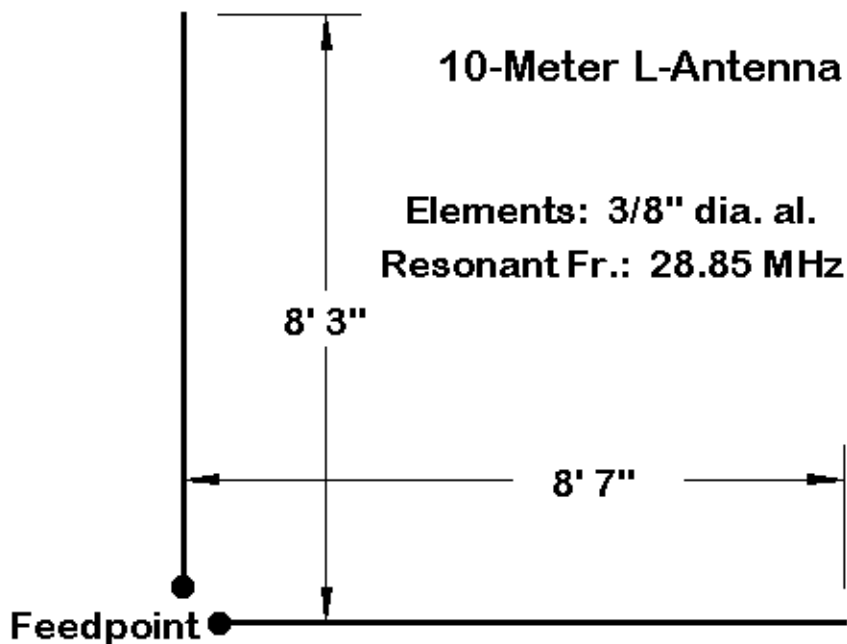


First, consider the common inverted Vee, shown in Figure A. When the legs make a 45-degree angle with the landscape or with a vertical line drawn between them, the impedance drops from the usual dipole value of 70 Ohms to about 50 Ohms. Let's imagine such a Vee with the apex about 30' in the air. Place a pin in the center feedpoint and start rotating the antenna until one leg is horizontal and the other points straight up. What happens to the convenient feedpoint impedance? Nothing. It remains in the 50-Ohm ball park.



Let's try that again, but this time, begin with a  $1/4$  wavelength ground plane vertical with the base at the 30' mark, as shown in Figure B. This vertical antenna is actually a special type of dipole, one where one of the legs consists of 4 wires arranged symmetrically and at right angles to the vertical part. The radiation from the four horizontal legs cancels out, so the antenna has a vertically polarized pattern. We could have used any number of ground plane legs greater than 1, so long as they form a symmetrical arrangement to insure cancellation of horizontally polarized radiation.

But what happens if we have only one ground plane leg. There is no opposite member to cancel out the radiation. So, we have not only the vertically polarized radiation from the vertical leg, but also the horizontally polarized radiation from the horizontal leg.



What has happened is that the rotated Vee and the 1-legged vertical have turned into the same antenna, which is simply the L-Antenna. Figure 1 shows a sketch of how to build one from 3/8" diameter aluminum tubing. I claim no originality for the antenna, since a version of it has appeared in Moxon's *Antennas for All Locations*. Apparently, the first commercial version appeared in the 1950s.

Actually, you can build such an antenna out of any good antenna materials you have handy. Tubing from 3/8" to 1" diameter will work for the vertical element. Tubing or wire will do fine for the horizontal element. Spar- varnished wood, PVC, or other materials will make a good center mount.



With the version of the antenna shown, the design center or resonant frequency was set at 28.85 MHz. The feedpoint impedance is about 45.5 Ohms at that frequency. If you use larger diameter tubing, expect to shorten the elements a bit and find a slightly lower feedpoint impedance. If you use wire for some or all of the antenna, then expect to use longer dimensions and have a slightly higher feedpoint impedance.

Notice in the sketch that the vertical portion happens to be a little shorter than the horizontal portion. All that this means is that the antenna is fed very slightly off center and has a very slightly higher feedpoint impedance than if fed at the exact center.

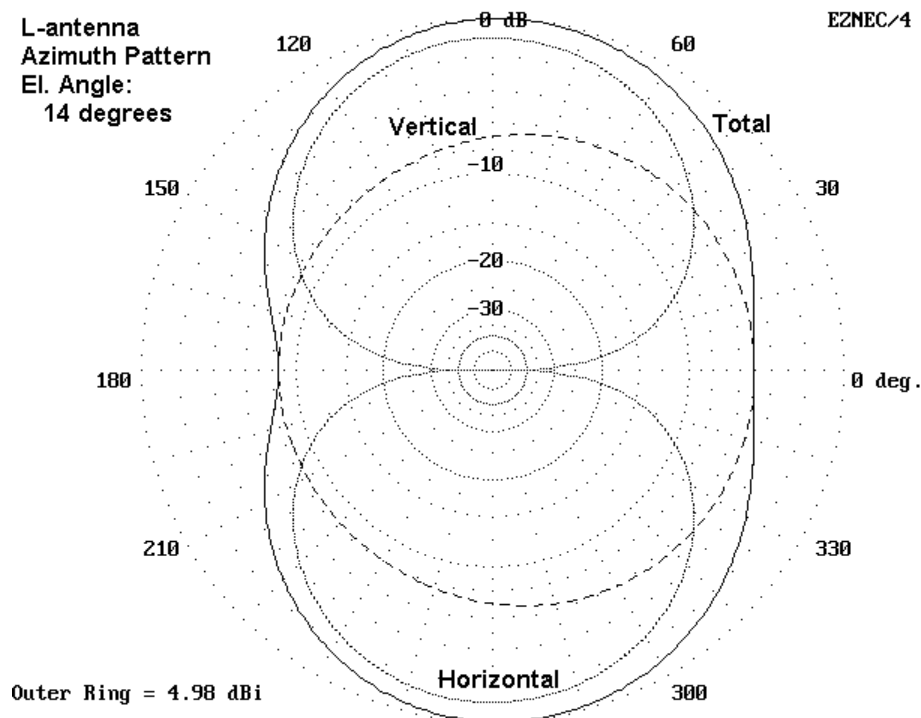
Now consider that the usual hardware store tubing comes in 8' lengths. If you use a larger diameter vertical tube that is 8' long, then the horizontal section will have to be increased in length to resonate the antenna. The further distance off-center for the feedpoint will slightly raise the feedpoint impedance to offset the use of fatter tubing, at least in the vertical portion of the antenna.

The horizontal section can be tubing, especially if it runs off into thin air. If you mount this antenna on your roof, then you can run the horizontal wire or tubing along the ridge-top and support the opposite end.

Before deciding just how you want to run the antenna, consider the azimuth pattern for the antenna. The one shown in Figure 2 is modeled at a height of 30' above average ground where the elevation angle of maximum radiation is about 15 degrees.

EZNEC/4

L-antenna  
Azimuth Pattern  
El. Angle:  
14 degrees



Notice that the vertically polarized circle of radiation is slightly offset from being truly symmetrical around the antenna. That shift is due to the presence of the horizontal leg. The horizontally polarized radiation shows the typical dipole figure-8 pattern, but not as strong as it would be if both halves of the antenna were horizontal.

The total pattern is a mild kidney beam, with unequal side rejection amounts (-5 dB for the side with the leg and -8 dB for the side without the leg). This total pattern is important only for skip communications. For local point-to-point communications, think about each of the sub-patterns. In planning an

installation, try to orient the antenna so that the horizontal radiation covers the local areas of greatest communications interest. The vertical pattern will largely take care of itself.

The reason for taking such care in laying out the antenna is that cross-polarization of local radiation results in a large drop in signal strength. Skipping radiation through the ionosphere largely (but sometimes not completely) skews the polarization. So local coverage is the chief concern for laying out the L-antenna.

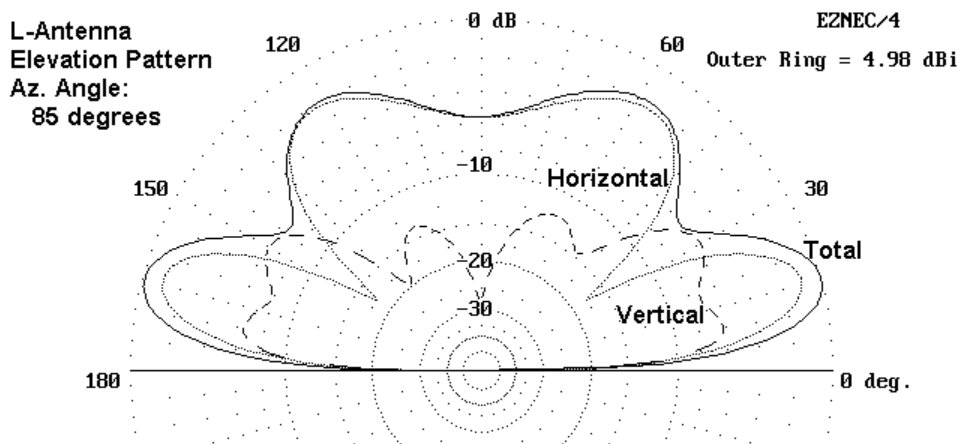


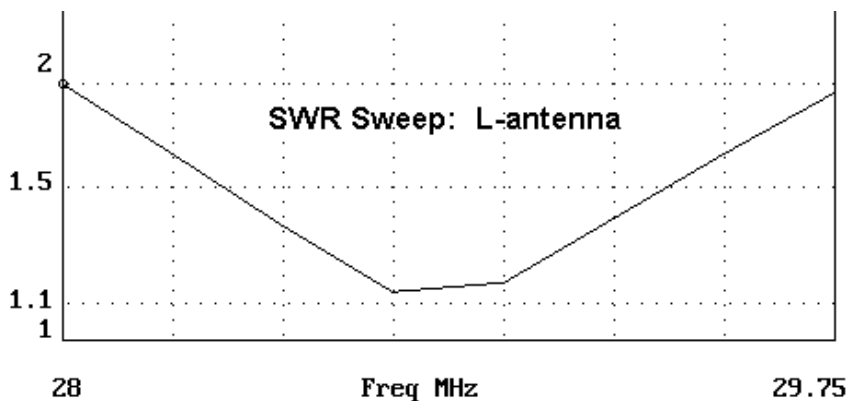
Figure 3 shows the elevation pattern of the antenna, again at 30 feet up. The pattern is taken through the axis of maximum gain, which is--for the total field--about 5 degrees off a true perpendicular line drawn to the horizontal element.

One of the advantages of the antenna for local work--or as a back-up for a more complex 10-meter antenna--is its broad operating bandwidth. By setting the resonant frequency up somewhat in the 10-meter band, the 2:1 SWR operating bandwidth of the antenna is the entire 10-meter band from 28.0 to 29.7 MHz. It may appear to be even wider, if readings are taken at the end of a length of coax.

For the record, here are the modeled impedance readings for the antenna across the band:

Frequency (MHz)	Feedpoint Impedance (R +/- jX Ohms)
28.00	41.1 - j 31.0
28.25	42.4 - j 21.7
28.50	43.6 - j 12.5
28.75	45.0 - j 3.2
29.00	46.3 + j 6.1
29.25	47.7 + j 15.4
29.50	49.1 + j 24.7
29.75	50.5 + j 34.1

Figure 4 shows the same information graphically. You should be able to obtain similar results across the band by judicious choice of materials and the feed point. Changing the lengths of the elements a little bit in either direction produces no significant change in performance.



Since materials and mounting positions will vary so much from one installation to another, I shall leave the construction details to you. I do recommend a height of over 25' for the base of the antenna, with a least a foot or two between the horizontal portion and any non-conductive rook top it might rest over. The greater the separation of the horizontal portion from other objects, the better the performance.

This antenna is not designed to compete in gain or directionality with any other type of antenna. Rather, it is designed to be simple, to provide both horizontal and vertically polarized radiation, and to have a feedpoint impedance that is compatible with common coaxial cable. As such, it can fill a useful niche in the array of ham antennas available for various purposes. The L-antenna is likely easy to scale to 12 meters as a utility antenna, but beyond that, may require some special effort to make it mechanically sound.

If you need a simple means to test the waters on 10 or to keep track of all the local operation, the L-antenna just might do the job for you--cheap and easy.

## **6-Meter Versions**

Feedback has resulted in a number of implementations for 6-meters, where local SSB nets, band openings, and some FM work are a common mix of activities. For either 3/8" or 1/2" tubing, each leg can be about 4.75' (57"), with slight trimmings for the best SWR curve. I cut the antenna for 51 MHz, which is slightly above most SSB work. However, with either of the 2 tubing sizes, the antenna shows a 50-Ohm SWR curve that is under 1.5:1 from 50-52 MHz.

As with a common dipole, bandwidth will be a function of the element diameter. Hence, the sizes listed--or a combination of the two--are recommended. Of course, if you have a pair of collapsible whips that each extend to 60 inches, you can use those for a field version of the antenna.

For 6-meter work, rooftop or higher mounting is useful to maximize the coverage.

You may make variants for almost any band by simply scaling all of the antenna dimensions, including the element diameter. To adjust the antenna to resonance, increase the leg lengths if your new diameter is smaller than the original and decrease the leg lengths if the new tubing is larger than the original (with the word "original" meaning the diameter after scaling).

The hub and feedpoint will always be the section of the antenna calling for the most ingenuity and adaptation of local materials. As you move the antenna upward in frequency, the legs grow lighter. Hence, you can more easily adapt hardware center plastics to the job. Be sure to seal the coax connector-to-leg junctions with something like Plasti-Dip to keep weather out of your coax.

## Chapter 16: Explaining the Inverted-L

**C**ommunications via radio is over a century old. One of the antennas that has been around almost that long is the inverted-L. It has passed through phases of love and hate, honor and denigration, use and disuse. However, it has never been through a phase of understanding. At most, it is just a simple wire whose properties are known only by the testimony (both prosecution and defense) of its successful and unsuccessful users.

I shall now dare a claim. The inverted-L is among the very best inexpensive wire field and small backyard antennas for multi-band general communications work. It is not a rotating or stationary beam. It is not a phased broadside, end-fire, or collinear array. Hence, it will never be the strongest signal in the band (if more than one station is active). However, it will in all of its simplicity put a usable signal in more places on more bands than almost any other contender, both in the field and in the typical small modern backyard.

All that we need to do to lay a foundation for this claim is to understand the inverted-L--both how it works and what to expect from typical installations. In the course of these notes, we shall look at the electrical properties of the inverted-L to understand and befriend it. However, the main body of these notes will be devoted to a tabular and graphical compendium of what inverted-Ls of various forms will produce by way of performance on the HF amateur bands. By picking the material most closely aligned with your installation, you will have a general idea of what to expect from the inverted-L that you build.

Of course, you will build your own. All you need are a length of wire (#12 or #14 copper or copperweld will do nicely), a set of insulators, some transmission lines, and an antenna tuner. If I kit up the wire and insulators and sell them to you for \$45 to \$50, then I have swindled you. And I could not live with myself for the hype it would take to make the kit seem like it will do everything short of slicing bread. Everything else that you need for an effective and safe installation will tend to be site specific, so you will need to visit your hardware depot. Before we

close, we shall examine some ideas for making the installation both effective and safe.

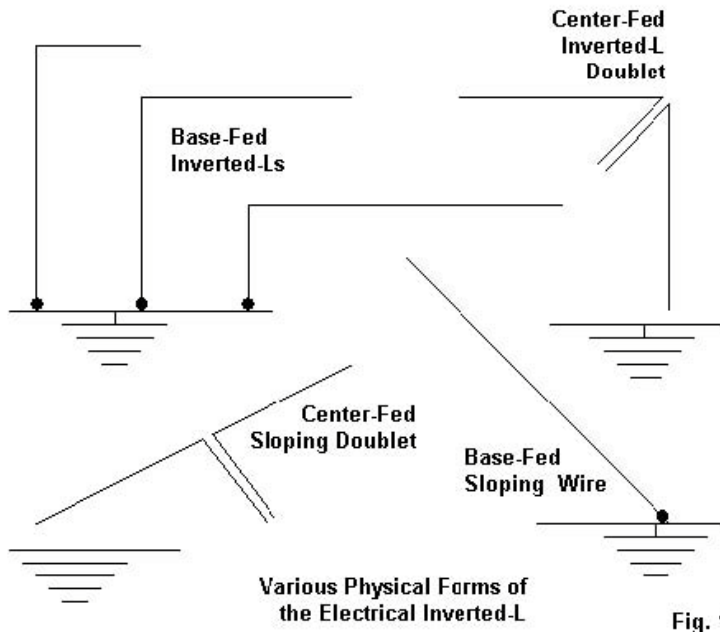
### **What is an Inverted-L?**

The simplest answer to this question is electrically wrong. The simplest answer is that an inverted-L is any antenna that looks like an upside-down L. (You may have to walk to the other side of the antenna to make a correct upside-down L.) The answer is defective in two ways. First, there are many antennas that do not look like an upside-down L, but that perform electrically just like an inverted-L. Second, if we could get the antenna high enough, there would be no significant difference in performance from an inverted-L and an erect L. In fact, a few years ago, I suggested the L-antenna as a workable simple solution to needs on 10, 6, and 2 meters to communicate with stations using antennas that are horizontally and that are vertically polarized. Of course, it is easy to raise an antenna 1 to several wavelengths over the ground at these frequencies, but much harder to push an 80-meter wire up that high.

We are not interested in looks, but in performance. If an antenna performs like an inverted-L, then it belongs to the same family of antennas, whatever family name we might concoct. However, we shall have to think in terms of an extended family, since we are speaking of a complex antenna in terms of its frequency coverage. Two inverted-Ls may perform similarly on the lowest band used, but show differences when used at much higher frequencies. Where we feed the antenna and what proportions we use may make a difference in that performance.

**Fig. 1** shows some of the members of the family. The upper family branch form distinctly L-shaped antennas. The center-fed doublet type normally uses a center feedpoint relative to the overall wire length. However, the base-fed types may bend over at almost any point along the way. We might even curl the horizontal portion. The DDDR car-rooftop antenna of past years is a variety of inverted-L.





The sloping wires seem a strange addition to the group of inverted-Ls, because they lack a definite bend. However, as a first attempt to imagine why they belong to the family, imagine one of the upper antennas being stretched slowly by the far end of the horizontal wire. The angle would become shallower as we continued pulling the antenna until it formed a straight line. However, in the process, it would not lose the basic electrical properties that made it an inverted-L in the first place.

The property that makes the inverted-L what it is as a multi-band antenna is the fact that it has visible or virtual horizontal and vertical parts that give the radiation pattern both vertical and horizontal components. As we change frequency, one or the other component may dominate, but both will be present. Except for wholly

negligible remnant components created by ground reflections, a true horizontal dipole has only a horizontal component to its field, while a vertical monopole has only a vertical component to its field. The inverted-L and its cousin, the sloping wire, have both.

You may instantly cry out that the inverted-V also has both components, especially when the sides droop 45 degrees downward from the horizontal line of a standard dipole. You would be correct. In fact, the inverted V (and the erect V) as well as the inverted (and erect) L belong to the same even more extended family. Not a member of this family is the quadrant antenna, one that bends in the middle on a 90-degree angle but remains parallel to the ground. That antenna has only a horizontal component.

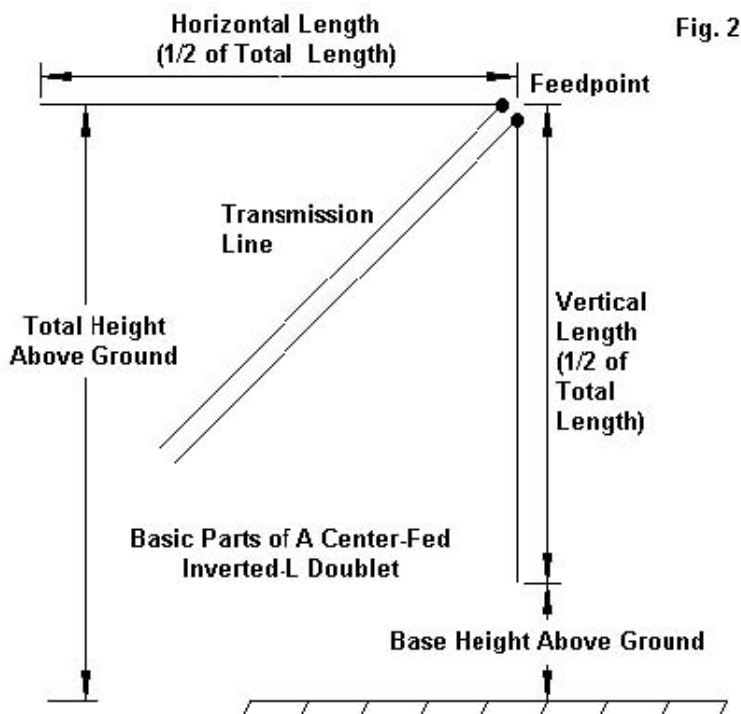
In the HF region, where most communications involve ionospheric reactions, the vertical and horizontal components join and skew so that what comes down is randomly polarized. However, that does not make the initial components meaningless. They play an important, if not determinant role in the transmitting and receiving patterns of the antenna. And those patterns make up the core of my starting claim about the utility of the inverted-L for general communications.

## **The Center-Fed Inverted-L Doublet**

We may feed an inverted L almost anywhere, but the most common places are at the end or the center. To lay out some foundations of inverted-L operation, the center-fed version is a bit more straight forward. **Fig. 2** shows the main parts of the center-fed inverted-L doublet.

The legs of the L are equal to each other. Hence, the total height of the horizontal leg must be the length of the vertical leg plus an additional length that I call the base height above ground. For these notes, I shall place the base of each center-fed antenna 10' above average ground for family and visitor safety. Since we shall operate the antenna on many bands, we shall need to use parallel feedline and an antenna tuner (ATU). Ideally, the feed line should depart the

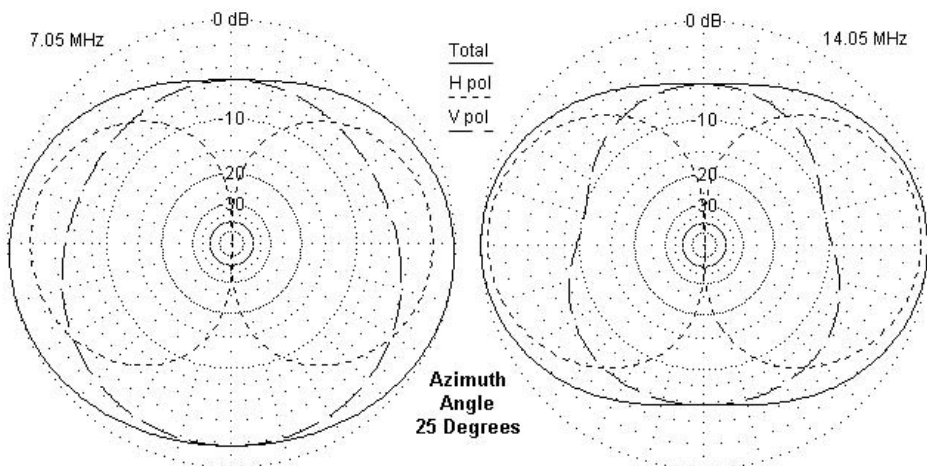
antenna at right angles, which would mean directly into or out of the page. However, approximating a 45-degree angle will also work in minimizing unwanted coupling between the wires and the line.



The inverted-L derives its special properties as a general communications antenna from the pattern components of the vertical and horizontal portions of the antenna. **Fig. 3** shows the total pattern and its component parts for two frequencies for a center-fed inverted-L that is cut for 40 meters. On both bands, the horizontal leg of the antenna would point straight up the page. Hence, the

vertical component of the pattern leans away from the horizontal leg. The horizontal component in both cases has the figure-8 look that we associate with a horizontal dipole. The vertical component is a distorted circle.

When we operate the 40-meter wire on 20 meters, we notice that the horizontal component becomes more dominant. The total pattern reduces from a circle with a depression into a distinct oval. Nevertheless, the radiation off the ends of antenna remains only 6 dB down from a true circle. It does not have the deep nulls that it might have if we were using a horizontal dipole. As well, the total radiation field is considerably stronger than we might derive from a standard monopole, thanks in part to the highly elevated feedpoint and thanks in part to the contribution of the horizontal component of the pattern. The total pattern on each band will always be a compromise, but a highly usable compromise.



The Vertical and Horizontal Components of a 69' Total Length  
Center-Fed Inverted-L Doublet 10'44.5' Above Average Ground

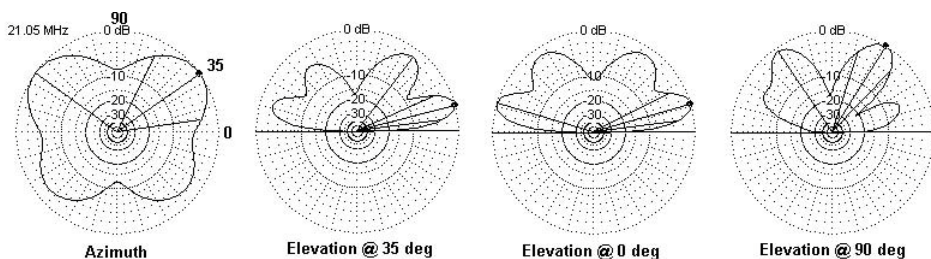
Fig. 3

Do not expect such neat patterns for every band. If all of the patterns were neat, I could stop here. However, as we continue upward in frequency, the patterns become more complex, but avoid the large collection of narrow lobes that we associate with long center-fed horizontal doublets. As well, the vertical component, even though weaker at higher frequencies, does fill in the nulls of a typical center-fed horizontal doublet.

To complicate matters a bit further, there are 4 typical lengths for center-fed inverted-Ls: the short 44' version for 40 to 10 meters, the 67-70' version for the same coverage, the short 88' version for 80-10meter coverage, and the 120-140' longer version for the same set of HF bands. Each version of the antenna deserves its own data so that we do not inadvertently introduce misleading performance ideas. However, the patterns and data that we shall show will presume two things, one important, the other not. The less important fact is that we shall use average ground as the soil beneath the antenna. Since we are not connecting the antenna to the ground, soil quality will not make much of a difference. The more important fact is that we shall presume level ground with no immediate obstructions to alter the patterns. You will have to make adjustments in your thinking about the patterns to account for both terrain tilting and yard clutter.

Every pattern presented--and the tabular data behind it--will use the elevation angle of maximum radiation. The tables will show the azimuth heading of maximum radiation. Along this axis, the table will list the vertical beamwidth. Although not precise, you may estimate that half the beamwidth is above and half below the elevation angle of maximum radiation. This calculation will give you a general idea of the lowest angle for a usable signal from the antenna. The tables will also list the maximum gain in dBi, and from that number, you can estimate the gain at other azimuth angle from the plot. Finally, the tables will list an approximate feedpoint impedance at the antenna terminals. If the antenna has a transmission line between those terminals and the ATU, the value at the ATU will be a function of the line's transformation properties that depend upon the length and characteristic impedance as they interact with the antenna terminal impedance.

Because the inverted-L is non-symmetrical with respect to the earth's surface, some of the values will have limited use. In other words, we should not assume that the elevation pattern is similar all around the azimuth circle. **Fig. 4** shows a typical azimuth pattern for a center-fed inverted-L antenna at 21.05 MHz. Beside it are three elevation patterns. The first one is along the heading for maximum gain on the azimuth plot, a heading of 35 degrees (and its 180-degree opposite, 215 degrees). The next two plots are at 0 (and 180) degrees, that is, broadside to the horizontal wire and at 90 (and 270) degrees, that is, along the horizontal wire.



Why the Pattern Compendium Is Only a Sampling

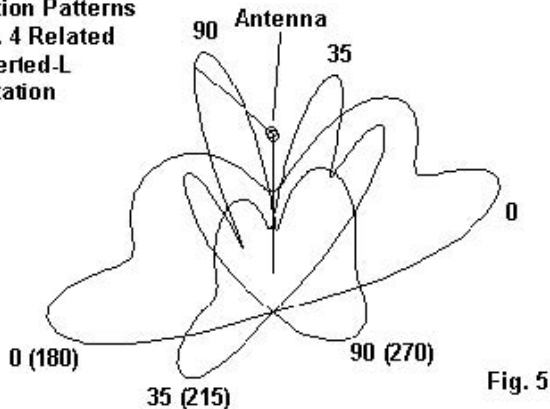
Fig. 4

Note that all three patterns have very different shapes. In some cases, although not in this one, the vertical beam width may differ along different headings. The elevation angle of maximum radiation certainly is different at 90 degrees. Although the patterns fill the rings, if you relate each one to the azimuth pattern, each has a quite different gain value. How the patterns relate to each other appears in **Fig. 5**.

In general, but perhaps not universally, the lower the gain along a given azimuth heading relative to the maximum gain heading, the more divergent the elevation pattern will be from the maximum gain heading values given in the tables. Despite these limitations, you may use the azimuth patterns and tabulated data in the compendia to follow to get a reasonably good idea of how

well each antenna will perform on each band. All sample antennas use AWG #12 copper wire.

Elevation Patterns  
of Fig. 4 Related  
to Inverted-L  
Orientation



#### 1. 44' Center-Fed Inverted-L for 40- to 10-Meter Use

The first version of the antenna (**Fig. 6**) varies in height from a base at 10' to 32' above ground. Higher mounting will tend to result in slightly more gain and slightly lower elevation angles of maximum gain, especially on the higher amateur bands. The total length of the antenna varies from 1.25 wavelengths at 10 meters to a little over 0.31 wavelength on 40 meters, the lowest frequency of operation (but with possible matching difficulties). Attempts to use the antenna on 60 or 80 meters will result in very low feedpoint resistances, with very high levels of capacitive reactance. Antenna is oriented as in **Fig. 5**.

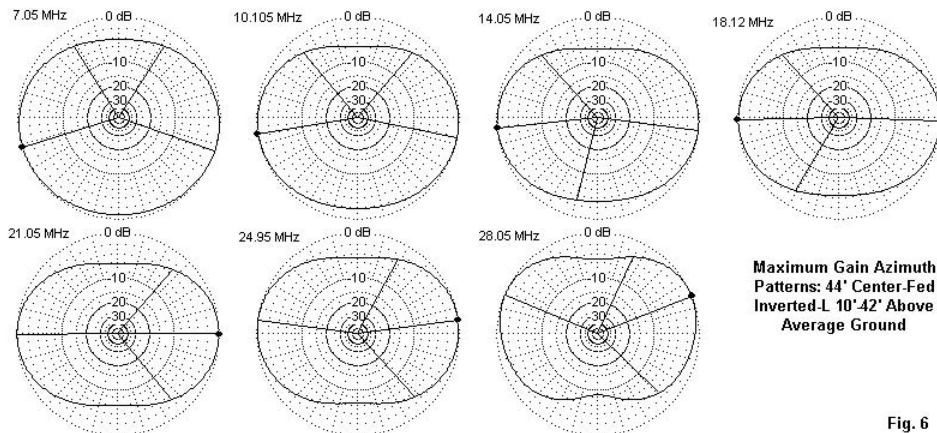


Fig. 6

Frequency MHz	Maximum Gain Angles		Vertical Beam- Width (deg)	Gain dBi	Impedance R+/-jX Ohms
	Azimuth (deg)	Elevation (deg)			
7.05	197	47	148	1.7	17 - j 620
10.105	189	37	152	2.7	41 - j 140
14.05	186	27	40	3.9	110 + j 440
18.12	181	22	28	4.8	570 + j 1600
21.05	0	19	23	4.9	5700 + j 930
24.95	8	17	19	4.1	530 - j 1500
28.05	22	15	17	4.1	200 - j 700

A very wide vertical beamwidth, such as 150 degrees, indicates that the gain does not vary by more than 3 dB across the entire arc of the sky from about 15 degrees above each horizon. Very high values of resistance or reactance may indicate a difficult match unless the feedline length is chosen carefully. A purely horizontal version of this antenna at 42' above ground would have bi-directional patterns broadside to the wire with lobes that become very narrow on the highest bands. The inverted-L version has a lower maximum gain, but better gain in most directions. On the lower bands, the elevation angle of maximum radiation is lower using the inverted-L version.



## 2. 69' Center-Fed Inverted-L for 40- to 10-Meter Use

The 69' inverted-L has a top height of 44.5' with the standard 10' base height. The horizontal leg is 34.5' long. It is also too short for effective use below 40 meters. However, the added overall length begins to show up in the 12- and 10-meter band patterns. See **Fig. 7**. Still, the lobes are fewer and broader than for a 69' horizontal doublet, and the nulls are not so deep. As usual, very high resistance or reactance values may foretell matching difficulties. Lower elevation angles relative to the 44' inverted-L are a function of the added top height of the horizontal wire.

Frequency MHz	Maximum Gain Angles		Vertical Beam- Width (deg)	Gain dBi	Impedance R+/-jX Ohms
	Azimuth (deg)	Elevation (deg)			
7.05	190	38	151	2.6	56 - j 4
10.105	184	28	39	3.8	220 + j 830
14.05	0	21	25	5.1	4800 - j 2800
18.12	26	18	19	4.1	180 - j 700
21.05	36	16	17	5.1	120 - j 66
24.95	36	13	14	5.9	310 + j 890
28.05	36	11	12	5.7	4900 + j 380

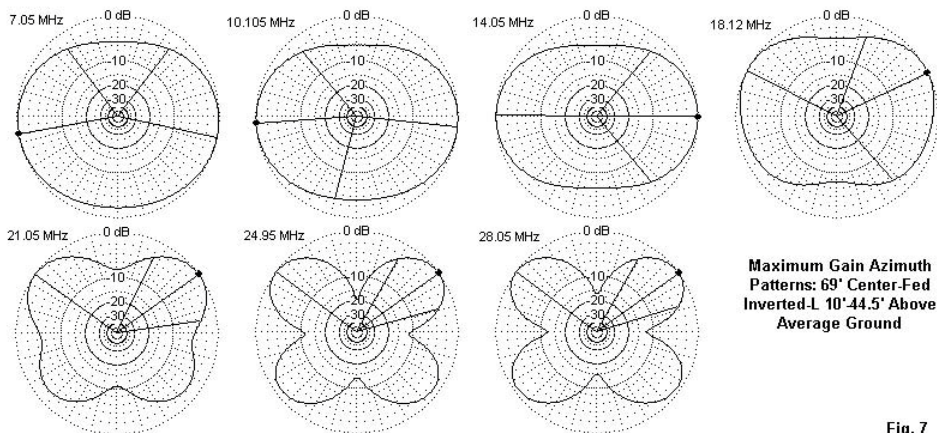
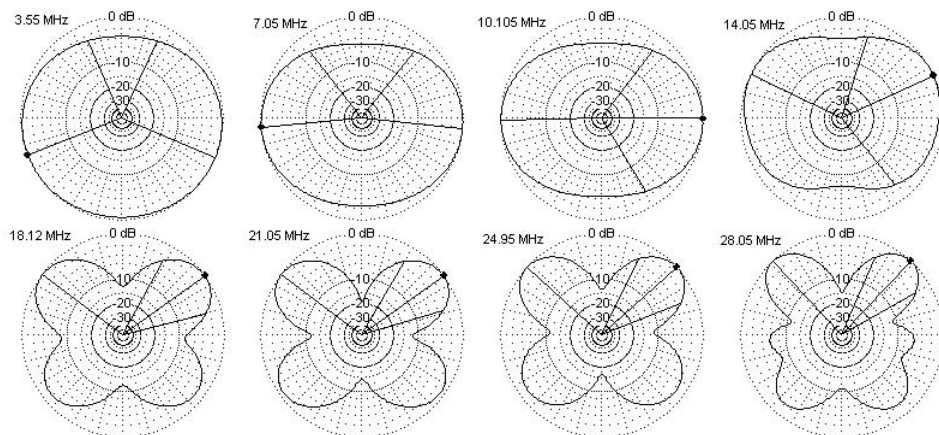


Fig. 7

### 3. 88' Center-Fed Inverted-L for 80- to 10-Meter Use

The 88' center-fed inverted-L is about the shortest recommended length (with marginal matching capabilities) for service down to 80 meters. The patterns omit the 60-meter band, although you can easily infer its shape from the 80- and 40-meter patterns plus the tabular data. By **Fig. 8**, you should be able to see the gradual evolution of the patterns as the antenna grows longer. For example, the 17-meter pattern of **Fig. 7** is similar to the 20-meter pattern for the longer antenna in **Fig. 8**. 10 meters shows the emergence of 2 additional lobes. As well, the tabular data shows slightly higher average gains as the antenna grows both longer and higher above ground. You may wish to imagine in advance the pattern shapes for the 136' center-fed inverted-L, the next antenna in the series, and then check **Fig. 9** to see if you are tracking well. The fact that patterns evolve rather than change suddenly with frequency will let us use fewer pattern samples in later exercises.



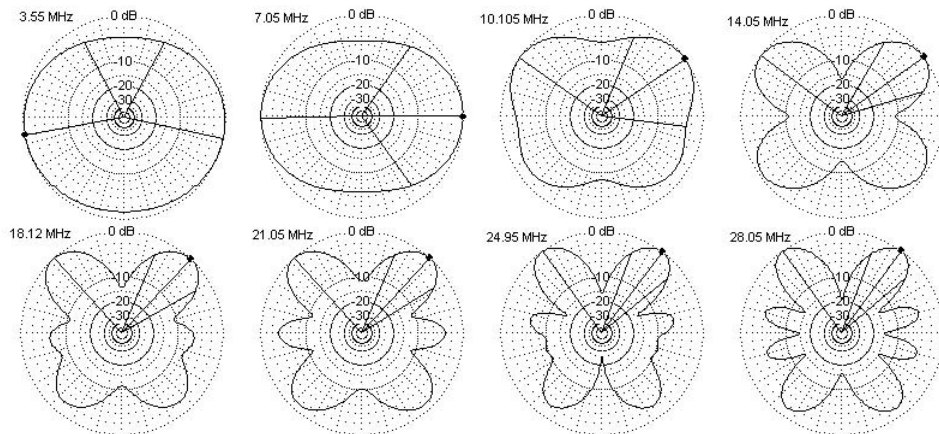
Maximum Gain Azimuth Patterns: 88' Center-Fed Inverted-L  
10' 54' Above Average Ground

Fig. 8

Frequency MHz	Maximum Gain Angles		Vertical Beam- Width (deg)	Gain dBi	Impedance R+/-jX Ohms
	Azimuth (deg)	Elevation (deg)			
3.55	201	47	148	1.0	20 - j 660
5.368	191	40	150	2.3	55 - j 50
7.05	185	32	52	3.2	130 - j 490
10.105	0	23	30	4.5	3000 + j 3200
14.05	25	19	21	4.0	190 - j 780
18.12	36	15	17	5.6	160 - j 370
21.05	36	12	14	5.8	1600 - j 2200
24.95	42	10	11	5.5	250 - j 810
28.05	47	9	10	6.3	150+ j 45

#### 4. 136' Center-Fed Inverted-L for 80- to 10-Meter Use

The 136' center-fed inverted-L doublet has a 68' top wire and a vertical wire that extends from 10' to 78' above ground. Although this antenna calls for a height that few may reach, it is useful to show the continued evolution of the azimuth patterns. See Fig. 9.



Maximum Gain Azimuth Patterns: 136' Center-Fed Inverted-L  
10'-78' Above Average Ground

Fig. 9

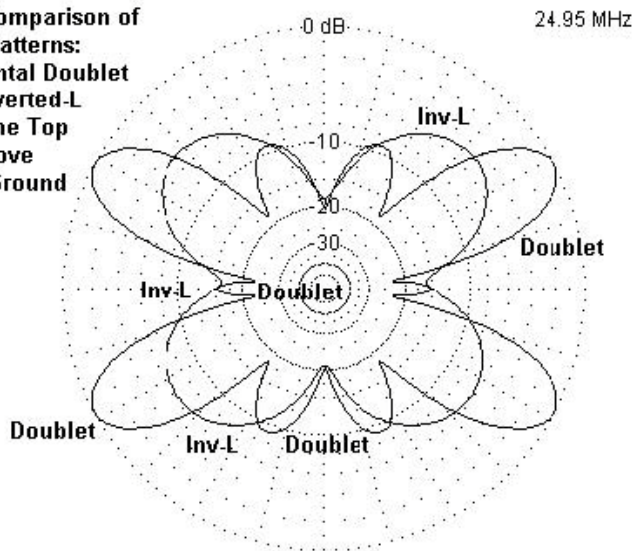
Frequency MHz	Maximum Gain Angles		Vertical Beam- Width (deg)	Gain dBi	Impedance R+/-jX Ohms
	Azimuth (deg)	Elevation (deg)			
3.55	190	42	150	2.1	60 - j 10
5.368	184	29	43	3.4	330 + j 1100
7.05	0	24	29	4.8	6300 - j 2000
10.105	34	19	21	4.5	130 - j 320
14.05	36	13	14	5.7	4300 + j 2000
18.12	47	10	11	6.1	150 + j 20
21.05	48	8	9	7.0	2000 + j 2100
24.95	53	7	7	7.4	160 - j 110
28.05	54	6	6	7.6	1100 + j 1600

Although the added height and length of the 136' inverted-L continues to lower the elevation angle and raise the maximum gain, the longest of our doublets raises two question marks. First, note the number of bands on which we have either very high resistance or very high reactance--or both. Second, note the increasing unevenness of coverage of the azimuth patterns on the upper bands. For some installations (but not for all) where this antenna is feasible, it may not be the best choice. For example, if we can install the 88' version at the 78' top level, we would gain most of the improvement in elevation angle and a bit of the gain, but have fewer matching challenges.

Before we turn to the next antenna, let's make a comparison of azimuth patterns. The sample in **Fig.10** uses the 88' inverted-L and an 88' doublet, both at the same top height and both on the 12-meter band.

The doublet has 10 lobes on this band, 4 of which are stronger than the inverted-L major lobes. However, for a very large portion of the horizon, the inverted-L shows a higher gain, with more even coverage of the entire horizon. For penetration in specific directions, the doublet may be better, but for general communications with an installation dictated by available supports (trees), the inverted-L is likely to make a very good showing of itself.

**Sample Comparison of  
Azimuth Patterns:  
88' Horizontal Doublet  
and 88' Inverted-L  
at the Same Top  
Height Above  
Average Ground**



**Fig. 10**

### **The Center-Fed Sloping Doublet**

At the start of this exercise, I noted that a simple center-fed sloping wire shares most of the main characteristics of an inverted-L. The time has arrived to demonstrate that fact. The first step is to note the presence in a sloping wire of both vertical and horizontal pattern components. Our sample antenna will be a 68' AWG #12 wire sloping at a 45-degree angle with its base 10' above ground. Just as the inverted-Ls that we have examined start with their vertical legs in the pattern centers, with the horizontal leg pointed upward on the page, so the sloper will also point upward on the page and in the patterns.

Compare **Fig. 11** with **Fig. 3**. In both cases, we can see for the sample bands the vertical component along with the horizontal component. The total patterns are very similar, but it is clear that the sloping doublet tends to concentrate the

vertical component on the antenna end that approaches the ground. This fact does not disable the sloping doublet from operating as a good general communications antenna. However, it does simplify construction somewhat, since we now need only 1 very tall support for the high end of the wire. For a 68' 45-degree sloping doublet, the top point is 58' above ground. If we lower the angle, we lose some of the advantages of the vertical component and raise the elevation angle. Hence, it may be wise to restrict band coverage and use a shorter wire at a high angle than to use a longer wire at a much lower angle.

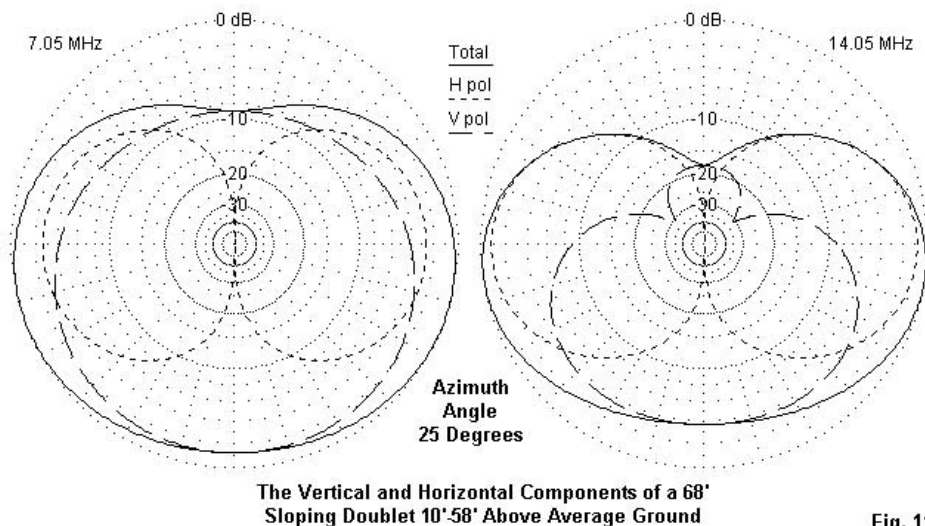


Fig. 11

The sample sloping center-fed doublet that we shall examine on a band-by-band basis is a 68' long AWG #12 wire extending vertically from 10' to 58' above average ground. The slope is 45 degrees. The inverted-L with which to compare this antenna is the 69' version whose patterns appear in **Fig. 7**. As **Fig. 12** reveals, when we compare the patterns with those of the 69' true inverted-L, we do not achieve the same smooth evolution of patterns. The vertical component

of the total pattern is better suppressed in the direction from the low to high end of the wire much more thoroughly than when the wire forms an L. The 20- and 17-meter patterns are elongated broadside to the wire, while the 12- and 10-meter patterns have relatively deep nulls in the broadside directions. See the data table for this antenna to uncover two more ways in which the antenna is not just like an inverted-L. Despite these differences, the antenna still covers a good portion of the horizon on almost all bands with moderate gain.

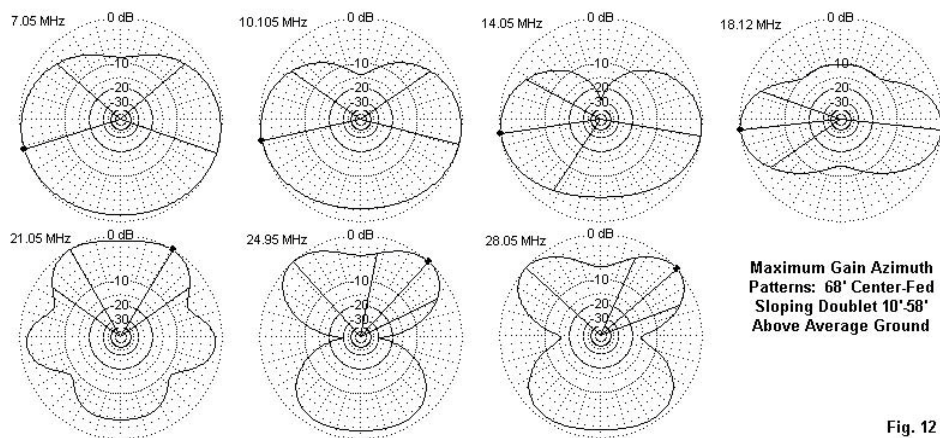


Fig. 12

Frequency MHz	Maximum Gain Angles		Vertical Beam- Width (deg)	Gain dBi	Impedance R+/-jX Ohms
	Azimuth (deg)	Elevation (deg)			
7.05	197	41	152	2.4	85 + j 7
10.105	192	30	59	3.6	330 + j 810
14.05	188	21	33	5.4	4600 - j 1300
18.12	186	16	23	6.2	170 - j 790
21.05	59	12 *	14	3.0	110 - j 80
24.95	49	12 *	14	4.5	480 + j 810
28.05	40	11	17	5.6	3100 + j 590

The starred entries in the elevation angle column represent cases in which the main lobe is straight up, and the indicated angle is for a secondary lobe. The gain difference between lobes is not significant on 12 meters, but is sizable on 15 meters. Most of the other values, including the feedpoint impedances, are quite comparable to those for the corresponding inverted-L.

### Does Ground Quality Make a Difference?

There may be some concern that because the center-fed inverted-L or sloping doublet has one end close to the ground, the ground quality may make a significant difference in performance. As the following short table shows, the difference is only about as much as variation in soil type would make for a horizontal antenna at the same average height in wavelengths above ground. "Cond" means conductivity in S/m and "Perm" means the permittivity or dielectric constant. The listing for each combination of soil quality and frequency shows the maximum gain followed by the elevation angle of maximum radiation.

Frequency MHz	Soil Quality Cond/Perm	Very Good 0.0303/20		Average 0.005/13		Poor 0.002/13		Very Poor 0.001/5	
7.05		2.9	39	2.6	38	2.5	37	2.2	36
14.05		5.5	21	5.1	21	5.0	21	4.3	21
21.05		5.5	15	5.1	15	5.0	15	4.4	15
28.05		5.9	11	5.7	11	5.7	11	5.3	11

The differentials are small. The variations are functions of the reflection of radiation off the different soil qualities at a distance from the antenna itself. Therefore, a radial system under the antenna or other measures to improve soil quality directly under the antenna will have no significant effect on the radiated signal.

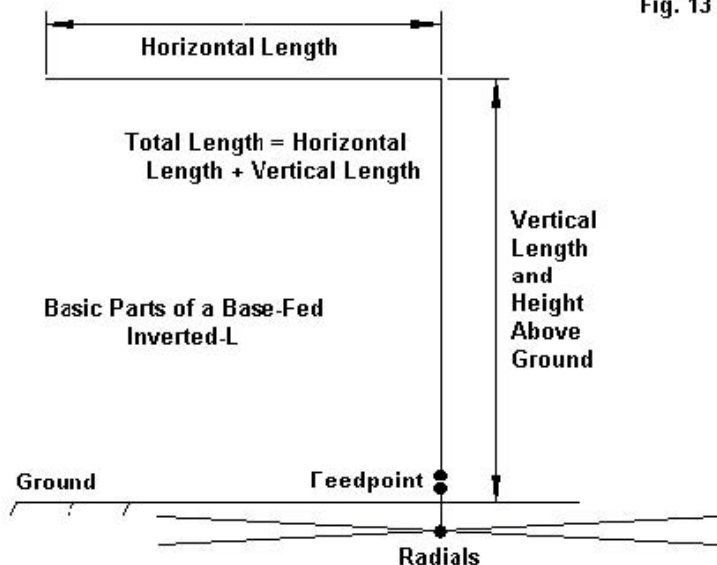


## The Base-Fed Inverted-L

Because it has a physically convenient feedpoint--at ground level--the base-fed inverted-L is considerably more common than the center-fed L. **Fig. 13** outlines the most basic parts of the base-fed inverted-L. Of course, we have the vertical and horizontal sections of wire that together make up the total length. However, since the feedpoint is no longer at the wire's center, we find considerable variation among installations, ranging from those that use more vertical and less horizontal wire to those that do just the opposite. The base-fed version of the antenna differs from the center-fed version also in the fact that its vertical wire must reach the ground, rather than terminating at some safe height above ground. Therefore, for any given antenna total length, the base-fed version will be about 10' lower at its top height.

Because the base-fed inverted-L is fed at its end, it requires a good RF ground when its length is at least  $\frac{1}{2}$  wavelength. If used as a  $\frac{1}{4}$ -wavelength monopole on its lowest frequency, then it also requires radials to complete the antenna. Ideally, for monopole use, the antenna requires the same ground radial treatment as any other ground-mounted monoband monopole. However, most backyard builders use only as many radials of whatever length they can squeeze into the available space. A scant, small, and short radial system can provide the good RF ground needed by the feedpoint, but it may fall short of an ideal radial system. **Fig. 13** shows only a few radials.

Fig. 13



Until recent years, feeding a base-fed inverted-L was somewhat of a challenge. As a field antenna, the L and its sloping cousin, tended to terminate at the operating table, using a manual ATU. However, we now have access to weather-sealed automatic tuners with remote tuning heads. Hence, we may mount the tuner directly at the feedpoint and use a length of coax rated for ground burial for the run to the operating position. However, the older methods will work perfectly well.

An inverted-L that is near resonance as a monopole on 80 meters is about 69' overall. Because we have so many variations on the basic L to consider, we shall largely focus on this length antenna, with only a few alternatives considered toward the end of this part of our exploration. As always, the wire will be AWG

#12. However, before we can examine the antenna on a band-by-band basis, we need to consider some of the alternatives to see how much weight they carry.

### How Many Radials and How Long?

Let's begin with a 69' long inverted-L with 34.5' horizontal and 34.5' vertical. One option available to us is simply to place a ground rod into the soil to use as the remote ATU ground terminal. Although this technique will work to some extent, a system of at least short radials will provide a superior RF ground. For a sample exercise, I created models with radials buried 1' deep, although the exact depth from 6" to 2' is not at all critical. I started with 1 radial, then increased the system size to 4, 16, and 32 radials. All tests initially used average soil with a conductivity of 0.005 S/m and a dielectric constant of 13.

On bands from 40 meters upward, the antenna wire is  $\frac{1}{2}$  wavelength. On 7.05 MHz, I obtained the following results using 15' long radials.

#### Short Radials: 7.05 MHz

No. of Radials	Maximum Azimuth (deg)	Gain Angles Elevation (deg)	Vertical Beam-Width (deg)	Gain dBi	Impedance R+/-jX Ohms
1	196	47	147	1.8	4200 - j 970
4	196	47	146	1.9	4100 - j 960
16	198	47	146	2.0	4100 - j 980
32	198	48	146	2.0	4100 - j 980

I then increased the length of the radials to 69' each to see if 80-meter monopole-length radials would make a significant difference in 40-meter performance.

#### Long Radials: 7.05 MHz

No. of Radials	Maximum Azimuth (deg)	Gain Angles Elevation (deg)	Vertical Beam-Width (deg)	Gain dBi	Impedance R+/-jX Ohms
1	196	47	146	1.8	4100 - j 1000
4	199	46	146	1.9	4000 - j 1000
16	199	47	147	2.1	3900 - j 1100
32	198	46	147	2.3	3900 - j 1200

In practical operating terms, the size of the radial field and its length makes very little difference to the antenna's performance when it is at least  $\frac{1}{2}$  wavelength. However, we cannot make the same claim for the operation of the antenna as an 80-meter  $\frac{1}{4}$ -wavelength monopole. I repeated the same modeling experiment using 3.55 MHz.

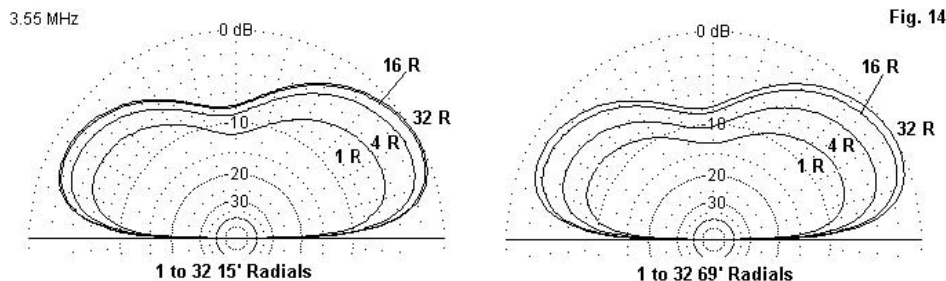
#### Short Radials: 3.55 MHz

No. of Radials	Maximum Azimuth (deg)	Gain Angles Elevation (deg)	Vertical Beam-Width (deg)	Gain dBi	Impedance R+/-jX Ohms
1	270	28	53	-5.6	94 + j 25
4	270	28	54	-2.5	50 + j 11
16	270	29	54	-1.5	40 + j 7
32	270	29	54	-1.3	38 + j 5

#### Long Radials: 3.55 MHz

No. of Radials	Maximum Azimuth (deg)	Gain Angles Elevation (deg)	Vertical Beam-Width (deg)	Gain dBi	Impedance R+/-jX Ohms
1	270	28	54	-6.2	112 + j 40
4	270	28	54	-2.5	51 + j 23
16	270	28	54	-0.4	32 + j 15
32	270	28	54	+0.3	28 + j 12

**Fig. 14** shows the elevation patterns for 3.55 MHz using the short radials on the left and the long radials on the right. The 4-radial patterns are of equal strength. Obviously, using the longer radials and more of them provides a significant improvement in 80-meter gain--almost 2 dB for the 32-radial system. Hence, the advice is this: install as many radials as possible--even up to 64  $\frac{1}{4}$ -wavelength radials--if circumstances permit. However, most backyard inverted-L users are likely to have room only for a smaller set of shorter radials--and their lengths and paths may vary according to what is already in the yard. Note that there is little difference between the 16- and 32-radial systems when using 15' radials--enough for a good RF ground and little more. Therefore, for the remainder of our sampling work, we shall adopt that system as the standard. However, if you plan to use the inverted-L as a monopole on the lowest band, strive for the largest, most complete, and most symmetrical system of radials that you can manage.



Maximum Gain Elevation Patterns: 69' Base-Fed Inverted-L With Different Size Radial Sets

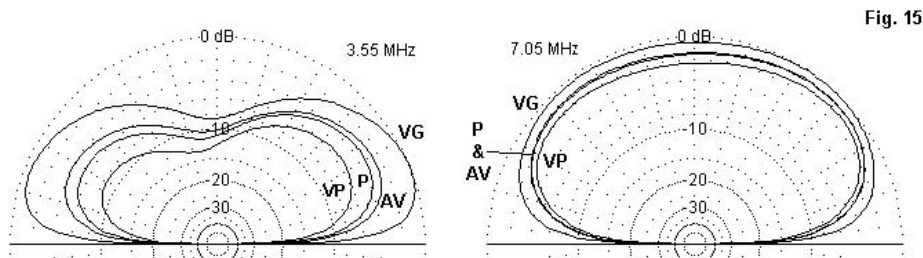
## Does Soil Type Make a Difference to the Base-Fed Inverted-L?

The answer to our next question is simple: yes and no. Which answer you choose depends on the band of concern. For the lowest or monopole band, the soil quality makes a considerable difference. However, for bands on which the antenna is at least  $\frac{1}{2}$  wavelength, Soil quality makes only a small difference. The following table compares 3.55-MHz and 7.05-MHz model reports for the soils we previously classified as Very Good, Average, Poor, and Very Poor under the center-fed version of the antenna. The listing for each combination of soil quality and frequency shows the maximum gain followed by the elevation angle of maximum radiation.

Frequency MHz	Soil Quality Cond/Perm	Very Good		Average		Poor		Very Poor	
		0.0303	20	0.005	13	0.002	13	0.001	5
3.55		1.1	21	-1.5	29	-2.2	31	-4.3	34
7.05		2.6	47	2.0	47	2.0	47	1.5	44

**Fig. 15** graphically portrays the differences for each band in terms of elevation patterns along the axis of maximum gain. Clearly, soil quality makes a considerable difference to the performance of the 80-m monopole, even with the short radials used in the test. The range of gain values is nearly 5.5 dB across the soil types. On 40 meters, the range of gain differences is just over 1 dB, not

dissimilar to the differences we might see with a horizontal antenna at the same top heights at the base-fed inverted-L. However, remember that the models use the same soil type both just below the antenna and at the distances responsible for ground reflections. So treating the local soil will have only a limited effect on improving antenna performance.



Maximum Gain Elevation Patterns: 69' Base-Fed Inverted-L With 16 Short Radials  
Over Very Poor, Poor, Average, and Very Good Soil

## Does the Ratio of Vertical Wire to Horizontal Wire Make a Difference in Performance?

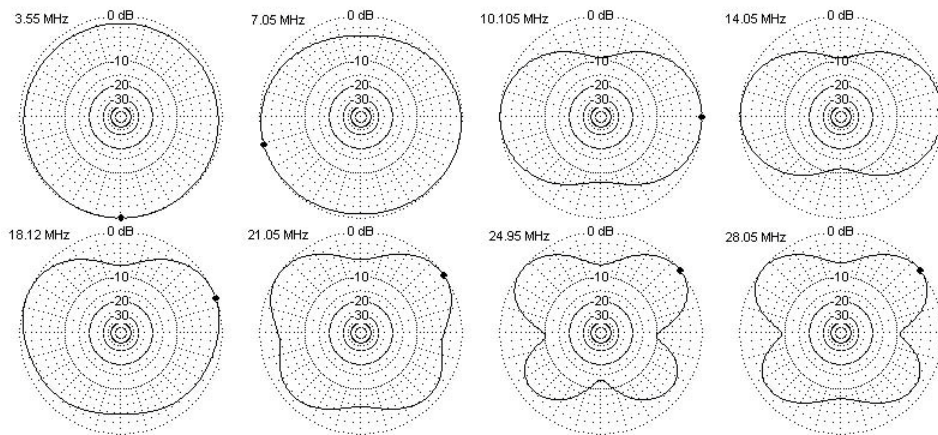
Base-fed inverted-Ls of any selected total length tend to vary in proportions according to how many convenient supports may be available. It is not possible to explore every possible variation, and even if it were possible, we could not include every yard or field clutter scenario. However, we can sample at least three variations on the 69' L. The basic version places 50% of the wire horizontally and 50% vertically. Next comes a short version, with 33% of the wire vertical and 67% horizontal. Finally, we can reverse the proportions, with 67% of the wire vertical and the remaining 33% horizontal. The most general conclusion that will aid you in keeping the tables that follow straight is that the low elevation angles at lower frequencies result from the vertical portion of the antenna. The higher the frequency that we reach before encountering a jump in the elevation

angle, the more of the antenna that is vertical. In all cases, we shall use the set of 16 15' radials.

*1. The 69' Base-Fed Inverted-L for 80- to 10-Meter Use, with 50% Vertical and 50% Horizontal*

As the following table shows, the antenna functions essentially as a monopole on 80 and 60 meters. Above that frequency, operation becomes much more like an end-fed horizontal wire with a minimum length of  $\frac{1}{2}$  wavelength. See **Fig. 16** for sample patterns (with 60 meters omitted to save space). As a reminder, the vertical part of the antenna is at the pattern center, and the horizontal part extends vertically, that is, up the page.

Frequency MHz	Maximum Gain Angles		Vertical Beam- Width (deg)	Gain dBi	Impedance R+/-jX Ohms
	Azimuth (deg)	Elevation (deg)			
3.55	270	29	54	-1.5	40 + j 7
5.368	257	32	78	-0.2	160 + j 580
7.05	198	47 <sup>^</sup>	146	2.0	4100 - j 980
10.105	0	40	64	5.6	75 - j 130
14.05	4	27	35	5.3	1500 + j 470
18.12	20	24	38	4.5	130 + j 80
21.05	34	21	28	4.6	1100 + j 620
24.95	38	16	20	5.8	160 + j 40
28.05	38	15 <sup>*</sup>	51	5.0	770 + j 360



Maximum Gain Azimuth Patterns: 69' Base-Fed Inverted-L With 16 Short Radials  
34.5' Vertical by 34.5' Horizontal, Over Average Ground

Fig. 16

The symmetrical division of the 69' base-fed inverted-L gives it performance values similar to those of the center-fed inverted-L of the same general length. The base-fed model has higher elevation angles in the upper HF region because it is lower overall compared to the center-fed version, with its 10' base height. However, the shapes of the patterns are quite similar to those of the center-fed model. Even when the pattern begins to form multiple lobes, they are broad, and the nulls are not fatally deep. In exchange for small deficits relative to the center-fed inverted-L, we gain operation on 80 and 60 meters.

The starred elevation angle entry indicates that the table uses a lower lobe when maximum gain belongs to a higher angle lobe. However, on 10 meters, the difference in strength between the two lobes is very small. See **Fig. 17** for a comparison between a "normal" upper HF elevation pattern and the worst case, which occurs on 10 meters. Starred entries generally were unnecessary with the center-fed inverted-L because its greater overall height tended to ensure that the lowest elevation lobe was the strongest. However, such entries will be common



in our survey of base-fed inverted Ls. The "^" indicates the band where the elevation angle increases rather than decreases.

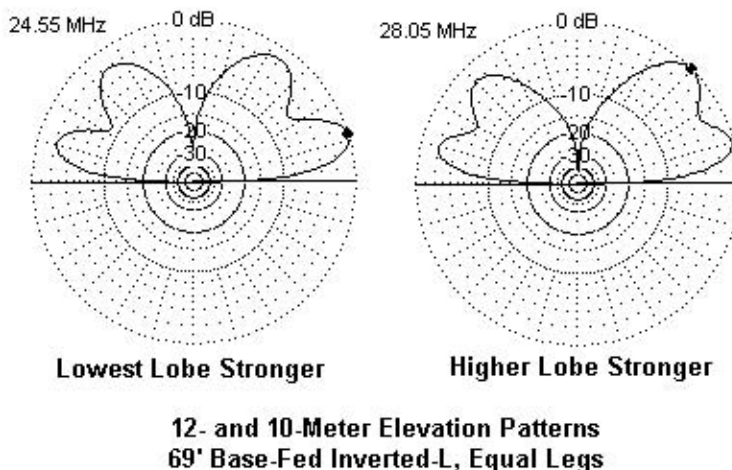
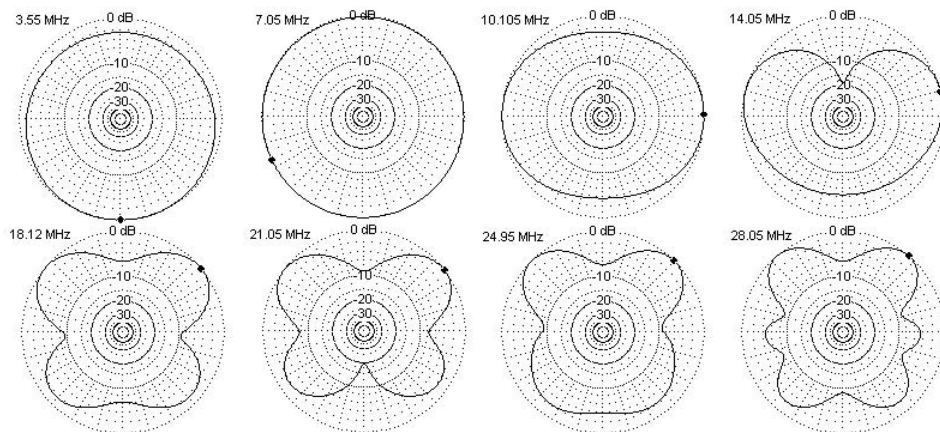


Fig. 17

*1. The 69' Base-Fed Inverted-L for 80- to 10-Meter Use, with 33% Vertical and 67% Horizontal*

The "short" version of the 69' base-fed inverted-L uses a 23' vertical wire and a 46' horizontal wire. Hence, we should expect some performance differences from the version just sampled. A lower overall antenna height (23') will produce higher elevation angles when the horizontal component becomes the dominant contributor to the total pattern. Even the feedpoint impedances will differ, but not so far from the initial values that we cannot recognize the relationships. **Fig. 18** supplies the patterns to go with the tabular data.



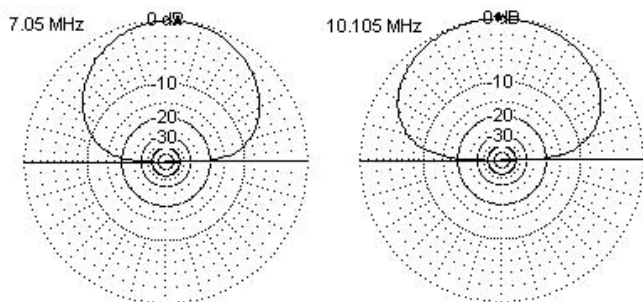
Maximum Gain Azimuth Patterns: 69' Base-Fed Inverted-L With 16 Short Radials  
23' Vertical by 46' Horizontal, Over Average Ground

Fig. 18

Frequency MHz	Maximum Gain Angles		Vertical Beam- Width (deg)	Gain dBi	Impedance R+/-jX Ohms
	Azimuth (deg)	Elevation (deg)			
3.55	270	33	72	-2.1	31 + j 7
5.368	237	64 <sup>^</sup>	129	-0.5	130 + j 590
7.05	210	84 <sup>++</sup>	110	4.4	3800 - j 1900
10.105	1	61 <sup>+</sup>	133	5.2	95 - j 95
14.05	15	35	71	3.5	2000 + j 450
18.12	39	32	42	5.6	130 + j 70
21.05	37	26	35	5.8	980 + j 450
24.95	45	25	34	6.1	140 + j 45
8.05	49	22	27	6.4	800 + j 570

The short version of the 69' inverted-L has no stronger upper lobes per se, but the overall decrease in height yields some entries marked with a plus sign. Note the very high angles for 60 through 30 meters, and see **Fig. 19**. These angles are generally well above normal skip angles, especially on 40 meters. At 7.05 MHz, the signal strength at normal skip angles for that band is considerably lower than indicated by the maximum gain value. Also note that by the 60-meter band,

the antenna has lost the low elevation angle advantage to compensate for a lower maximum gain value. Even on the upper HF bands, the elevation angle of maximum radiation is 7-8 degrees higher than it is with the evenly divided version of the inverted-L. The longer horizontal length shows up in the fact that on 10 meters, we find the emergence of 2 more lobes to the overall azimuth pattern structure. Although this version of the antenna is perfectly usable, it approaches perfection far less closely than the basic antenna with equal vertical and horizontal legs.



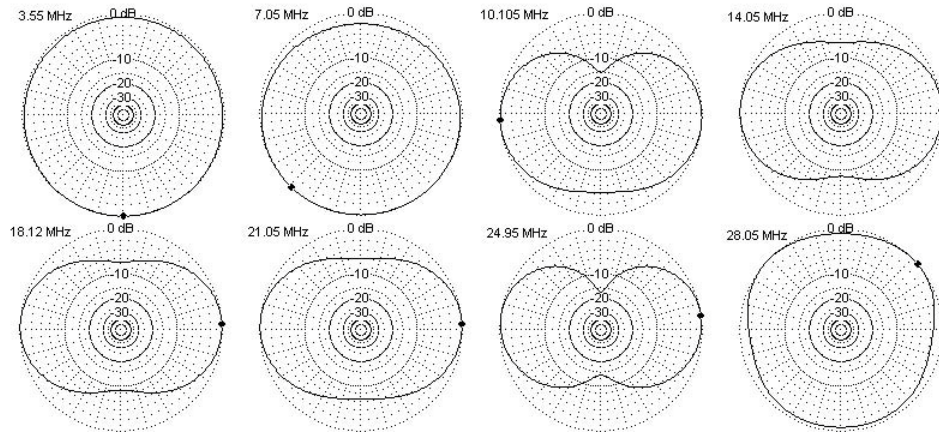
**Very High Angle 40- and 30-Meter Elevation Patterns  
69' Base-Fed Inverted-L, Short Vertical Leg**

**Fig. 19**

1. The 69' Base-Fed Inverted-L for 80- to 10-Meter Use, with 67% Vertical and 33% Horizontal

Frequency MHz	Maximum Gain Angles		Vertical Beam- Width (deg)	Gain dBi	Impedance R+/-jX Ohms
	Azimuth (deg)	Elevation (deg)			
3.55	270	26	47	-1.4	49 + j 10
5.368	270	25	46	-0.4	200 + j 570
7.05	227	24	45	0.5	3600 - j 660
10.105	184	32 <sup>A</sup>	45	4.5	40 - j 120
14.05	2	27	27	4.5	2000 + j 660
18.12	3	17	20	5.0	140 + j 70
21.05	3	15*	52	4.1	1000 + j 420
24.95	8	12*	15	3.8	160 + j 50
28.05	40	39+	24	5.2	860 + j 480

The final version of the 69' base-fed inverted-L reverses the vertical and horizontal proportions. It is 46' tall by 23' horizontally. **Fig. 20** presents the azimuth patterns that coincide with the data in the table.



Maximum Gain Azimuth Patterns: 69' Base-Fed Inverted-L With 16 Short Radials  
46' Vertical by 23' Horizontal, Over Average Ground

Fig. 20

The tall version of the 69' inverted-L retains its vertical component domination through 40 meters. However, on 15 and 12 meters, the lowest elevation lobe is not the strongest, although it is not far behind the higher-angle main lobe. See **Fig. 21** for a picture of how the elevation pattern evolves with increasing frequency. On 10 meters, the lowest lobe is somewhat diminutive, making the high angle (39-degree) lobe the major lobe worth notice. The 10-meter pattern in **Fig. 20** may be somewhat misleading: although coverage is wide, it is at an angle well above most signals on the band.

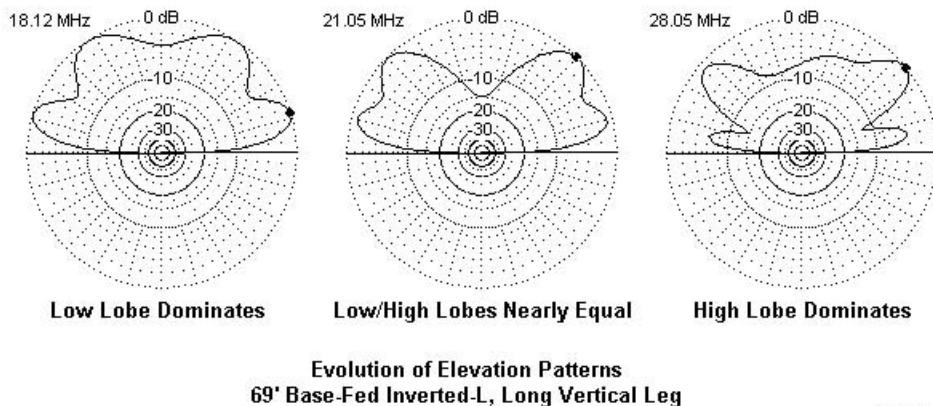


Fig. 21

Of the three variations on the 69' inverted-L, the first version, with balance between the horizontal and vertical legs, offers the best combination of patterns and elevation angles. The others are usable, but tend to have 2 or more bands with lesser performance.

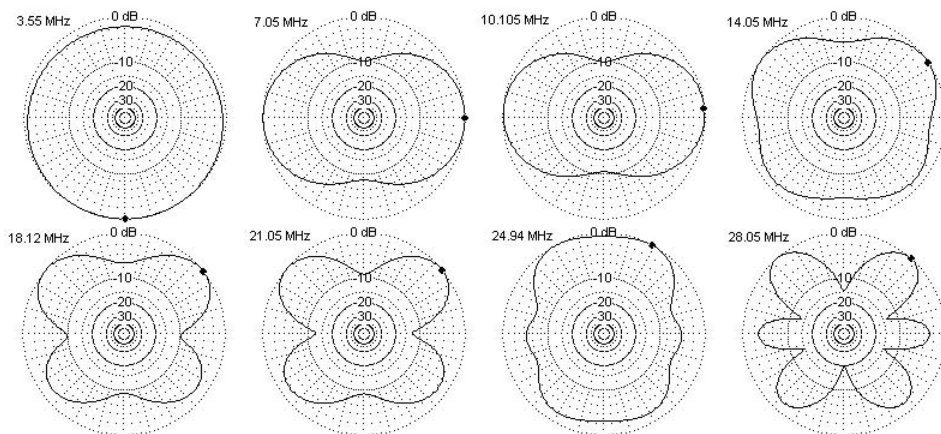
## A 100' Base-Fed Inverted-L for 80- to 10-Meter Use, with 50' Vertical and 50' Horizontal

A second typical length for a base-fed inverted-L is about 100'. Although it is equally subject to variations in proportions, we shall examine only the version using equal lengths for the vertical and horizontal lengths. From that data, you can easily infer the likely performance variations for other ratios of vertical to horizontal legs. With a greater top height (50' rather than 34.5'), we might expect slightly higher gain values and slightly lower elevation angles than for the corresponding 69' model. However, inverted-L antennas are in fact fairly complex in the interactions between vertical and horizontal components of the total pattern. So the antenna may offer a few surprises. See **Fig. 22** for a selection of representative azimuth patterns for the 100' inverted-L.

Frequency MHz	Maximum Gain Angles		Vertical Beam- Width (deg)	Gain dBi	Impedance R+/-jX Ohms
	Azimuth (deg)	Elevation (deg)			
3.55	270	30	70	-0.3	130 + j 490
5.368	189	49 <sup>^</sup>	141	3.6	430 - j 1400
7.05	0	38	60	5.6	76 - j 120
10.105	5	26	33	5.6	1300 - j 830
14.05	33	23	31	4.4	570 + j 680
18.12	38	16 <sup>*</sup>	20	5.1	270 + j 250
21.05	39	14 <sup>*</sup>	18	6.0	260 - j 270
24.95	61	37 <sup>+</sup>	19	7.5	960 - j 360
28.05	48	10	10	5.3	320 + j 290

The 100' inverted-L offers fairly easy matching on all bands, with the possible exceptions of 60 and 30 meters. However, the spectrum from 17 through 12 meters is subject to wasting energy at very high angles relative to the normal skip angles on those bands. On 17 and 15 meters, the lower lobe is nearly as strong as the higher main lobe, but on 12 meters, the high angle lobe dominates. Hence, the high gain for 12 meters may be more illusory than real in practical operation. On 10 meters, we find 6 well-developed lobes and nulls. For general HF communications, the 100' length may not be as satisfactory as the 69' version of the antenna. Greater length of an antenna does not always mean that it is a

better antenna for a particular situation or task. Nor does it always mean better gain, if we think about general communications and the need for some gain all across the horizon.



Maximum Gain Azimuth Patterns: 100' Base-Fed Inverted-L With 16 Short Radials  
50' Vertical by 50' Horizontal, Over Average Ground

Fig. 22

### Is There A Perfect But Realistic Inverted-L Length?

The practical inverted-L builder has two considerations to balance in answering the lead question. Let's consider versions of the antenna between 69' and 100' on the premise that one of those considerations--pattern properties--is satisfactory at both ends of the progression. Since patterns evolve, you can infer the small changes in pattern shape with each step by reviewing the patterns for the 69' base-fed inverted-L and those for the 100' version. As well, we shall restrict ourselves to antennas in which 50% of the wire is horizontal and 50% is vertical. Again, you can review the variations presented for the 69' inverted-L to infer both pattern changes and impedance changes as we alter the ratio of vertical to horizontal sections.

The consideration that may override perfection of pattern is the impedance at the antenna feedpoint. We shall use the 16-short-radial antenna model as a basis for seeing if there is a probable ideal length in a 50-50 inverted L by looking at the impedance on all HF bands from 80 through 10 meters. The table of impedances provides approximate values and does not take into consideration variations created by the actual radial system available or by the effects of nearby objects. However, the data may be useful for initial planning, assuming that available supports will cooperate. Each data entry lists the resistance plus or minus the reactance in abbreviated form. All modeled values are rounded to 2 significant digits.

Freq. MHz	Total Length of the Inverted-L, With Half Vertical and Half Horizontal						
	69'	75'	80'	85'	90'	95'	100'
3.55	40+7	49+82	58+150	70+220	85+300	110+390	130+490
5.368	160+580	290+880	590+1300*	1700+2K*	4400-610*	1300-2K*	430-1400*
7.05	4100-980*	590-1500*	210-900	110-580	82-380	73-240	76-120
10.105	75-125	97+57	140+220	240+410	520+660	1400+650*	1300-830*
14.05	1500+470*	520-740	170-350	110-92	130+120	220+350	370+680
18.12	130+80	290+430	1200+630*	610-740	170-270	160+17	270+250
21.05	1140+620*	310-500	150-77	230+190	560+390	900-270	260-270
24.95	160+39	430+370	920-200	230-200	190+140	490+440	960-360
28.05	770+360	280-230	200+150	550+470	660-460	180-40	320+290

To use this initial guidance chart, evaluate two factors in addition to the maximum size of inverted-L that you can install. First, what length provides the most easily matched impedances on the bands that you wish to work--using long-range thinking rather than just short term habits. The chart stars entries in which either the resistance or the reactance exceeds 1,000 Ohms, and those bands might be difficult to match well. The goal is to select an antenna length that minimizes starred entries next to bands you may wish to use. Compare the 75' and 85' versions of the antenna. Both star only one entry, but the 75' antenna shows a high impedance on one of the most popular general communications bands.

Second, consider the matching range of your tuner. Most automatic tuners placed at the antenna feedpoint have somewhat restricted ranges of reactance compensation, but resistance matching may also be somewhat more limited than



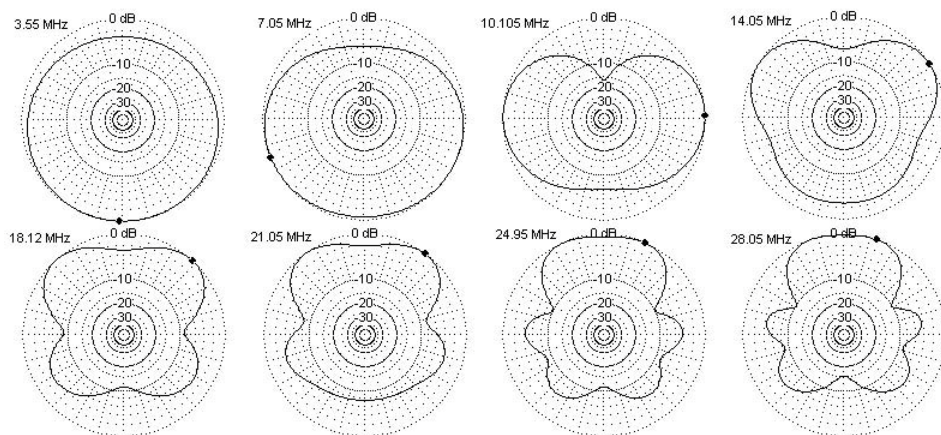
for other antenna tuner types. If we eliminate 60 meters, then the 85' and 90' versions of the antenna may provide a satisfactory match on all of the other HF bands. If the tuner will handle 60 meters and its reduced power levels with under 2:1 SWR at the rig end of the line, then we can use that band also. However, remember that your backyard may have enough clutter to alter the listed values significantly. As well, changing the ratio of vertical to horizontal sections of the wire may also change the impedance at the feedpoint.

Nevertheless, the chart gives you some idea of what to expect. The modeled ideal length range of about 85' to 90' is not usually recommended, most likely because few folks have surveyed what inverted-L length means to the matching problem. Now that you have some initial guidance, as limited as it might be, you can also use the chart as a suggestive start in knowing whether to lengthen or shorten an installation that presents a matching problem on one or more desired bands. Shortening is usually no problem. If you have to add a few feet of wire, do not be afraid to let it hang down so long as no one can touch it.

### **The Base-Fed Sloping Wire**

We covered the center-fed sloping doublet earlier because, like the inverted-L doublet, it included both vertical and horizontal components in the formation of its total patterns on each band. A sloping base-fed wire shares that property with base-fed inverted-Ls, so we should briefly check out its potential performance. Let's use a 69' wire sloping at an angle of 45 degrees. In all patterns, the wire will extend from the pattern upward on the diagrams, just like the horizontal leg of the inverted Ls. The top height of the AWG #12 wire will be at 48.8' above ground. **Fig. 23** shows the patterns that go with the tabular data.

Frequency MHz	Maximum Gain Angles		Vertical Beam- Width (deg)	Gain dBi	Impedance R+/-jX Ohms
	Azimuth (deg)	Elevation (deg)			
3.55	270	30	63	-1.4	46 + j 18
5.368	226	35	108	-0.0	230 + j 630
7.05	203	46^	150	1.4	2100 - j 1500
10.105	2	40	65	2.9	70 - j 80
14.05	32	23	116	2.5	2200 - j 620
18.12	47	19	109	2.9	110 + j 130
21.05	53	16	61	3.3	1800 + j 190
24.95	66	14*	25	3.7	110 + j 100
28.05	71	12*	25	3.9	1400 + j 520



Maximum Gain Azimuth Patterns: 69' Base-Fed Sloping Wire With 16 Short Radials  
45-Degree Slope, Top Height 48.8' Over Average Ground

Fig. 23

The sloping wire is similar in performance to, but not just like, the corresponding inverted-L. On the lowest 2 bands, performance is as good as, if not a tiny bit better than, the L. However, all of the gain values from 40 meters through 10 meters are lower than the L values by a noticeable amount, that is, by 2 dB or more. Most of the gain reduction stems from the very wide vertical beamwidths.

Even though the elevation angle of maximum gain is low, the gain remains considerable even at high angles well above normal skip angles on each band. On 12 and 10 meters, there is a high-angle lobe that is stronger than the low-angle lobe listed.

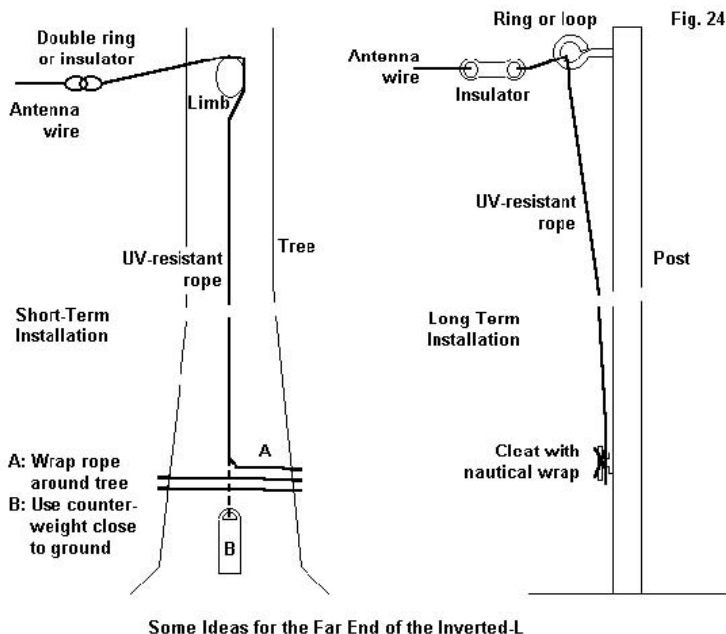
As a consequence, a true inverted-L is more likely to give satisfactory performance than the sloping wire. However, where there is only 1 high support, the sloping wire will provide communications across most of the horizon. As well, for emergency communications work in the HF region, the sloping base-fed wire is a proven performer, and one that you can easily replace should it break due to weather conditions.

### **Some Notes on Building an Inverted-L**

The performance of an inverted-L or its sloping cousin will depend as much upon using sound mechanical and electrical installation techniques as upon the wire itself. Therefore, in our effort to straighten out the inverted-L, we should close with a potpourri of building ideas. Not all of them will apply to a given backyard or field situation, but the general principles involved will trigger more specific ideas for actual antenna sites.

Let's begin at the far end of the antenna, the elevated wire end that is common to both an inverted-L and a sloping wire. **Fig. 24** encapsulates a number of sound practices for both temporary and permanent installations.

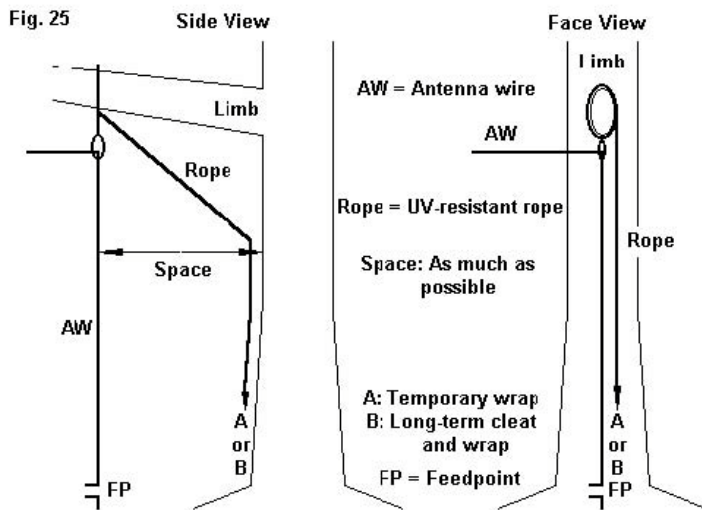
In the field, throwing a rope over a high and handy limb is a time-proven method of securing a wire end. The rope should be both UV and abrasion resistant, or else it requires replacement after every few field exercises. Since these antennas are useful for HF emergency communications, it never pays to use cheap materials that fail in the midst of public service activity. Of course, with this end of the antenna and all other parts, inspection before taking to the field is not merely recommended; it is mandatory.



You may secure the lower end of the rope by several wraps round the tree or with a weight. If you use a counter-weight, be certain that it is low to the ground for safety. With a long-term (sometimes miscalled a permanent) installation, a boat or pick-up truck cleat is a superior way to lock down the extension tope to the wire and the insulator. In long-term installations, an insulator usually provides smoother surfaces around which to wrap the wire on one side and the rope on the other, thereby reducing the chance of cutting the rope with the wire as the two bounce in the breezes. Use a nautical wrap around the cleat for a no-knot, secure, termination.

The near end of an inverted-L presents the builder with the greatest challenges. **Fig. 25** shows some ways to achieve a satisfactory installation of the vertical

wire. First and foremost on the list of necessities is to set the vertical wire as far from any vertical support or other object as possible. Tree trunks and house sides will change conductivity with the weather and the season, and houses have all manner of hidden metal in their walls. The sketch shows the vertical wire spaced many feet from a tree trunk. Increase that spacing if you use a tower or a house as the support. If the vertical portion of the antenna does little other than to irradiate a tree trunk or house wiring, the antenna performance will range from poor to pathetic.



Some Ideas for the Near End of the Inverted-L

At the upper end, the antenna wire will make a right-angle turn. Support it with a non-conductive ring. Do not use a metal ring, and do not drape the wire directly over a limb or other support. Trees and other wood supports are not true insulators. At best, they are semi-conductors capable of dissipating a good bit of

power over their surfaces. Even in the 1920s, amateurs used wood insulators only after soaking them in boiling paraffin. Since that practice is not applicable to a limb that is still on the tree, some variant of the rope and ring system is necessary for proper support of the L. At the base, you may use either the field or long-term techniques of **Fig. 24** to secure the rope.

For a center-fed inverted-L doublet, replace the suspended ring with an insulator or a commercial doublet centerpiece designed for use with parallel feedline (either ladder line or vinyl-covered transmission line). Use care to design the center support of the junction of transmission line and antenna wire for the type of support that you will use. A tree limb will require a flexible support. However, if you use a tall wooden post or similar structure, then you may wish to devise a more rigid extension to the doublet center insulator to reduce movement. Parallel feedlines show their greatest weakness where they emerge from the junction fixture. 24-hour a day wind movement will gradually flex the wires to the breaking point.

**Fig. 25** does not show any particular means of mechanically terminating the lower end of a sloping or vertical wire. The base-fed and center-fed terminations require different treatments. **Fig. 26** is only a starter set of ideas, designed to show what is necessary by way of installation, but not necessarily what specific hardware you will need. What both systems have in common is the need to pin down the end of the vertical assembly without creating so much tension that the system breaks in the middle or at the far end.

With the base-fed inverted-L, the wire descends all of the way to near-ground level. Even in a field operation, do not connect it directly to an ATU terminal. The diagram shows a non-conductive plate with terminals. On one side, the terminal connects to a ground stake or rod, and to that rod, we connect the radials. The other terminal secures the antenna wire. Then, leads from the ATU connect with no stress to the plate terminals. In permanent installations, waterproof all connections. In fact, consider adding a secondary weatherproof housing to the commercial remote antenna tuner as an added layer of protection. Do not place

the ATU directly on the ground. In fact, keep it above the level of water that even the worst yard flooding might produce.

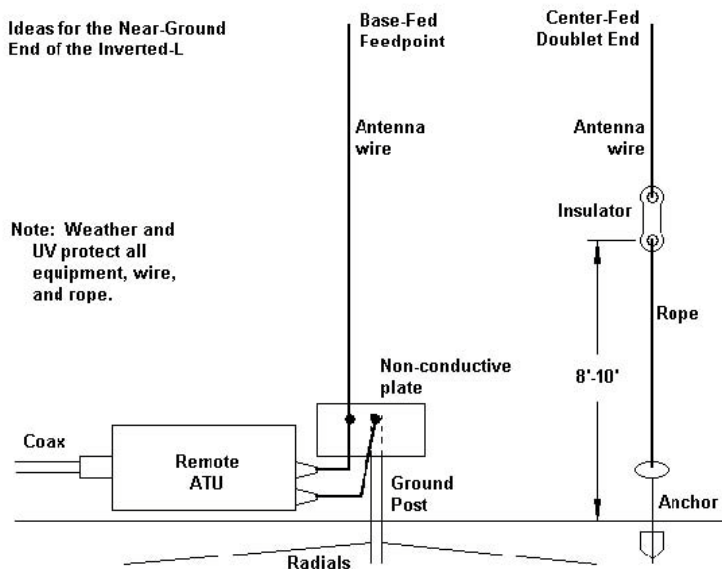


Fig. 26

The center-fed doublet requires an extension rope (and insulator) between the wire and a ground anchor. Unless the installation is very heavy or undergoes extreme stresses, a guy-wire screw anchor is usually not necessary. There are pet chain anchors that will secure AWG #12 wire and rope ends quite well. However, be certain that the device is non-rusting.

The diagram lists a height of 8' to 10' as the distance between the ground and the element end. A better way to determine the minimum height above ground for the antenna wire end is to consider the highest level a family member or visitor

(or pet) might jump (with arms extended) and then add 2' to that level. The goal is to ensure that no one can reach the wire under any normal circumstance. Doublet wire ends can carry considerable voltage, even at low power levels. Safety is the first concern in all antenna installations.

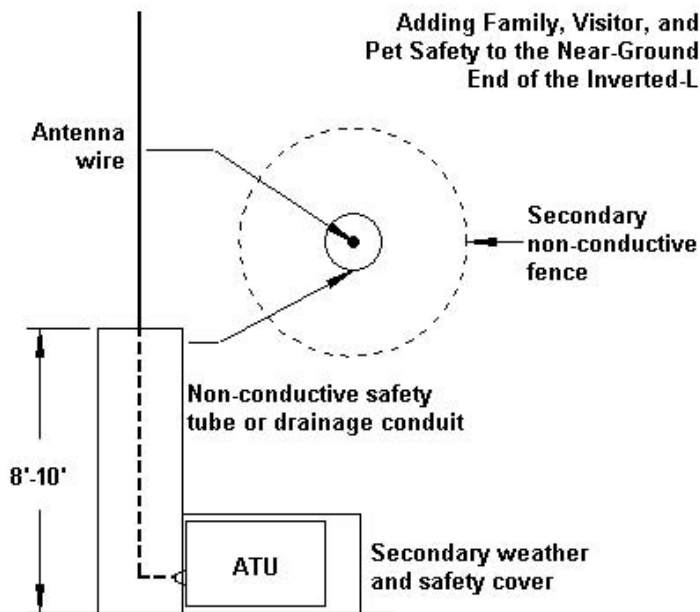


Fig. 27

The base-fed inverted-L is not amenable to the safety height that we can build into the center-fed inverted-L. Therefore, we must take other steps to keep family members, pets, and visitors from accidental contact with antenna wires and terminals. **Fig. 27** shows essentially a 2-tier safety arrangement for the casual backyard installation.



The first line of safety defense consists of a non-conductive tube placed over the wire and extending high enough that no one can jump and touch the wire emerging from it. For HF, rigid PVC drainage pipe is usable by cutting a slot along the ATU side to pass the leads from the tuner. The plate and the ground rod go inside the tube. Less rigid but equally usable are section of ABS or similar drainage pipes designed to carry downspout water away from a house. By lightly sanding the surface of either type of protective pipe, you may prime and paint the pipe to a yard-compatible color, so long as you use a paint with no metallic content. Note that this first line of defense also contains a safety cover for the ATU to prevent unwanted contact. This same cover may also act as the recommended secondary weatherproof shield for the unit.

The second line of defense consists of a non-conductive fence, such as a set of PVC or similar pickets. This fence adds a radius of a few feet from the central tube and tuner (if the antenna is base-fed). Adding a flowerbed inside the fence but away from the antenna itself further discourages the inquisitive from entering the area just to see what the end of an antenna really feels like. Similar techniques have long been used around the bases of towers to discourage potential climbers.

In the field, you are unlikely to use any of these safety measures. However, do not presume that everyone at the site will be on the watch for your antenna wires. Add flags to all wires, and if they slope, add several to make the angle obvious. Use construction perimeter flags to mark the route of any cable. And never set any wire in a position that it might catch a passerby just under the chin.

These precautions take some of the excitement out of antennas. But all antennas must have a mixture of excitement and responsibility, with a heavy dose of the latter.

In the end, either the center-fed or the base-fed inverted-L has a number of properties that make it a good candidate for the amateur seeking multi-band general communications in as many directions as possible. The vertical and horizontal components combine to produce moderate gain in most directions.

The lobes tend to be fewer and broader--and the nulls shallower--than they are when using a horizontal doublet. The antennas are not perfect. But they are cheap and relatively easy to build from locally available parts. If they do not merit first place among your antennas, they make very good back up antennas for the main system. However, for many field operations and small backyards, they may be the best choice for a simple, multi-band wire antenna.

## Chapter 17: The All-Band Inverted-L

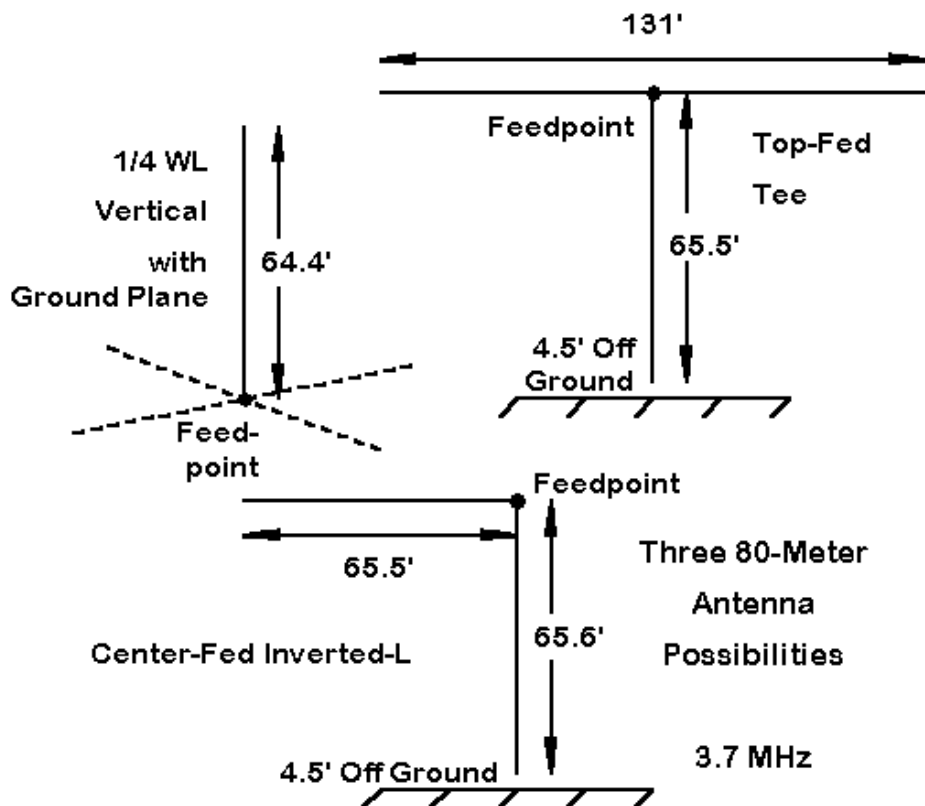
**W**hen I wrote on "The L-Antenna" for 10-meters in the previous Chapter 13, I noted that the antenna was not likely new. I have since learned that the basic idea seems to have originated with VK3AM in the early 1950s and is described in L. A. Moxon's (G6XN) classic ***HF Antennas for All Locations*** (pp. 154-156 of the first edition). This antenna is a standing L, although Moxon has no problems with viewing it inverted. Ralph Holland, VK1BRH, includes the L in his computer study of several antennas, including an interesting variant of the L: the 1/2 wl inverted-L. (VK1BRH's interesting modeling studies, published in ***Amateur Radio***, the journal of the Australian Wireless Association, can be found at his web site: <http://www2.dynamite.com.au/vk1brh/Antsim.htm>)

Perhaps the earliest article on the inverted-L as an all-band antenna may have been "The 'Inverted L' Ham Antenna," by Bob See, W5LTD, which appeared in *Radio and TV News*, January, 1959, pp. 64-65. Bob used base feeding to operate the antenna as a standard inverted-L monopole with a ground plane on 80 and as an end- or voltage-fed longer wire above 80, as his measured impedance figures attest. The 1/2 wl inverted-L can also be center-fed using parallel feedline and an ATU. We shall focus on the center-fed version: it is an antenna with excellent potential as an all-band substitute for the 135' center-fed doublet.

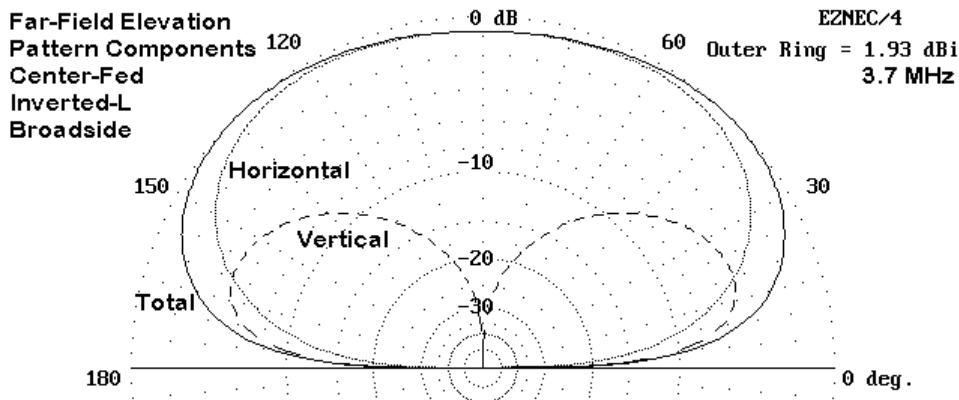
The 1/2 wl inverted-L which we shall examine differs from standard 1/4 wl inverted-Ls in 2 ways: First, it is longer, of course. Second, it is normally current fed at the center (although end- or voltage-feeding is always possible, even if not always convenient). Hence, it can be viewed as an inverted Vee tilted over by 45 degrees. Alternatively, it can be viewed as a 1-leg-ground-plane 1/4 wl vertical upside down.

If the upside-down vertical had a second leg going in exactly the opposite direction, the result would be--to a large degree--cancellation of the horizontally polarized radiation. Let's call this antenna the T.

Both the L and the T differ from the standard  $1/4 \text{ wl}$  ground plane vertical by being complete antennas--dipoles as it were. Hence, neither requires a ground plane beneath them. For some situations, this fact can simplify construction. The figure below shows the structural differences among the three antennas for models set at 3.7 MHz. The L and T models were set at a top height of 70', with the vertical arm terminated 4.5' off the ground.

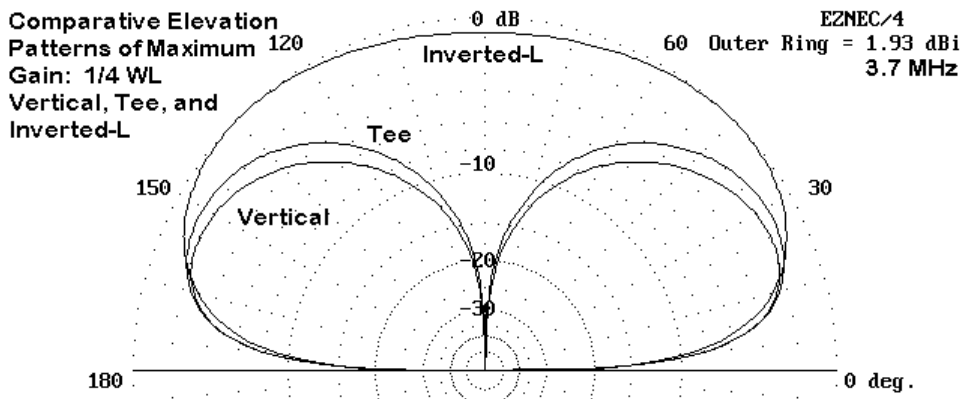


Each antenna was modeled using #14 copper wire and average ground throughout. Note that the inverted-L and the T present challenges to the builder in terms of routing the parallel feedline to the top feedpoint. We shall do some comparisons, but first, let's become a bit more familiar with the inverted-L basic pattern.



The elevation pattern above shows the vertical, horizontal, and total field components of the inverted-L radiation pattern taken broadside to the horizontal arm of the antenna, where radiation is strongest. In the plane off the ends of the horizontal arm, horizontally polarized radiation is somewhat weaker, but the vertically polarized radiation remains at full strength, with some pattern bending away from the horizontal arm.

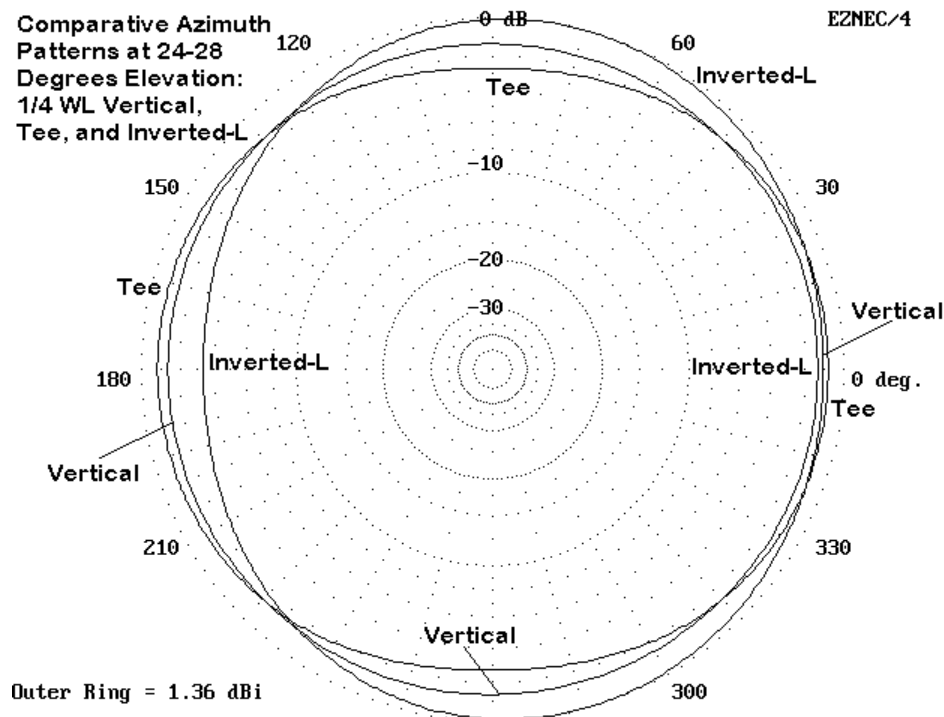
A fair comparison might be made among elevation patterns for the L, T, and vertical. Since the total pattern of the L is a broad oval, let's take the strongest direction also of the T, which happens to be off the ends of the horizontal arms. The vertical is truly omni-directional, so let's set at least 20 radials beneath it.



The comparative pattern above shows the rough equality of the T and the ground-plane-vertical patterns under the specified conditions. Surprisingly, the inverted-L comes close to both antennas in low angle radiation. It also has stronger high angle radiation--without becoming a cloud burner--which is useful for shorter skip contacts. In other words, the inverted-L has potential as an all-purpose low-band antenna.

Comparative Azimuth  
Patterns at 24-28  
Degrees Elevation:  
1/4 WL Vertical,  
Tee, and Inverted-L

EZNEC/4



The azimuth patterns of the three antennas--taken at elevation angles between 24 and 28 degrees--show the slight oval of the T and the slightly more radical oval of the inverted-L. The L's azimuth pattern also shows the slight displacement in the direction away from the horizontal arm. However, these effects are small enough not to stand in the way of using the antenna for general operating purposes.

## The Ground-Plane Question

In principle, as a complete 1/2 wl antenna, the inverted-L requires no ground plane. Likewise, the T should require none. In contrast, the 1/4 wl vertical requires a ground plane to complete the antenna. To test the relative need and utility of a ground plane, I modeled all three antennas with ground planes, first using 4 wires and then using 20 wires. I set each ground plane first at 1' below ground, then at the surface, and finally at 1' above ground. The vertical's source segment touches the ground, which gives erroneous results in NEC-4. Therefore, the surface ground plane for the vertical was set 0.1' above ground. The radial wires were the same length as the vertical radiators, which means slightly shorter radials for the vertical than for the L or T.

The following table summarizes results for the three antennas with 4 and 20 wire ground planes.

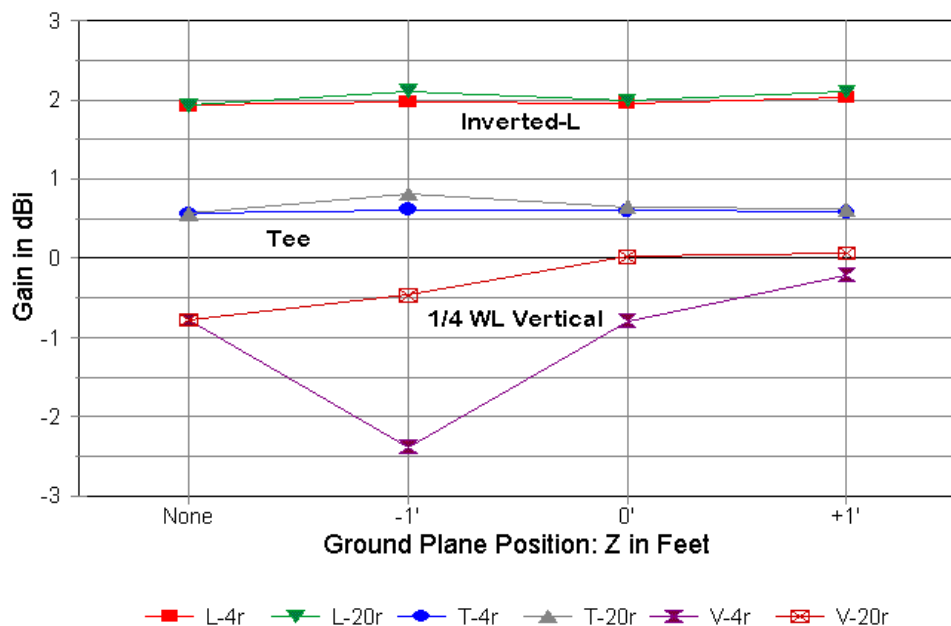
Antenna/GP level Impedance	Gain dBi	TO angle degrees	Source R +/- jX Ohms
<b>4-radial tests</b>			
<b>Inverted-L</b>			
No GP	1.93	44	66.1 + j 3.8
GP -1'	1.97	45	66.1 + j 4.5
GP 0'	1.96	44	66.0 + j 4.0
GP +1'	2.03	46	65.6 + j 4.5
<b>T</b>			
No GP	0.56	28	42.7 - j 5.2
GP -1'	0.61	28	42.7 - j 4.6
GP 0'	0.60	28	42.7 - j 5.0
GP +1'	0.58	28	42.3 - j 5.2
<b>Vertical</b>			
No GP	-0.78	24	48.2 + j 0.2
GP -1'	-2.38	25	68.5 + j 8.1
GP 0'	-0.79	25	45.5 + j32.5



GP +1'	-0.21	24	39.6 - j 9.3
20-radial tests			
Inverted-L			
No GP	1.93	44	66.1 + j 3.8
GP -1'	2.11	45	65.4 + j 6.5
GP 0'	1.99	44	66.3 + j 4.4
GP +1'	2.10	46	64.5 + j 4.7
T			
No GP	0.56	28	42.7 - j 5.2
GP -1'	0.81	28	41.9 - j 3.0
GP 0'	0.65	29	42.9 - j 4.7
GP +1'	0.62	28	41.3 - j 5.2
Vertical			
No GP	-0.78	24	48.2 + j 0.2
GP -1'	-0.47	25	45.3 - j 0.9
GP 0'	0.02	24	37.1 - j 3.9
GP +1'	0.06	24	36.8 - j14.6

Although the tables give the most data, comparisons are more difficult than with a graph.

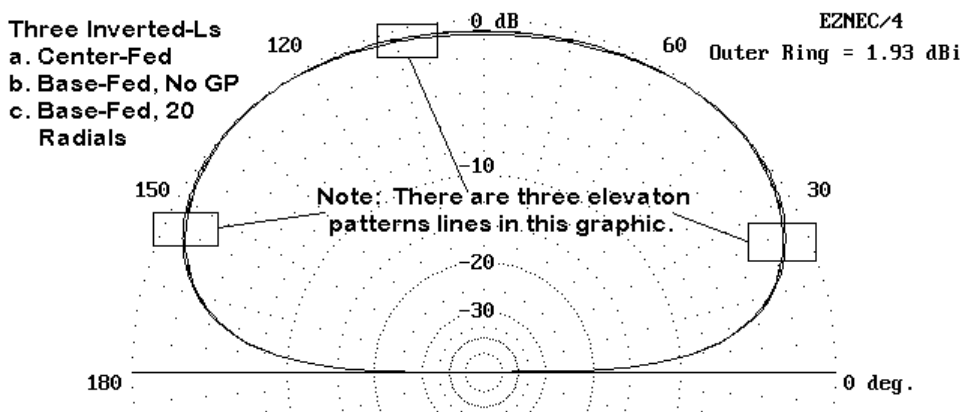
## L, T, and Vertical Gains Various Ground Planes



The antenna gains are compared in the graph above. The line connections between points are not real connections, but only let the eye tell which data points go together. As is evident, NEC-4 modeling strongly suggests that the addition of a ground plane adds virtually nothing to antenna performance for the inverted-L and the T, both of which we have described as complete antennas. In contrast, the vertical is dependent upon the most extensive (up to 60-100 radials) that a builder can install. (The vertical antenna data point for "No Ground Plane" should be used for reference and does not represent accurate data relative to a real antenna.) I further modeled the vertical with 64 radials. At a depth of 1', the

antenna gain increased to 0.19 dBi, while setting them 1' above ground yielded a gain of 0.02 dBi. Modeling has consistently suggested that for perfectly symmetrical ground planes above ground, more than 6-8 radials may be superfluous. This conclusion does not necessarily apply to ground planes that are not perfectly symmetrical.

An alternative to high-altitude center feeding of the inverted-L is to base feed it at the low end of the vertical. Models of this mode of feeding the antenna show patterns quite consistent with those for center feeding, with a source impedance in the neighborhood of 5000 Ohms. Once more, the addition of a ground plane does not aid antenna performance in any way, as the following elevation plot shows.



However, the absence of need for a ground plane should not be mistaken for an absence of a need for a good RF ground. In turn, we should not presume that the ground rod near the shack, which provides AC and DC power grounding for safety, also provides an adequate RF ground. Army tests established a couple of decades ago that a good RF ground needs periodic short (<2') rods connected by a perimeter wire or strap that essentially surrounds the entire station location.

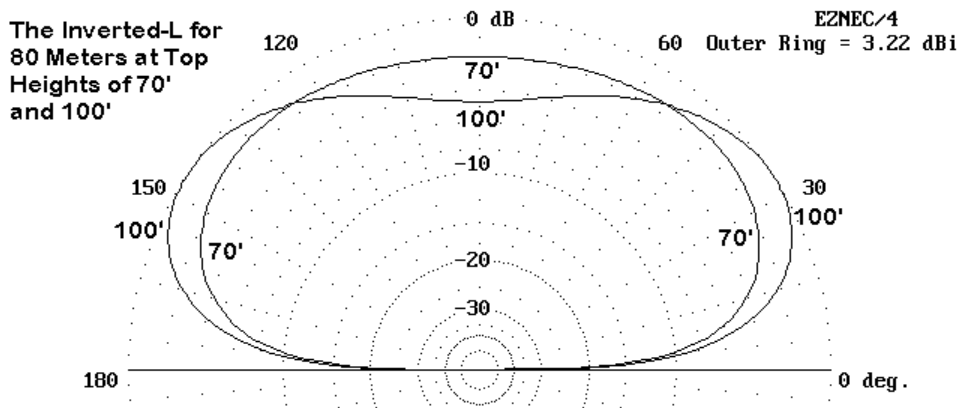
## Installation Variations

Knowing that not everyone tempted to use the inverted-L will have all of the space needed, I checked some variants that represent typical construction compromises or changes. Since the antenna will be fed with parallel transmission line, matching is not a major problem. However, changes of gain and elevation angle may indicate that some variations are better than others.

**1. Height:** elevating the inverted-L is a route to slightly more gain and a lower take-off angle broadside to the horizontal arm. Here is a table of values modeled with top heights at every 5' from 70 to 100 feet up.

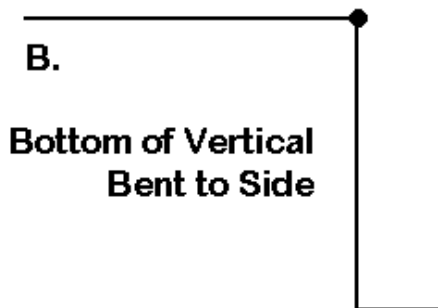
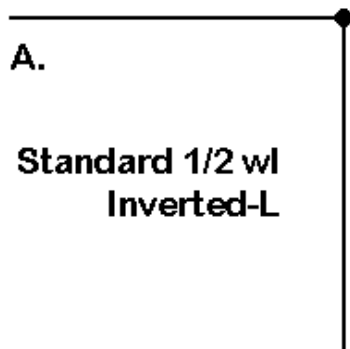
Top Ht. feet	Bottom Ht. feet	Gain dBi	TO Angle degrees	Feed Impedance R +/- jX Ohms
70	4.5	1.93	44	66.1 + j 3.8
85	9.5	2.20	42	62.8 - j 4.2
80	14.5	2.43	41	60.1 - j 9.3
85	19.5	2.63	38	57.6 - j12.8
90	24.5	2.83	37	55.3 - j15.4
95	29.5	3.02	34	53.0 - j17.2
100	34.5	3.22	33	50.9 - j18.5

Nothing drastic happens between any two levels, but the trends are clear. Gain increases and take-off angle decreases. The antenna plays shorter, the higher we go. However, unless one plans to use a monoband coax feed system, the precise dimensions are not at all critical.

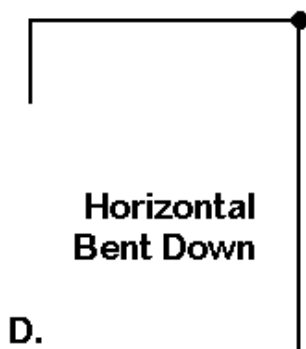
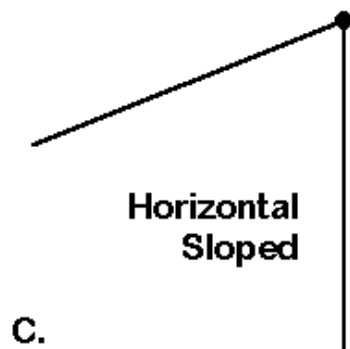


The elevation patterns in the figure compare the antenna at 70' and at 100' and add visual confirmation of the conclusion drawn from the table.

**2. Sloping and Bending:** The more normal problem for home installation is too little vertical or horizontal space. As the figure below shows, there are a number of installation "tricks" we might use. The question at hand is how much each will hurt performance.



● = Feedpoint



### Installation Variations on the 1/2 wl Inverted-L

*Bending the vertical at the bottom:* The first way to save vertical space or to protect family members from the high voltage at the antenna element end is to bend the lower end of the vertical to the side. The upper horizontal arm remains 65.5' long. The overall length of the vertical is also 65.5', but part is now vertical and part horizontal. I tested three scenarios, listed in the table below:

Max. Ht feet	Vert. Wire feet	Low Hor. feet	Gain dBi	TO Angle degrees	Feed Impedance R +/- jX Ohms
70	60	5.5	2.04	45	64.2 - j 4.4
70	55	10.5	2.22	47	61.8 - j11.3
65	55	10.5	1.92	49	64.8 - j 2.7

The chief effect of the bend is to raise the high angle radiation strength a small bit and to raise the elevation angle of maximum radiation. The latter figure indicates a slight loss in the lowest angle radiation, which one would anticipate from shortening the vertical length. None of these small changes in dimension affect the usability of the antenna.

*Sloping the horizontal arm down:* One might wish to use the antenna where there is only one truly tall support and the support for the far end of the horizontal arm is lower. The result is a sloping horizontal arm. Using a peak height of 70' and keeping the dimensions of each wire at 65.5', I tested 2 scenarios, representing two degrees of slope, against the standard installation.

Max. Vert Ht feet	Hor. End Ht feet	Gain dBi	TO Angle degrees	Feed Impedance R +/- jX Ohms
70	70 (no slope)	1.93	44	66.1 + j 3.8
70	60	2.26	51	58.6 + j 8.4
70	50	2.66	58	52.4 + j32.0

Gain increases are at high angles of radiation, with some loss of low angle radiation strength. Although a true horizontal is perhaps the best compromise for maximum low and high angle performance, the patterns with a modest slope to the horizontal arm do not make the antenna unusable by any means.

*Bending the horizontal arm far end down:* If horizontal space is limited, a common practice is to bend (or dangle) the outer ends of a dipole downward. since the region is the high voltage and low current portion of the antenna, the radiation pattern is least affected by modifying the geometry. Again, I compared 2 scenarios to the full-length horizontal arm configuration.

Max. Ht	Hor. Arm Lth	Bent Length	Gain	TO Angle	Feed Impedance
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feet	feet	feet	dBi	degrees	R +/- jX Ohms
70	65.5	0.0	1.93	44	66.1 + j 3.8
70	55.5	10.0	1.82	45	62.7 - j 5.9
70	45.5	20.0	1.62	43	54.6 - j12.2

Low angle radiation remains essentially constant, since the vertical arm has not been altered. Further shortening of the horizontal arm would show a gradual further reduction in maximum gain and in the take-off angle. Higher-angle radiation is decreased, although the antenna remains eminently usable.

Like many wire antennas, the inverted-L will tolerate moderate alterations of geometry to fit the space available and still yield good, if not peak, performance.

### Multi-Band Use of the Inverted-L

One disadvantage of the 135' horizontal doublet when used on the upper HF bands is that the pattern breaks into a collection of fairly narrow lobes with deep nulls between them. Since the nulls change position from band- to-band, the user is often surprised to discover that signals from certain directions are weaker than expected.

The inverted-L, when fed with parallel transmission line and an antenna tuner, is not wholly exempt from this phenomenon. However, since one arm is fully vertical, the nulls tend to be much shallower. At the same time, gain peaks are less pronounced.

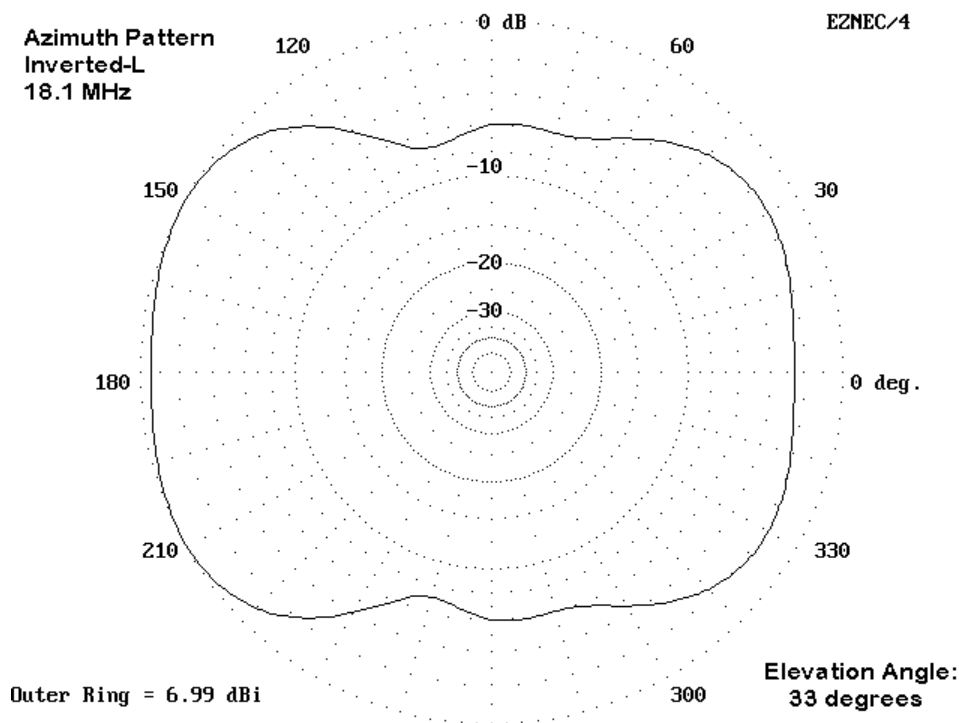
The following table provides a rough guide on what to expect from each of the amateur HF bands:

Frequency MHz	Gain dBi	To angle degrees	Feed Impedance R +/- jX Ohms	Pattern Shape (approximate)
3.7	1.93	44	66 + j 4	Broadside oval
7.1	4.09	26	6500 + j 300	Broadside oval
10.1	4.04	20	150 - j 500	Square
14.1	5.38	14	2000 + j2300	4 lobes

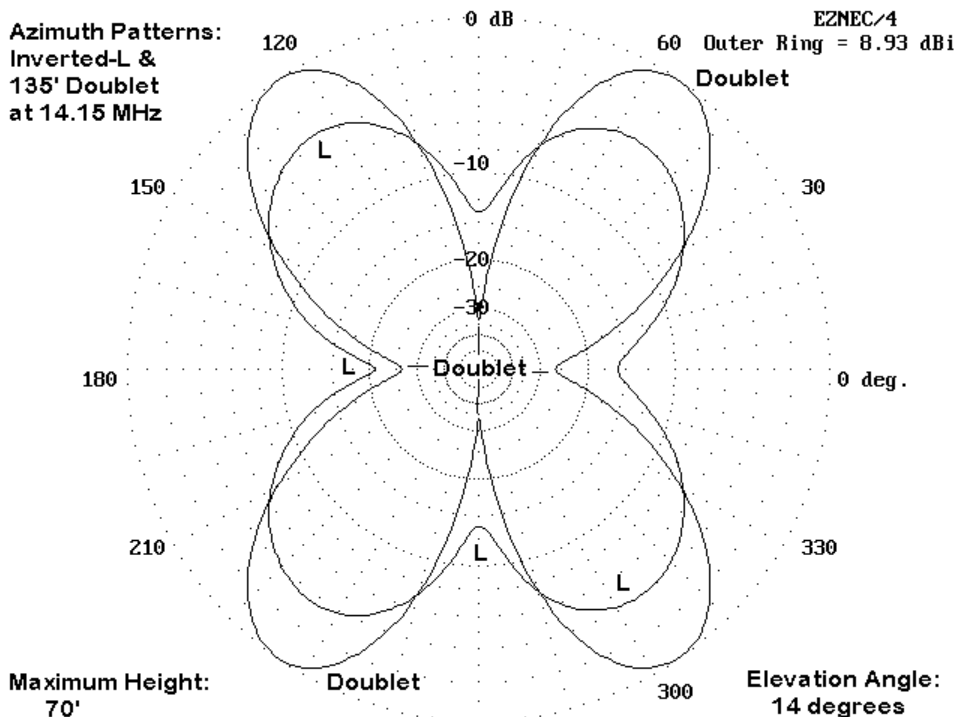


18.1	6.99	33	165 - j 255	Square
21.2	6.74	9	750 + j1400	6 lobes
24.9	6.63	8	210 - j 520	6 lobes
28.5	7.55	7	575 + j1000	8 lobes

Even harmonics of the antenna's fundamental frequency show high impedances, in some cases with a high reactive component. The WARC bands show more moderate impedances at the antenna feedpoint. Use of 450-Ohm or 600-Ohm parallel feedline is recommended in order to provide reasonable values of impedance at the antenna tuner terminals. As with all such antennas, if a tuner seems unable to effect a match on a given band, adding a short section of feedline between the existing line and the tuner output terminals will often correct the situation.



The annotation "square" to describe the azimuth pattern is illustrated by the 18.1 MHz pattern. On this band, the strongest signal occurs at the second elevation lobe. There is a usable but less strong lobe at about 16 degrees elevation. Note the absence of sharp nulls and lobes.



Even where lobes and nulls do occur, both are much less pronounced than they are with a standard doublet. The figure shows the differences for the 20-meter band. Doublet nulls exceed -25 dB relative to the lobes, whereas inverted-L nulls are under -10 dB relative to the lobes, which are also broader than those of the doublet. Of course, peak gain of the lobes is about 4 dB less than for the doublet lobes. For some types of operation, but certainly not for all, the absence of strong nulls can be more advantageous than a few extra dB of gain in very specific directions.

## The 100' Center-Fed Inverted-L

Many hams who cannot erect a full 135' long inverted-L can often manage a 100' version of the antenna. This length would require 50' of horizontal run and about 55' of height to place the vertical section at least 5' off the ground. As we have seen, higher installations will yield better results, but the present values will provide a kind of worst-case scenario for modeling that antenna. Since the sketches for this shortened version of the inverted-L, which is about 70% full size at 80 meters, would be the same as those for longer versions, we can jump directly to a table of values for multi-band use of the antenna. Note the cases in which the ratio of reactance to resistance is very high: these conditions tend to increase line losses and to challenge tuners in finding satisfactory and high-efficiency matching settings.

Frequency MHz	Gain dBi	To angle degrees	Feed Impedance R +/- jX Ohms	Pattern Shape (approximate)
3.7	1.32	51	30 + j 425	Broadside oval
7.1	3.13	31	305 + j1010	Broadside oval
10.1	4.95	24	2150 - j3100	Broadside oval
14.1	4.64	19	120 - j 185	Square
18.1	5.51	34	965 + j1785	4-Leaf clover
21.2	5.00	12	475 - j1300	4-Leaf clover
24.9	6.07	10	160 + j 95	6 lobes
28.5	7.03	9	1775 + j1990	6 lobes

As one might expect, the shorter antenna breaks into multiple lobes more slowly with increases in frequency. Moreover, the pattern of high and low feedpoint impedances differs greatly from the pattern for the 135' version. Given the lower top height, the elevation angles of maximum radiation are somewhat higher, especially on the lowest bands of operation. (Note that the band on which an unexpected high angle of maximum radiation occurs for both versions also shows a lobe of nearly the same strength at a lower angle--just about 20 degrees lower. Hence, useful radiation occurs on that band--in this case 17 meters.) Shorter antennas--down to about 90' overall wire length can be built and used on 80 meters. Below about 90' overall wire length, the antenna becomes essentially a 40-meter-and-up inverted-L.

## **Conclusion**

The center-fed inverted-L has the potential to be a quite satisfactory all-band wire antenna suited to certain environments. The length can be almost anything about  $3/8 \lambda$  or longer for the lowest frequency of intended operation. Although the overall gain will be lower for each band than the gain of a horizontal doublet using the same overall wire length, the elevation angle of maximum radiation for the L will be lower than for a doublet with the same top height.

There is little evidence, despite the vertical position of one arm of the antenna, that the inverted-L would benefit from a ground plane beneath the antenna. The actual low-angle gain of the inverted-L will, however, vary with the quality of the soil in the region of reflection at a distance from the vertical arm. All patterns were taken over average soil, and soils that are either poor or better than average will tend to show a higher gain and lower take-off angle, at least on the fundamental frequency.

The electrical lineage of the center-fed inverted-L is from the dipole by way of the inverted-Vee. For the amateur yard that is short on horizontal space but long on tall supports, the inverted-L may be the antenna of choice as an all-band wire--whether used as the primary station antenna or as the back-up for more complex arrangements.

## Chapter 18: The Multi-Band Inverted-V

**T**he smaller the backyard, the less room that we have to construct a full-size 135' level center-fed doublet as an all-band HF antenna. As a work-around, many amateurs try the inverted-V configuration. It requires only one very tall center support, with lower supports for the wire ends. Handbooks reassure us that the inverted-V will perform quite well, with only a small reduction in gain and a slight expansion of the radiation pattern off the ends of the wire. So we dutifully build the inverted-V and then wonder why neighboring hams are doing so much better at hearing stations. We rationalize that perhaps our antenna is broadside in the wrong direction. We may think that we have to grow taller trees to raise the feedpoint of the antenna even higher. Possibly, we need to buy a new rig. We never stop to think that the basic antenna may be at fault, especially on the upper bands. After all, the handbooks have reassured us that the all-band inverted-V is a good general purpose antenna.

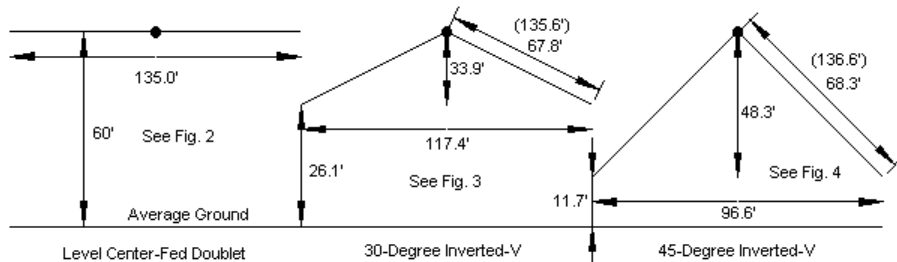
Let's back up a step and make a plan to study the situation. The first step is to review what we can expect from a level doublet with the same feedpoint height as our inverted-V. We cannot possibly survey every feedpoint height in this exercise. So I shall set the feedpoint at 60' above average ground. That level is somewhat high for the average backyard, but I have reasons for picking it, and they will appear in a moment.

The second step is to replace the level doublet with an inverted-V, keeping the same feedpoint height. The immediate problem that we face is selecting an angle at which to slope the wires relative to the doublet. Again, we cannot possibly survey every sloping angle. However, we likely only need to look at two angles. One is a slope of 30 degrees down from the doublet. The other angle is 45 degrees down from the doublet. The difference is only 15 degrees, but--as we shall see--what a big difference those 15 degrees will make. **Fig. 1** sketches the 3 antennas that we shall include in our survey.

All Antennas: AWG #12 Copper Wire

All Antennas Resonant at 3.5 MHz

Fig. 1



Typical Amateur All-Band Doublet Configurations Sampled for Radiation Patterns

If we start on the right in the figure, we can see why I chose the 60' feedpoint height. The wire ends are between 11' and 12' above ground. Letting inverted-V ends go any lower is an invitation for someone to receive an RF burn, since the wire ends will carry a high voltage when we transmit. Hence, safety dictates that we keep the inverted-V ends at least 10' above ground, and higher, if feasible.

The inverted-V sketches show the length of the legs, with the total wire length in parentheses. All three antennas are resonant at 3.5 MHz (using AWG #12 or 0.0808" diameter wire). As we slope the wires into the inverted-V configuration, we need slightly more wire to achieve resonance at the baseline frequency.

We can also see the important reason for using an inverted-V instead of a doublet. Every addition degree of slope reduces the required end-to-end span for the antenna. The 45-degree slope allows the antenna to fit a yard with a maximum dimension of 100'. For this exercise, then, I shall assume that the backyard has one mighty oak--or Douglas fir--or ancient magnolia--that is precisely positioned to let us construct an inverted-V to use on all of the HF bands.

The next question is simple: what can we expect from our antenna. To create a basic answer and set up some reasonable expectations, we should survey all of the HF amateur bands. Therefore, I shall sample each amateur band, jotting down some basic information and creating both elevation and azimuth patterns for the antennas. For each band, I shall use the lowest frequency in the band, since the patterns will not change much within a given band. The one exception is 75 meters, where I used 4.0 MHz to allow us to see how much the very wide 80/75-meter ham band changes antenna performance.

My procedures will be fairly simple, but there will be a twist or two along the way. I shall collect information on the gain level of the strongest lobe(s) in the pattern. In the azimuth patterns, I shall record the first maximum-gain lobe away from the broadside direction to the wire, unless the strongest lobe is exactly broadside to the wire. I shall also record the take-off (TO) angle, that is, the elevation angle of strongest radiation. Wherever the strongest lobe is not broadside to the wire, I shall make my elevation pattern using the direction of the strongest lobe. If the elevation angle of maximum radiation is above 45 degrees, I shall create the corresponding azimuth pattern at 45 degrees. Under these conditions, you must assume that the azimuth pattern has a maximum strength that is lower than the maximum possible gain, since that gain value is for another elevation angle.

For reference, I shall also record the modeled feedpoint impedance as a series resistance and reactance--rounding just a bit. This impedance will be at the antenna feedpoint. However, you will undoubtedly use a parallel transmission line--probably with an impedance between 300 and 600 Ohms--to connect your antenna to an antenna tuner in the shack. Since the transmission line impedance will rarely--if ever--match the antenna feedpoint impedance, the line will become an impedance transformer. The impedance that appears at the antenna tuner terminals will be a function of the antenna impedance, the line impedance, and the length of the line. Since I cannot cover every possible type of line and every possible line length, the antenna feedpoint impedances will have to do for our information collection.



For each antenna, we shall create two graphical documents. The first is a table of information gathered from the antenna model. The second is a page of elevation and azimuth patterns. My reason for creating both the tables and the patterns as graphics is simple. You may be keeping a notebook of what you learn about antennas. You can copy and save the graphics from these HTML notes as separate files. Then, you can import them into a word processing program, such as Word. The program's importation feature should size the galleries of patterns to fit the margins of your paper. Printing the gallery and its associated tables of data will let you store the information nearly in your notebook. That way, you can omit the commentary that I weave around the tables and the patterns.

### **The 135' Center-Fed Doublet**

Although our main topic is the inverted-V, we need a point of reference in order to make sense of the data that we gather. The doublet is the root antenna, of which the inverted-V is one variation. Therefore, reviewing what happens to the patterns of a center-fed doublet is critical to our overall understanding. The doublet that we shall use is 135' long, just long enough to be a resonant dipole at 3.5 MHz, at least when we place the antenna 60' above ground and build it from AWG #12 copper wire. 60' is not very high if we measure the distance as a fraction of a wavelength. In fact, the height is less than 1/4-wavelength at the root frequency. If we lower the height of the antenna, then the 80-meter TO angle will be higher, whereas if we raise the antenna, the TO angle will be lower. To really obtain good DX results from a horizontal dipole or doublet, we should increase its height to 3/8-wavelength--and much more if possible. But 3/8-wavelength on 80 meters is close to 100', and so we may have to settle for mostly regional contacts on that band. Of course, as we raise the operating frequency, the antenna height increase as measured in wavelengths. By 40 meters, the antenna is getting close to 1/2-wavelength above ground. For all higher bands, 60' is not a significant problem for a general purpose antenna, even though the old saying that higher is better still applies to this or any other horizontal antenna (but not necessarily to HF vertical antennas).

Let's see what we derive from our 135' doublet on the amateur HF bands. **Table 1** provides the tabular data, while **Fig. 2** presents the gallery of patterns.

Table 1. Modeled Data for an AWG #12 Copper-Wire Level 135' Center-Fed Doublet 60' above Average Ground

Band Meters	Frequency MHz	Max. Gain dBi	Lobe Azimuth Angle degrees	TO Angle degrees	Impedance R+/-jX $\Omega$
80	3.5	6.41	0	83	75 - j0
75	4.0	6.29	0	63	130 + j250
60	5.332	6.65	0	44	500 + j1070
40	7.0	8.41	0	32	5150 + j95
30	10.1	9.01	0	22	86 - j325
20	14.0	8.94	35	16	3580 + j790
17	18.068	9.82	59	12	125 - j5
15	21.0	9.96	47	11	2140 + j1270
12	24.89	9.79	66	9	125 - j195
10	28.0	10.99	54	8	1460 + j1240

Notes: 1. Frequencies are at the low end of each band except for 75 meters. 2. Maximum gain is for the strongest lobe at the TO or elevation angle of maximum strength. 3. Lobe azimuth angle is the bearing of the strongest lobe, where 0° is broadside to the wire and any other angle is a departure from broadside.

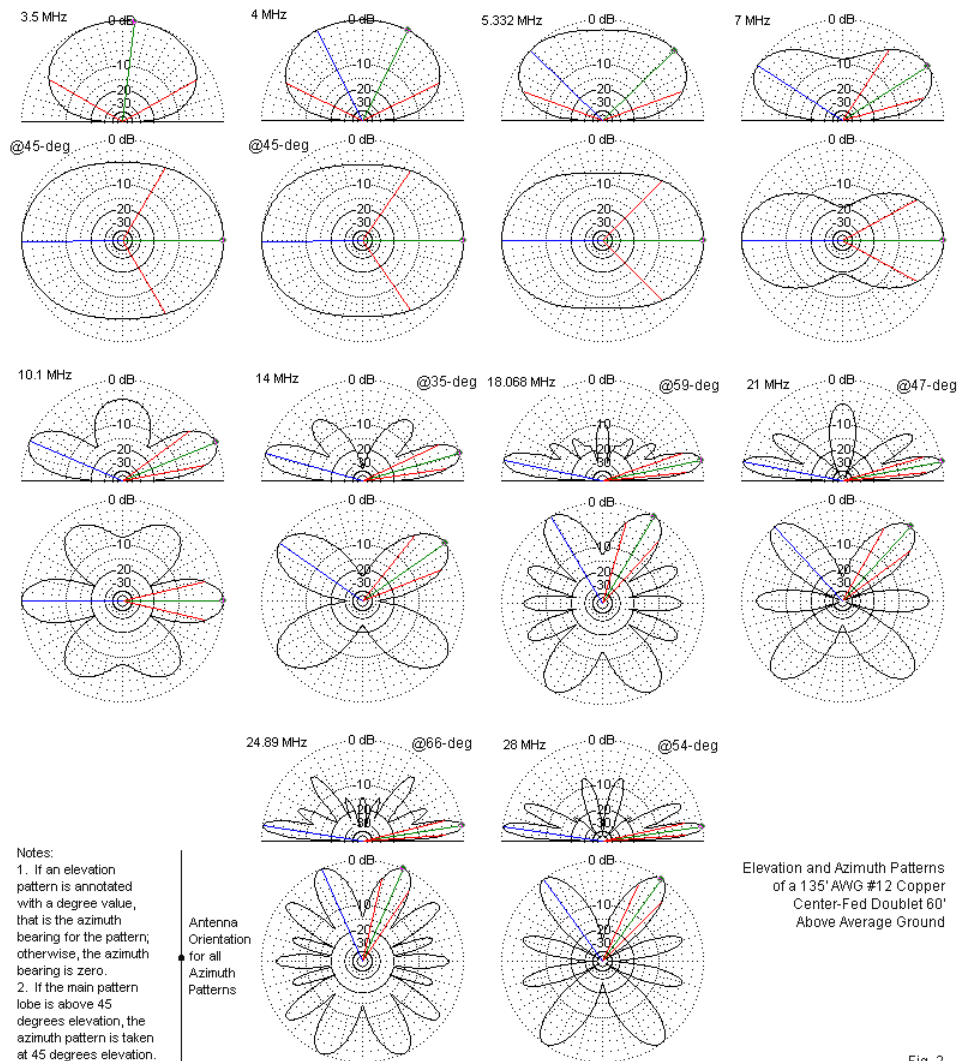


Fig. 2

We can begin with the table and immediately jump to the feedpoint-impedance column. The values seem to be all over the place, with some very high values and some fairly low values of resistance. The reactance also shows very wide swings. To make sense out of the column, we have to think about the antenna length. At 3.5 MHz, the antenna is 1/2-wavelength, and so we expect and receive a lower impedance with almost no reactance. At 7, 14, 21, and 28 MHz, the antenna is close to 1, 2, 3, and 4 wavelengths, respectively. At these lengths, we expect very high impedances--and get them. At 10.1, 18.068, and 24.89 MHz, the antenna is 3, 5, and 7 half-wavelengths, respectively--or thereabouts. Since these bands do not have a direct harmonic relationship to 3.5 MHz, we cannot expect precision. But we can expect and obtain fairly low impedance values with relatively modest reactance values. So the impedance values in the table do make sense after all.

Note in both the table and the gallery that on 80 and 75 meters, the TO angle is higher than 45 degrees, and that requires azimuth patterns at 45 degrees. There is nothing magical in my selection of 45 degrees. It is too high for good DX work and too low for most NVIS work. Its one claim to fame is that it gives us a reasonably good picture of the azimuth pattern shape at that angle and below. Hence, we can clearly see the gradual narrowing of the beamwidth up through 40 meters, although the azimuth pattern remains broadside to the wire.

From 30 meters through 10 meters, we find that the pattern is breaking into many lobes. For a center-fed doublet, let's measure the antenna length in wavelengths. For lengths that are near an integral multiple of a wavelength (that is, 1-wavelength, 2-wavelengths, etc.), the number of lobes will be twice the antenna length in wavelengths. Hence, at 20 meters, the antenna is 2 wavelengths and we find 4 lobes. The situation changes for lengths that are odd multiples of 1/2-wavelength (that is, 3/2 wavelengths, 5/2 wavelengths, etc.). Now the number of lobes will be twice the number of half-wavelengths. So at 24.89 MHz, we have close to 7 half-wavelengths, and we find 14 lobes. Since lobes do not simply pop into and out of existence, we find on odd frequencies a mixture of lobes emerging or decaying. Note that when the antenna length is closer to an odd multiple of 1/2-wavelength, we not only see more lobes, but the strongest lobe is further

away from a direction that is broadside to the wire and closer to the axis of the wire. Hence, the tabular data shows an up-and-down swing to the azimuth angle of the strongest lobe as we check out the bands from 20 through 10 meters.

The elevation angle of maximum radiation or TO angle of a doublet is almost wholly a function of the height of the antenna above ground. An antenna that is about 1/2 wavelength up will show a TO angle of about 25-26 degrees. When 1 wavelength up, the angle drops to about 14 degrees. If we physically raise or lower the entire antenna, we can change the elevation angle, but the lobe structure of the azimuth patterns will remain intact.

You can use the table and the gallery when planning an all-band doublet installation, assuming that you have some room to maneuver. Pick your favorite bands and see where the lobes go. Then align the antenna wire so that the lobes are in the direction of your choice communications targets. It is likely that you will have to compromise--not only in terms of lobe direction, but also in terms of the limitations of your yard. However, be careful of making too strict of a compromise, or your lobes may miss all of your targets.

If you shorten the antenna--perhaps making it resonant at 4 MHz instead of 3.5 MHz--then you will have to create your own gallery of patterns. You will not find much trouble on most bands, but the highest 2 or 3 bands may be a good bit away from the antenna lengths that produced these patterns. Hence, the exact directions of the lobes may differ enough to make a difference. I recommend that you obtain a rudimentary antenna modeling package and master it enough to plan an effective all-band doublet.

### **A 30-Degree 135.6' Inverted-V**

The level doublet provides a touchstone for the results that we receive from any inverted-V antenna. We shall first look at a modest inverted-V, one with legs that slope downward 30 degrees from the horizontal. With a 60' feedpoint, the ends are about 26' above ground. 30-degree slopes on each side of the feedpoint

mean that the angle between wires is 120 degrees (instead of the 180-degree value that applies to the level doublet). This version of the inverted-V is perhaps typical of amateur installations, although the exact top height may change from one location to another.

Without further ado, let's see what kind of performance we can expect from the 30-degree inverted-V. **Table 2** provides the tabular data, and **Fig. 3** gives us a gallery of patterns.

Table 2. Modeled Data for an AWG #12 Copper-Wire 135' Center-Fed  
30° Inverted-V with a Feedpoint 60' above Average Ground

Band Meters	Frequency MHz	Max. Gain dBi	Lobe Azimuth Angle degrees	TO Angle degrees	Impedance R+/-jX $\Omega$
80	3.5	5.40	0	88	60 - j0
75	4.0	5.46	0	85	105 + j255
60	5.332	5.42	0	57	460 + j1145
40	7.0	6.01	0	45	4805 - j580
30	10.1	7.31	0	50	125 - j580
20	14.0	6.45	39	20	3270 + j1495
17	18.068	5.17	62	13	130 - j25
15	21.0	7.43	53	13	1940 + j1955
12	24.89	5.98	71	9	160 - j165
10	28.0	7.11	61	10	1160 + j1550

Notes: 1. Frequencies are at the low end of each band except for 75 meters.  
2. Maximum gain is for the strongest lobe at the TO or elevation angle of maximum strength. 3. Lobe azimuth angle is the bearing of the strongest lobe, where 0° is broadside to the wire and any other angle is a departure from broadside.

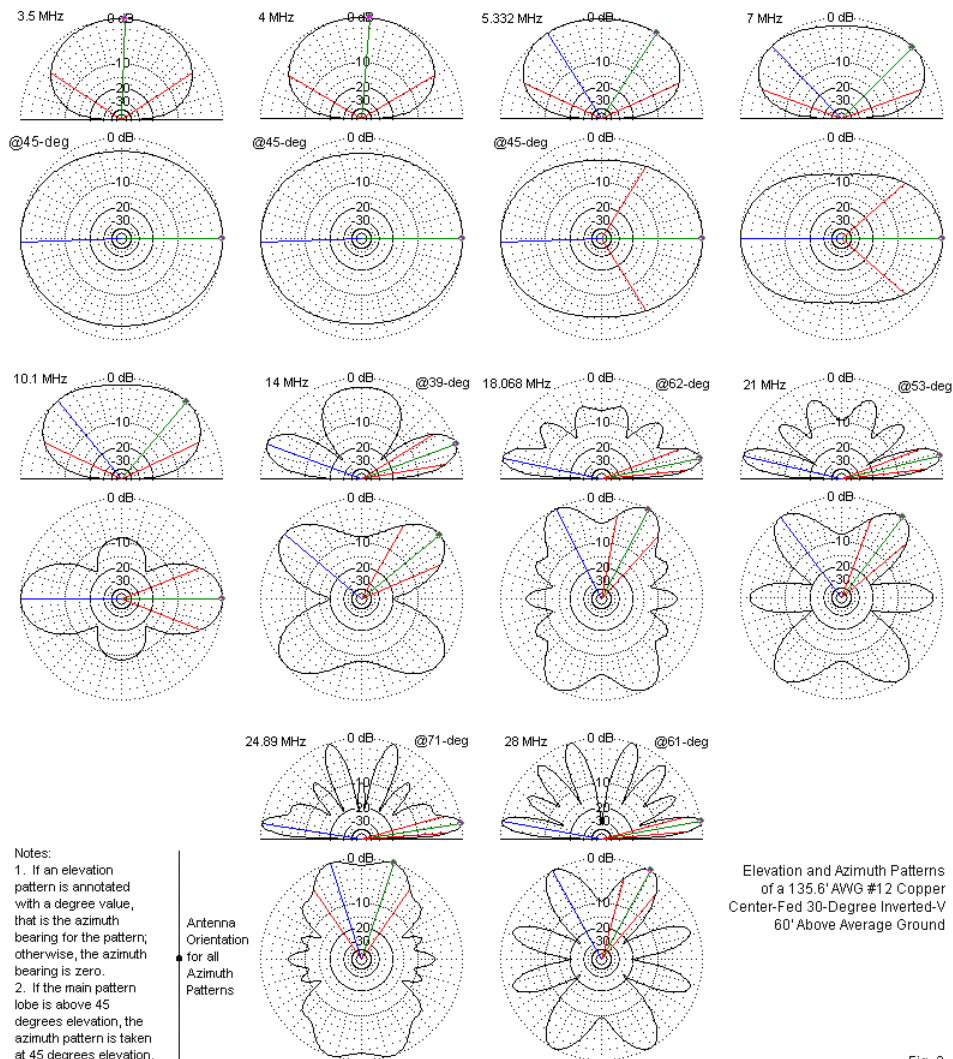


Fig. 3

We shall not find very significant changes in the impedance column. Since the antenna is resonant at 3.5 MHz, its electrical length is similar to the length of the doublet on every band. The sloping wires do interact a bit, and the wire ends are closer to the ground. But the changes to the feedpoint impedance are moderate to modest.

If we look at the column of TO angles, we find that they are typically higher than the TO angles for the doublet. In fact, the azimuth patterns for 80 through 30 meters require a default 45-degree elevation angle for the azimuth patterns due to the higher TO angles. (The doublet required this treatment only on 80 and 75 meters.) Even though the inverted-V has the same feedpoint height, it is lower at every other point along the wire. In general, the effective height of an inverted-V is about 2/3 of the way upward between the lowest point and the highest point along the wire. Hence, our inverted-V is effectively lower than the doublet at every operating frequency.

We can easily compare the two tables and see that the inverted-V yields a lower value for maximum gain than the doublet. The lower effective height is partially responsible. In addition, there is some radiation off the ends of the wires, since they now slope and have a vertical as well as a horizontal component. That energy has to come from somewhere, and a good part of it comes from a reduction of the gain of the main lobe or lobes. Nevertheless, the amount of reduction is not enough to disqualify the 30-degree inverted-V as a good general-purpose all-band HF antenna.

We should also compare with some care the gallery of patterns for both the doublet and the 30-degree inverted-V. From 80 through 40 meters, we notice seemingly small changes. For example, the inverted-V 40-meter pattern is an oval that has lost the "peanut" waist of the doublet. However, from 30 meters upward, the pattern changes are much more pronounced. For example, the doublet on 30 meters had 6 lobes, but we can only identify 4 in the inverted-V pattern for the same band. As we continue to increase the operating frequency, the sharply defined doublet azimuth lobes give way to less defined undulations,



especially on 17 and 12 meters, two bands in which the patterns have many lobes.

Do not forget to review the two galleries with respect to the elevation patterns. On the highest bands, note the growth of the high-angle lobes relative to the much more modest development of the same lobes with the level doublet. Energy that goes almost straight upward is not available at the lower angles more favorable to making contacts. As a result, the maximum gain values of the inverted-V shows a greater high-band deficit relative to the doublet than the gain values for the lower bands. What is more important, perhaps, is that these high-angle lobes foreshadow what is to come with our next inverted-V.

### **A 45-Degree 136.6' Inverted-V**

If we add only 15 degrees to the slope of each inverted-V leg, can anything harmful happen? The legs now slope downward by 45 degrees relative to the horizontal. The angle between the legs is 90 degrees. Since the antenna will fit inside my 100' lot, it is a tempting construction project.

To find the answer to our question, we need only examine the information. The changes in patterns and performance that we saw between the doublet and the 30-degree inverted-V suggest that we might see some further evolution in key properties. However, I wonder if we are prepared for some surprises. **Table 3** supplies the tabular data, while **Fig. 4** gives us the associated pattern gallery.

Table 3. Modeled Data for an AWG #12 Copper-Wire 135' Center-Fed  
45° Inverted-V with a Feedpoint 60' above Average Ground

Band Meters	Frequency MHz	Max. Gain dBi	Lobe Azimuth Angle degrees	TO Angle degrees	Impedance R+/-jX $\Omega$
80	3.5	4.08	0	87	50 - j0
75	4.0	4.19	0	86	85 + j260
60	5.332	3.99	0	66	410 + j1230
40	7.0	3.76	0	53	4480 - j1950
30	10.1	5.84	0	86	150 - j285
20	14.0	8.19	0	75	4400 + j815
17	18.068	8.29	0	90	180 + j45
15	21.0	9.32	0	84	2295 + j1760
12	24.89	8.38	0	90	175 - j95
10	28.0	8.66	0	90	1340 + j1550

Notes: 1. Frequencies are at the low end of each band except for 75 meters.  
2. Maximum gain is for the strongest lobe at the TO or elevation angle of maximum strength. 3. Lobe azimuth angle is the bearing of the strongest lobe, where 0° is broadside to the wire and any other angle is a departure from broadside.

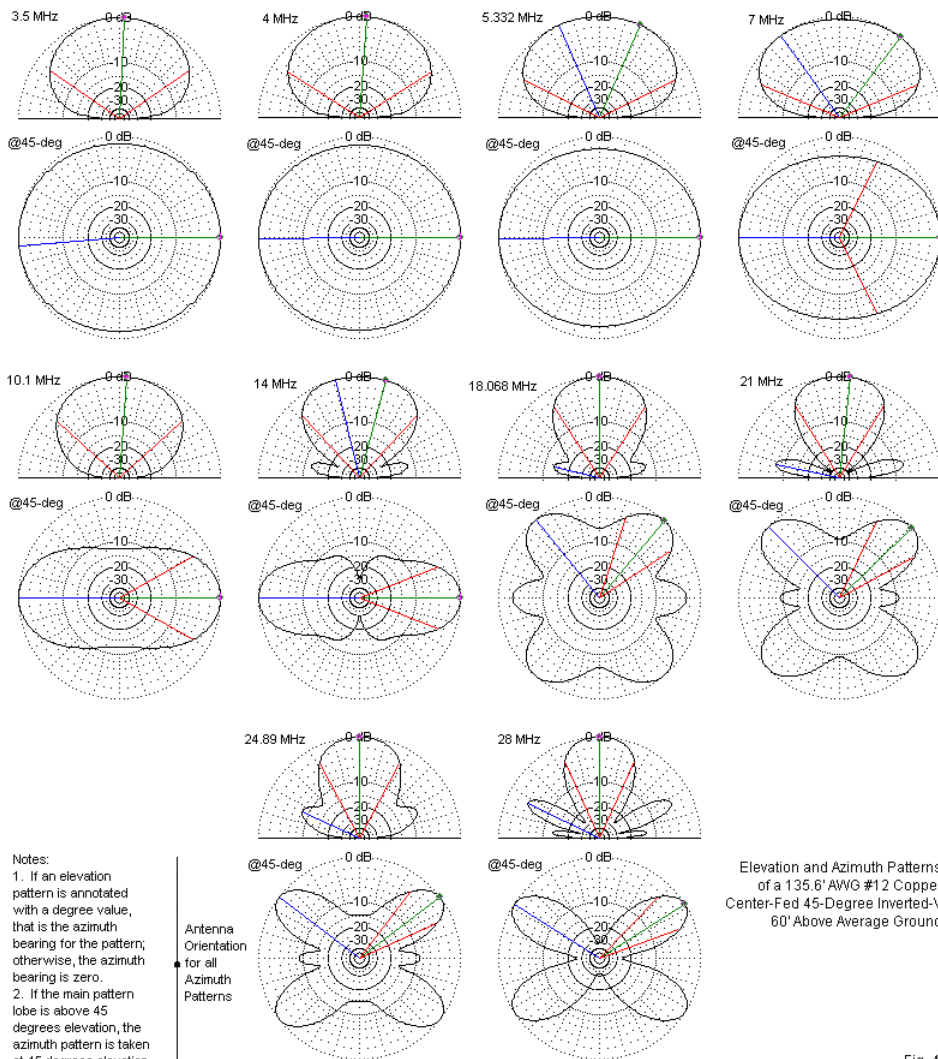


Fig. 4

Once more, the impedance column in the table gives us no clues to revolutionary changes, since the values show only a small evolution in the progressions of values that began with the doublet. As well, the gain column seems a bit odd, with lower values for the lower bands and higher values for the higher bands. The most meaningful changes occur in the two columns that list the azimuth angle of the strongest lobe and the TO angle. All TO angles are very high, indicating that on all bands, the predominant energy focus is straight upward or nearly so. The gain values shown are all for frying clouds and little else.

As a result of the very high TO angles, all azimuth patterns are at 45 degrees elevation. The azimuth patterns show some lobe development at this angle. However, the maximum number of lobes is 6. Up to 14 MHz, we find only 2 lobes. At 28 MHz, the old lobes that are broadside to the wire have finally disappeared, leaving only the 4 lobes that emerged around 18 MHz. In effect, the 45-degree inverted-V shows only half the number of lobes that we find in a doublet of the same overall wire length. Moreover, these lower-angle lobes are considerably weaker than the very-high-angle main lobe. As the elevation patterns suggest, the 45-degree inverted-V provides relatively weak radiation at angles suitable for long-distance communications.

Although the 45-degree inverted-V might be useful for NVIS or regional communications through about 30 meters, it is not a desirable antenna for use above that band. In effect, the added 15 degrees of slope to each leg transformed the performance of the inverted-V. Given the normal desire for lower-angle radiation, the transformation has indeed been harmful. There is a limit to the slope of an inverted-V if we intend to use it for an all-band HF antenna. That limit is not much beyond a 30-degree slope.

## **Conclusion**

By reviewing the properties of a 135' level doublet on all HF bands, we have been able to watch the evolution of inverted-V patterns as we increased the wire slope from 30 degrees to 45 degrees. While the 30-degree inverted-V gave

useful general purpose performance, the 45-degree version of the antenna became generally useless on most bands for normal HF skip communications.

Had we begun with a set of antennas with a resonant 40-meter length, the results would not have ultimately changed. However, the complete degradation of patterns would not have occurred until about 20 MHz with a 45-degree inverted-V. If we had started with an antenna whose length was suitable for 160 meters, the patterns would have gone to pot at around 5 MHz. Indeed, the 45-degree inverted-V yields such poor performance that one might well do better by eliminating one leg and feeding the remaining leg at its center as a sloping doublet. Alternatively, an inverted-L--either base or center fed--might also yield better performance. The lesson is simple: if you must use an inverted-V as an all-band HF antenna, do not make the V too sharp.

## Chapter 19: The Turnstile - an Omni-Directional Antenna

I have received a number of inquiries over the last year or so concerning the best way to get omni-directional radiation from a horizontally polarized antenna on the HF bands. We have often tried to use the inverted Vee, but that antenna only turns the dipoles peanut-shaped pattern into an oval. The radiation off the ends of the wire is usually down by 8 to 12 dB--depending on the slope of the Vee legs--relative to the maximum gain broadside to the wire.

If you are truly serious about having an omni-directional horizontally polarized pattern, try the turnstile antenna. The turnstile was often used on VHF, especially in the days before repeaters, that is, when horizontal polarization was still standard. The antenna has dropped out of sight, but may have a new home on the HF bands for those who must use a fixed antenna but who also wish to have roughly equal radiation in all directions. The basic outlines are shown in **Fig. 1**.

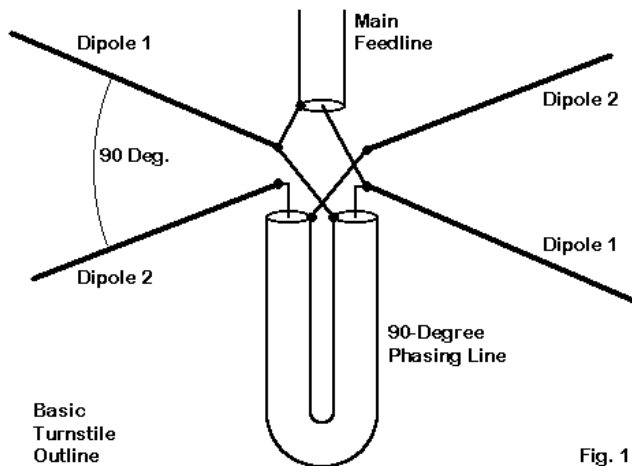


Fig. 1

The turnstile consists of two resonant dipoles at right angles to each other and crossing in the center. The two antennas do not touch. The main feedline (the usual 50-Ohm coax, with a 1:1 balun) goes to one dipole's feedpoint connections. A 90-degree phasing line of 72-Ohm coax goes from the main feedline connections to the other dipole feedpoint connections. The 90-degree phasing of the two dipoles is crucial in obtaining an omni-directional pattern.

The phasing line length will depend on the velocity factor of the line you use. 72-Ohm coax comes with either solid or foam insulation. The solid insulation usually gives the line a 0.66 velocity factor, while foam lines have a velocity factor of about 0.78.

Use the velocity factor as a multiplier on the basic 1/4 wavelength calculated from the frequency and wavelength of use in order to determine the physical length of the line. Let's use 10-meters as an example. 1/4 wavelength is about 8.63' at 28.5 MHz. A 0.66 VF line will be about 5.69' long, while a 0.78 VF line will be about 6.73' long. As with any antenna, be sure to weatherproof all connections to prevent rain from entering the coax line. Technically, coax is not necessary, but 72-Ohm parallel line is almost impossible to obtain in the U.S. Although the example is for 10 meters, the turnstile concept is relevant to any frequency whatsoever, from LF to UHF.

To build a turnstile, first build a single dipole and trim it to resonance. Then construct the second dipole to exactly the same dimensions. The construction details will depend on the band and materials. Add the phasing line, calculated for the band in use. Finally add the main feedline.

Let the phasing line hang down from the dipole junction. You can tape the "down" and "up" halves of the line together to control erratic swaying in the wind. However, it is best to space the line a bit from any metal mast you might use to support the antenna center.

Now the big question: what do we get for our efforts? The turnstile azimuth pattern for nearly any antenna height appears in **Fig. 2**.

Basic Azimuth Pattern  
Turnstile Antenna

EZNEC/4

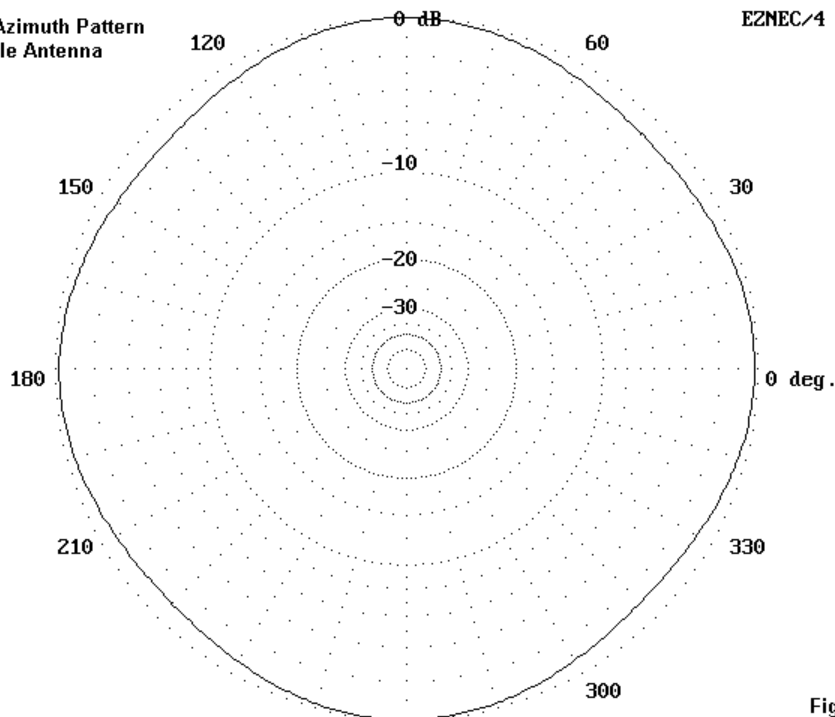


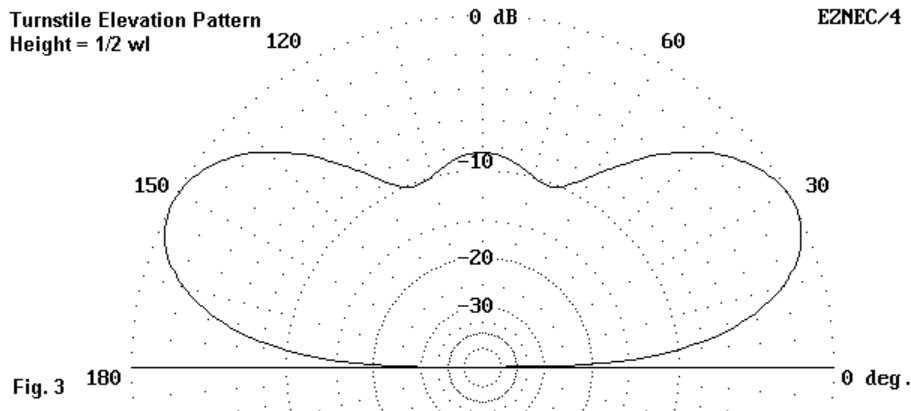
Fig. 2

The pattern is nearly circular. The maximum flattening along the sides is 2 dB or under for most common heights. The following table will give you some idea of the gain of the lowest lobe and the degree of "flattening" of the circle for various heights above ground in terms of wavelengths.



Height wl	Max. Gain dBi	TO Angle degrees	Flattening dB	Feedpoint Z Ohms
0.25	3.9	45 (arbitrary)	0	35.7
0.50	5.2	28	2.5	37.0
0.75	4.5*	18	1.5	36.0
1.00	4.7*	14	2.0	36.0
1.25	5.6*	11	1.5	36.1
1.50	5.2*	9	1.5	36.0

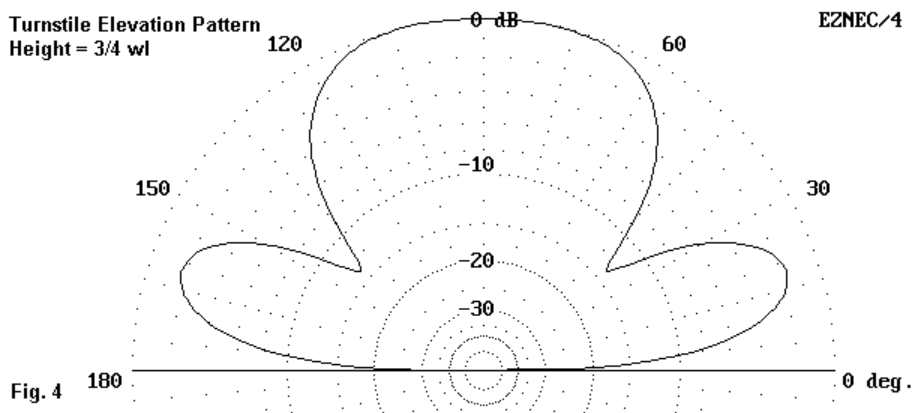
For lower HF use, a wire turnstile will rarely reach above a 1/2 wavelength in height. Since there is only a single elevation lobe at this height, the antenna might be viewed as operating under the most optimal conditions. See **Fig. 3**.



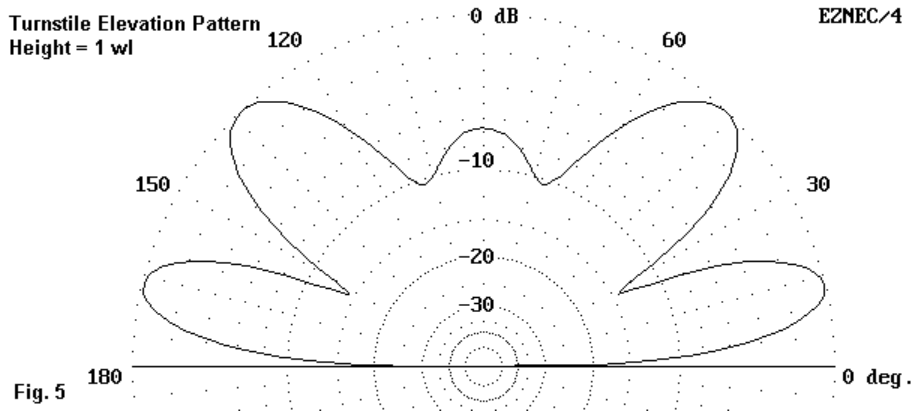
Despite having a single elevation lobe, the maximum gain will still be about 2 dB lower than the maximum gain of a single dipole. However, the single dipole has only 2 lobes, whereas the turnstile has 4 overlapping lobes that form its omnidirectional pattern. To fill the dipole "gaps," power has to come from somewhere, and it is from the maximum lobes of each dipole. Hence, slightly less gain for the turnstile, but gain in every direction around the compass.

The starred (\*) gain entries list the gain at the lowest elevation lobe. However, these lobes are not the strongest in the antenna pattern. It has long been known that between  $3/4$  and  $7/8$  wavelength of height, a dipole actually exhibits a reduction in gain from its lowest lobe. This phenomenon is due to the formation of a new second lobe at very high radiation angles.

The turnstile shows the same phenomenon, but somewhat more extremely. The situation is shown in **Fig. 4**, the elevation pattern for a turnstile at a height of  $3/4$  wavelengths.



The strongest lobe is straight up. However, the lower lobes are still usable, being only 1.25 dB weaker than the upper lobe.



As the antenna is raised further to about 1 wavelength in height, the upper lobes decrease their angle and equalize with the lower lobes. See **Fig. 5**. The 1 wavelength height might be considered a dual-purpose antenna, with lower lobes for DX and higher lobes for short skip.

As you raise the antenna further--to the 1.25 to 1.5 wavelength region--a new third lobe makes its appearance. Again, the new lobe is initially straight up. A simple dipole at this height would show its major strength in its lowest lobe. However, the dual dipole arrangement of the turnstile places maximum gain in the new lobe, although the difference in strength among lobes is much less than at the 3/4-wavelength height.

The lobe formation characteristics of the turnstile are simply one of its limitations. For lower HF use, most wire dipole arrays will be 1/2 wavelength or lower, a fact that eliminates the limitation. Heights up to about 5/8 wavelength tend to be ideal. For upper HF use, a height of just about 1 wavelength may be best: that height will equalize the lobes and provide dual skip performance.

The turnstile has other limitations as well. It is essentially a monoband antenna, since the phasing line is specific to a narrow frequency range. Operating the

antenna on other bands is possible with a parallel feedline and an antenna tuner. However, with the phasing line in place, the patterns will be erratic.

One possible solution to this problem is to install a relay switching system at the feedpoint for bands other than the fundamental frequency to which the dipoles are cut. One can remove the phasing line and use either dipole to provide fairly standard patterns on frequencies higher than the fundamental. One more switch position for the relay system might permit switching from one wire to the other to obtain the strongest signal.

In fact, this system might also be useful at the fundamental frequency. Having omni-directional reception would allow you to hear signals that would disappear in the end-nulls of a single dipole. Then, switching whichever dipole provides the strongest signal might improve contact ease by up to about 2 dB (or nearly half an S-unit as meters are usually calibrated).

Construction of the turnstile will be largely a matter of the materials used. Wire construction will require special attention to the weight of two coax lines at the junction. For this kind of application, copperweld strength is recommended. For upper HF use, aluminum tubing becomes a possibility, and this type of construction usually involves a central mast. To mount the antenna elements, you can use a plywood or Lexan plate--or even crossed 2x2s (weather sealed, of course). Dipoles can be mounted on opposite sides of the plate or cross--or they can go on one side if the feedpoint ends are separated to prevent contact.

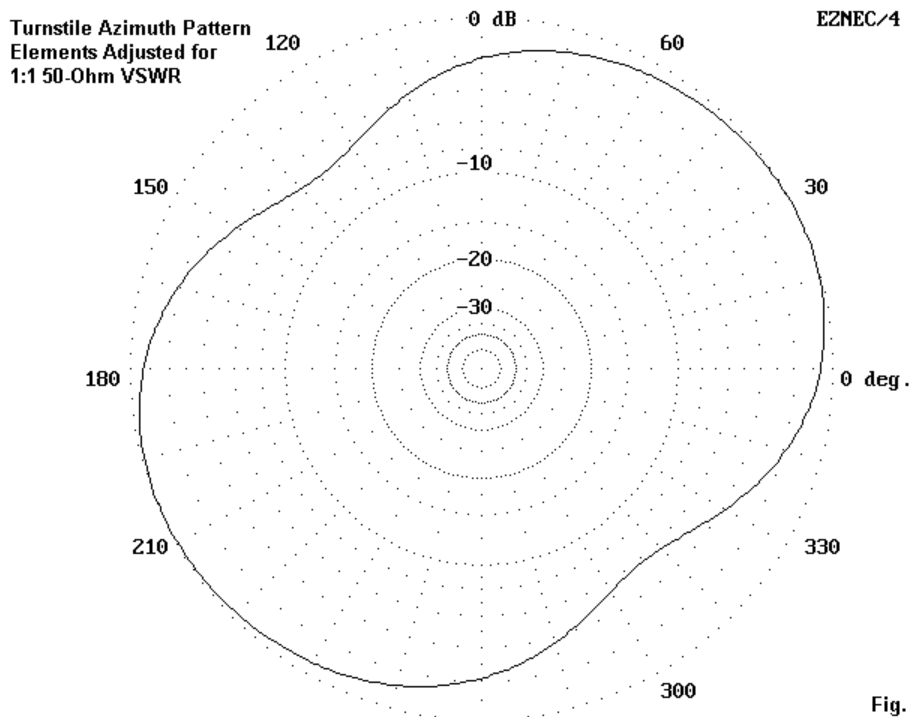
Adding a relay box requires attention both to securing it well and to weatherproofing the box. Of course, a set of control lines to activate the relays will be needed as an added cable weight to the pair of coax lines already noted.

Tuning up the turnstile system requires some care. Begin by adjusting a single dipole for resonance and then add a second dipole of identical construction. There is an important reason for this procedure, based on the properties of the two dipoles when phased by 90 degrees.

The feedpoint impedance of properly adjusted turnstile dipole pairs is just about 36 Ohms. This value yields an SWR between 1.3:1 and 1.4:1 at the feedpoint. Normally, we try to reduce the SWR to the lowest possible value. Do NOT use this procedure with the turnstile.

The turnstile exhibits a very broad stable feedpoint impedance. When properly adjusted, the antenna will easily cover any of the ham bands, including all of 10 meters. So SWR is only an indicator that you have made all of your connections properly.

What becomes unstable as the antenna is operated at frequencies up to 3% or 4% away from the design frequency is the omni-directional pattern. It is possible to lower the operating frequency until you obtain the lowest 50-Ohm SWR. Equivalent to this move is shortening the dipole elements until you get the same result. Unfortunately, in the process, you will have lost the omni-directional pattern--as well as the ability to operate each dipole independently at a low SWR.



**Fig. 6** shows the azimuth pattern of a turnstile adjusted for the lowest possible 50-Ohm SWR. The side nulls are now deeper than 6 dB, partially cancelling the advantage for which we wanted to use a turnstile. (If one reverses the connections at one end of the phasing line, then the pattern will tilt in the other direction.) Unfortunately, this condition yields no significant added gain to the main lobes, so it is not a substitute for the suggested switching system for using the dipoles independently after locating a desired signal.

The best procedure for constructing the turnstile is the one recommended, starting with a single dipole. When both are in place, carefully cut the phasing

line, and then add the main feedline--plus any desired switching system. This procedure will prevent inadvertent loss of the antenna's omni-directional properties.

There are other temptations to avoid. One prominent one is to bend the outer ends of the dipoles to form an incomplete square along the perimeter--in an effort to save space. Moves like this will also ruin the omni-directional pattern, since the radiation from the bent wire ends will partially cancel the necessary radiation balance. Once more, the pattern will degrade into something like the one in **Fig. 6**. If a bi-directional pattern is what you need, a single simple dipole will do the job better.

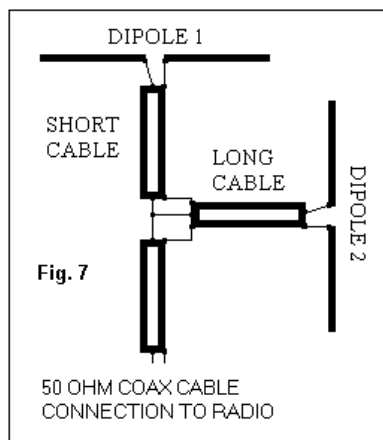
Likewise, avoid making the turnstile into an inverted Vee. At downward angles between 30 and 45 degrees, you would need to use a 50-Ohm phasing line, and the feedpoint impedance will drop into the 20-25-Ohm range. As well, the gain from the antenna will decrease. If some shortening of the elements is necessary to fit a given space, the best procedure appears to be to equally fold down the ends of each dipole.

The turnstile is not a magic answer to every horizontally polarized antenna need. Instead, it is one answer to a special need for omni-directional patterns for either transmitting or receiving in a specific frequency band. Among all of the schemes designed to achieve omni-directional radiation with maximum efficiency, the turnstile has one of the very best patterns, along with the simplest construction. Perhaps we have consigned it to the annals of VHF history too long and have forgotten that it is a design that is equally adept at fulfilling HF needs as well.

## **Improving the Match**

Since the appearance of the turnstile note, I have received suggestions for improving the match of the antenna from the present 36-Ohm value encountered by the 50-Ohm coax line. One system came from Leland Scott, KC8LDO, in the

form of a useful MathCAD worksheet. See **Fig. 7** for the outlines of the basic scheme.



The "short cable" will be  $1/8$   $wl$  long for a pair of resonant dipoles. The "long cable" will be  $3/8$   $wl$  long. (If the antenna feedpoints presents some reactance, the requisite lengths will be offset from the  $1/8$  and  $3/8$   $wl$  figures used for resonant individual dipoles.) Both are RG-62, a 93-Ohm cable with a velocity factor of 0.86. The differential in cable length maintains the  $1/4$   $wl$  phasing between dipoles. In addition, it provides a pair of impedances at the junction between the two cables and the main line of about 100 Ohms. The  $1/4$   $wl$  differential in length yields conjugate reactances which cancel when connected in parallel. The resulting impedance presented by the parallel cables is exceptionally close to 50 Ohms resistive. The short cable is 3.71' and the long cable is 11.13' for a 28.5 MHz design frequency. Models of the antenna using this system show a maximum SWR of about 1.16:1 over the span from 28 to 29 MHz. Relative to the version using a single 72-Ohm phasing line, the only drawback to the system that the models suggest is a slightly higher non-circularity to the patterns. The maximum to minimum gain span averages about



3.34 dB, compared to 2.12 dB for the 72-Ohm phase-line model. It is unlikely that the degree of increased non-symmetry would be operationally noticeable.

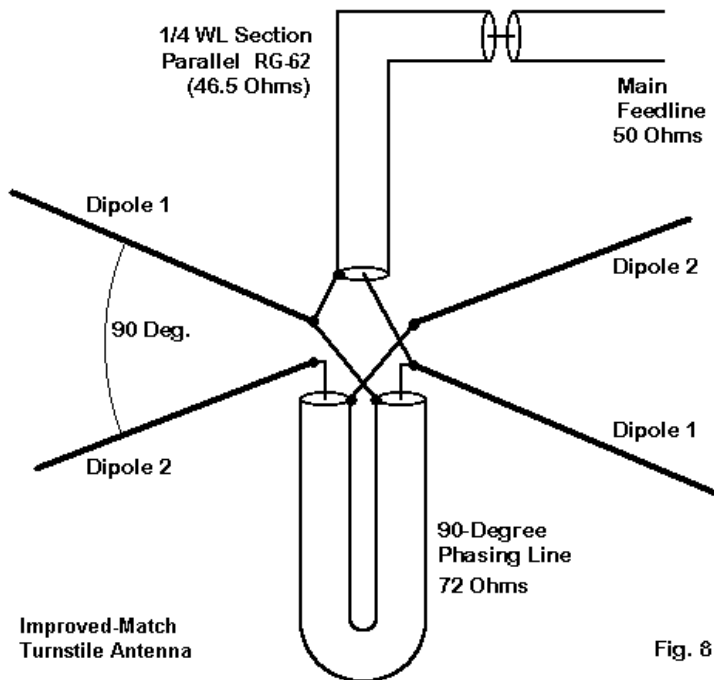


Fig. 8

It is also possible to improve the match of the original model without disturbing the phasing or the pattern by using a 1/4 wl section composed of paralleled pieces of RG-62, as shown in **Fig. 8**. The 7.42' section of parallel RG-62 has an impedance of about 46.5 Ohms. The impedances presented to the main 50-Ohm feedline range between 56.5 and 60 Ohms, with virtually no reactance, for a maximum SWR of 1.2:1 in the 28 to 29 MHz range.

Further possibilities exist for improving the match of a turnstile to a 50-Ohm cable without upsetting the near-circularity of the pattern, for example, the series matching techniques described by Regier and outlined in another note in this collection. Whatever scheme is used, it is first crucial to establish correct phasing for the most circular pattern possible and then to become concerned with matching the unit to a given main feedline characteristic impedance. For non-symmetrical patterns, there are likely better antenna choices available.

## Chapter 20: 1/2-Length 40M-Dipoles - Full Length Standard

**B**elow 20 meters, full-length dipoles (and other antennas based on the dipole) present space problems. For many amateurs, such antennas are simply too long to fit within the modern urban and suburban yards. So the antenna builder begins to think of ways to shorten the dipole. The questions surrounding shortened antennas are complex. Some involve performance levels compared to the full-length dipole. Others concern the relative efficiency of antennas that use different means of shortening. Another group of questions focus on the mechanical issues created by various methods of shortening. Moreover, there are auxiliary matters, such as matching the shortened antenna to one of the standard feedlines in common use.

To explore these questions in a somewhat systematic manner, we shall pick a single antenna length on a single amateur band. 40 meters (7.0 to 7.3 MHz in the U.S.) is handy, since the average dipole length is in the vicinity of 67', just on the verge of fitting or not fitting a typical back yard. Let's use a half-length dipole and set its length at a fixed value of about 33' for our explorations. Our antennas will use AWG #12 (0.0808" diameter) copper wire, although we shall occasionally look at fatter elements for special purposes. With these simple premises, we can examine a myriad of ways of shortening dipoles, including but not limited to, folding back the elements, using inductive loads at the dipole center or along the element length, using end "hat" loads or element extensions, and employing U shapes. Each alternative method of shortening the length of a dipole has its own cluster of variations, its own set of issues, and its own set of consequences.

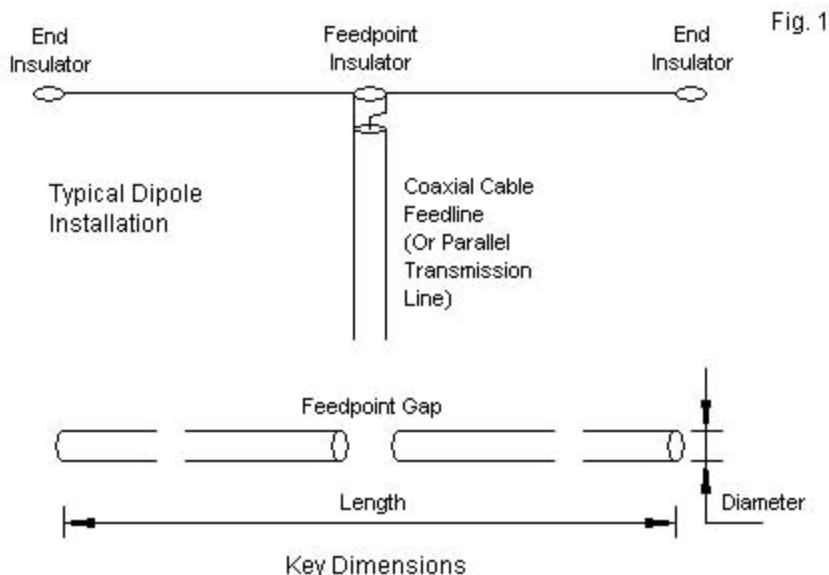
Ultimately, we shall want to be able to make a set of comparative evaluations of the different methods of shorten a dipole to about half-length. To make sense of the comparisons, we shall need a standard against which to measure the changes that we encounter. The logical standard for assessing a half-length dipole is a full-length dipole. This first episode in our journey will deal solely with full-length 40-meter dipoles. The more we understand the practical electrical and physical properties of a full-length dipole, the easier it will become to understand what we gain or lose by shrinking the length by half.

*The Basic Properties of a Full-Length 40-Meter Dipole*

What we loosely label as a dipole is actually a special version of the dipole. A dipole is any antenna that has a current distribution that shows a single peak value at its center. Conversely, there are two voltage peak values, one at either end of the antenna. This condition can exist only for antennas that are electrically  $\frac{1}{2} \lambda$  or shorter. Once the antenna length exceeds  $\frac{1}{2} \lambda$ , we find multiple current peaks along its length.

A second special feature of what we call a dipole is that the feedpoint is at the element center. There are ways of feeding elements of the same length off center or even at the end. But our common notion of a dipole includes the idea that it is center fed. A third feature is that the antenna be resonant, in other words, that the feedpoint impedance at the design frequency be purely resistive. In the models that we shall use, we may define a resonant condition as a feedpoint impedance with less than 1- $\Omega$  of reactance (either inductive or capacitive). We shall use the arithmetic mid-band point of 40 meters (7.15 MHz) as the design frequency throughout.

As a result of these considerations, what we simply call a dipole is actually a center-fed resonant  $\frac{1}{2} \lambda$  dipole. **Fig. 1** shows a typical dipole as installed. In one or another form, we find end insulators to isolate the element from its supporting structure. As well, we find a gap at the element center. We connect the feedline (usually but not necessarily a coaxial cable) in series with the element, with one line conductor going to one side of the element, and, of course, the other feedline conductor going to the other side of the element. A full installation might include other features, such as a lightning protection device or a common-mode current attenuator. However, the sketch includes only the essential electrical elements to set up the dipole.



Basic Practical Properties of a Dipole Antenna

We specify a dipole in terms of its length and the element diameter. To appreciate the importance of how these two facets of a resonant dipole interact, let's set up in a free-space environment resonant dipoles using various diameter elements. **Table 1** shows some typical examples, ranging from relatively thin AWG #14 copper wire to very heavy 2" aluminum tubing. Operationally, any of these dipoles would give equivalent service, but the fine shades of numerical difference among the entries have a story to tell.

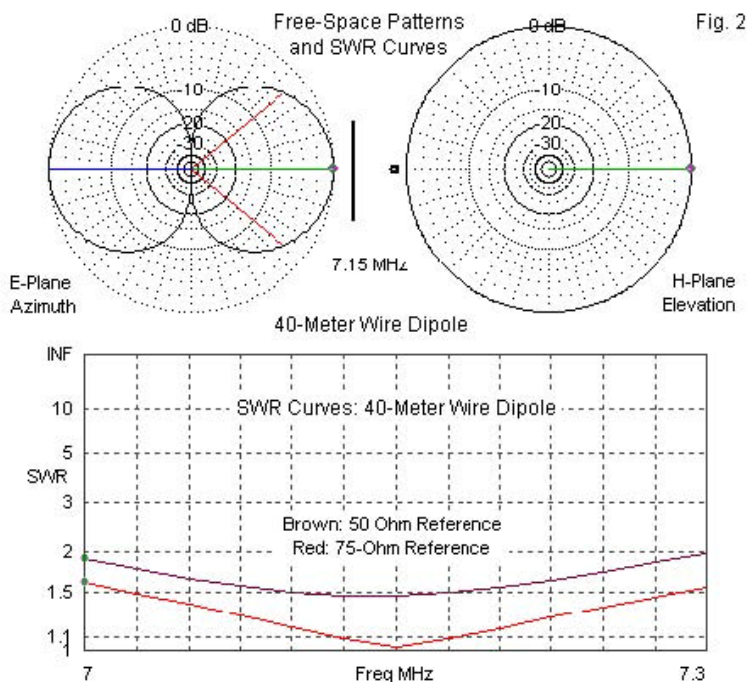
Table 1. The relationship between a resonant dipole's length and diameter in free space

Material	Diameter	Length		Feedpoint Z R +/- jX $\Omega$	Max. Gain dBi
		Feet	Inches		
Copper	#14 (0.0621")	36.92	803.0	73.5 + j0.2	2.05
Copper	#12 (0.0808")	36.87	802.4	73.2 - j0.0	2.07
Aluminum	0.5"	36.33	796.0	72.2 - j0.1	2.12
Aluminum	1.0"	36.00	792.0	72.0 - j0.4	2.13
Aluminum	2.0"	35.60	787.2	72.0 - j0.5	2.13

An electrical half-wavelength at 7.15 MHz is actually 68.78' (825.37"). All of the entries are shorter than this value. Two factors contribute to the shorter lengths required of real dipoles to achieve resonance at the design frequency. The major factor in most cases is the phenomenon called end effect that results from the slight alteration of fields due to the area that forms the wire end. A second factor is the conductivity of the element (or its resistivity). All common metals have a finite conductivity. The lower the conductivity, the shorter becomes the length of a resonant dipole. Copper and aluminum in the common diameters that we use for dipole elements have very high conductivity values and thus contribute little to antenna shortening.

However, the actual conductivity of the element is also a function of the element diameter. Increasing the diameter increases the surface area of the element. Skin effect forces currents to exist near the surface of the antenna at RF frequencies. The higher the frequency, the thinner the region of the element in which we find significant current. Hence, hollow tubing functions just as well as solid wire for the same material and diameter. Copper-bonded wire has a steel core for strength, but the core does not enter into the electrical operation of the wire in antenna applications. The surface layer of copper is thick enough in quality versions of the wire to contain virtually all of the electrical activity.

End effect tends to dominate the factors influencing the resonant length of a 40-meter dipole. Therefore, as we increase the element diameter, we find a decrease in the resonant length. Physically shorter antennas also show lower feedpoint impedance values, and we see this phenomenon at work in the table's entries. Fatter elements have less loss than thinner ones, and so we find that the free-space maximum gain figure increases as we increase the element diameter. However, note that the gain value levels off. Gain also decreases as we shorten a resonant dipole, so we have a balance between the element diameter with lower losses and the element length with its natural variation in gain. The gain numbers in the table are noticeable, but would not result in any detectable difference in operational performance.



**Fig. 2** shows the free-space E-plane and H-plane patterns for the dipole in free space. An E-plane pattern for a linear antenna element is in the plane of the wire, while the H-plane looks at the antenna element from its end. In free space, with no ground reflections, the H-plane pattern is perfectly circular. A  $\frac{1}{2} \lambda$  dipole has almost no far-field radiation off its ends, so we obtain an E-plane pattern with the familiar figure-8 shape. The reduction in radiation off the element ends and the increase in radiation broadside to the wire give the antenna its gain value over an isotropic source of radiation. We measure the gain in dB relative to an isotropic source that radiates equally well on all possible directions, hence, the values in dBi.

The figure also shows the SWR curves for the free-space version of the dipole. The 75- $\Omega$  curve uses a reference value close to the resonant impedance of the antenna, so the minimum SWR value goes down to 1:1. As we add either inductive reactance (above the center frequency) or capacitive reactance (below the center frequency) to the feedpoint impedance, the SWR goes up. The resistive component of the impedance is also changing: it increases as the frequency increases. However, the rate of change of resistance for a common dipole is usually much less than the rate of change of the reactance. So the reactance tends to play a greater role in the dipole's SWR increase away from resonance.

The SWR reference impedance represents the value of the source impedance, in most cases, the characteristic impedance of the feedline that we attach to the antenna feedpoint. Since most amateurs will connect a 50- $\Omega$  coaxial cable to the dipole, the figure also shows the SWR with a 50- $\Omega$  reference. Note that the curve has a minimum value that is greater than 1:1. The curve barely manages to stay within the common amateur limit of 2:1 across the band. However, most amateurs do not measure the SWR at the antenna terminals. Instead, they measure the SWR at the equipment end of a length of feedline. We shall eventually look at that situation.

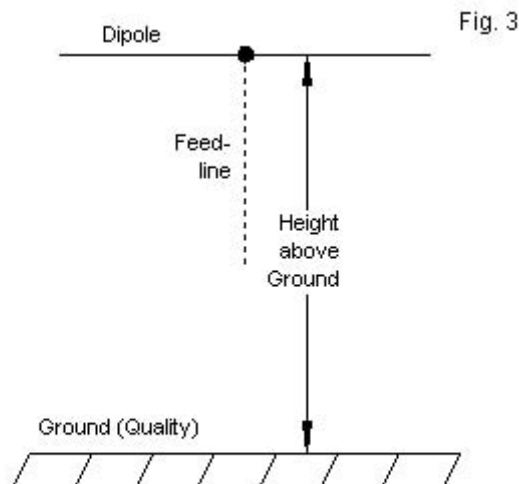
The feedpoint SWR and the resonant condition of the antenna do not affect the element's ability to radiate. The element length—and to some degree, its



diameter—determine the radiation pattern strength and shape. Having a resonant feedpoint impedance and a low SWR are merely conveniences that allow the antenna builder to create a simple but effective basic antenna installation. There are many other types of linear antenna elements, such as the  $1.25 \lambda$  extended double Zepp, that operate efficiently with a feedpoint impedance far from resonance and with a relatively high SWR on a low-loss parallel feedline.

The feedpoint gap shown in the dipole sketch calls for special attention. The gap is part of the overall length of the element. A practical feedpoint insulator might range from  $\frac{1}{2}$ " to perhaps 6" on 40 meters. The actual gap is simply the spacing between the two conductors of the feedline. Whatever the mechanical gap that we create, we run leads from each side to the feedline conductors. These leads are properly part of the antenna element. All antenna specifications include the feedline gap as part of the length figure for the total element.

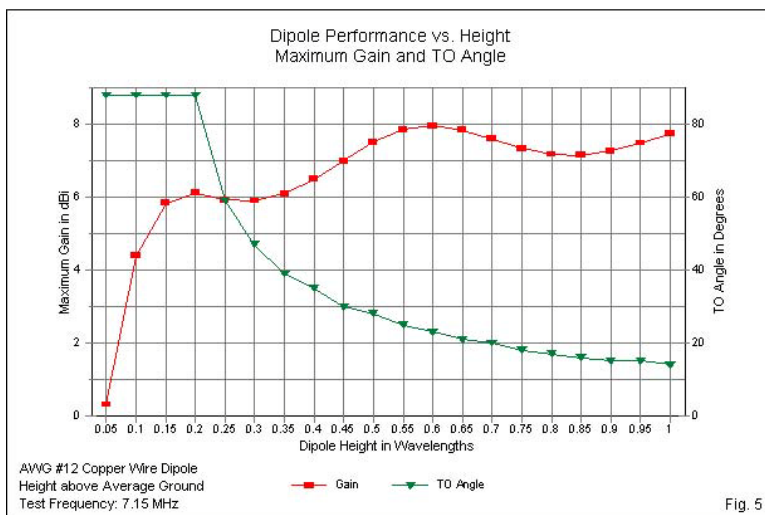
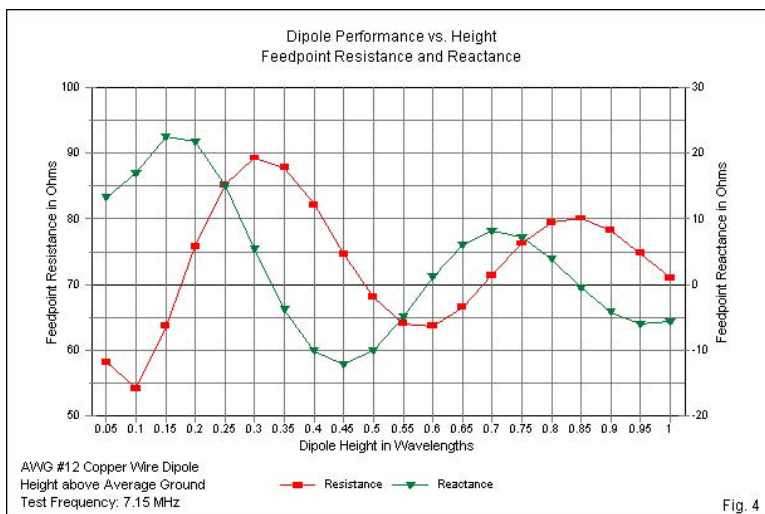
From this point forward in this part, we shall work only with the AWG #12 copper wire version of the dipole. We shall retain its free-space resonant length of 66.87' (802.4"), but we shall next change the environment. We shall place the antenna over ground, more specifically, "average" ground with a conductivity of 0.005 S/m and a permittivity or relative dielectric constant of 13. **Fig. 3** shows the general situation for a dipole above real ground. Note that the sketch shows the antenna height and the ground quality as significant factors, but initially, we shall work only with the middle level of ground quality using the antenna that we set to resonance in free space.



Dipole Height and Ground Quality  
as Performance Variables

The maximum gain and the feedpoint impedance of a dipole systematically change as we change the height of an antenna above ground, measuring the height in terms of a wavelength. **Table 2** shows the changing values for heights of  $0.05 \lambda$  up to  $1.0 \lambda$  on  $0.05 \lambda$  increments. For easier reference, **Fig. 4** graphs the pattern of resistance and reactance values, while **Fig. 5** traces the changes in the dipole's gain and its take-off (TO) angle.

Dipole Performance as a Function of Height above Ground					
AWG #12 Copper Wire			Average Ground		7.15 MHz
Height wl	Height ft	Gain dBi	TO deg	Resist	React
0.05	6.88	0.31	88	58.2	13.2
0.10	13.75	4.40	88	54.1	17.0
0.15	20.61	5.84	88	63.6	22.5
0.20	27.48	6.12	88	75.8	21.7
0.25	34.35	5.92	59	85.2	15.1
0.30	41.22	5.90	47	89.3	5.4
0.35	48.09	6.10	39	87.8	-3.9
0.40	54.95	6.50	35	82.2	-10.2
0.45	61.82	7.00	30	74.7	-12.2
0.50	68.69	7.51	28	68.0	-10.0
0.55	75.56	7.86	25	64.0	-4.9
0.60	82.43	7.97	23	63.6	1.2
0.65	89.30	7.85	21	66.6	6.0
0.70	96.16	7.60	20	71.4	8.2
0.75	103.03	7.34	18	76.3	7.2
0.80	109.90	7.18	17	79.5	3.8
0.85	116.77	7.16	16	80.1	-0.5
0.90	123.64	7.28	15	78.2	-4.2
0.95	130.50	7.49	15	74.8	-6.1
1.00	137.37	7.74	14	71.1	-5.7
Notes:	Gain dBi: maximum gain in dBi at take-off (TO) angle				
	TO deg: elevation of maximum gain in degrees				
	Resist: feedpoint resistance in Ohms				
	React: feedpoint reactance in Ohms				Table 2



For a fixed dipole length, the resistive and the reactive components of the impedance at the test frequency will change in a cyclical manner as we change the antenna height above ground. The resistive and the reactive component peaks do not occur at the same heights. Rather, the resistance reaches a peak value at a height where the reactance is close to zero. The curves repeat themselves at approximately half-wavelength intervals in height. As the antenna height increases, the curves flatten out, eventually dwindling to an insignificant variation at a height well above  $1 \lambda$ . We need not trace the curves beyond the table and graph limits since few amateurs install 40-meter dipoles much above  $\frac{1}{2} \lambda$ .

The TO angle, or the elevation angle of maximum field strength, undergoes a continuous decrease once we elevate that antenna to at least  $\frac{1}{4} \lambda$  above ground. The angle for the lowest (sometimes the only) elevation lobe in the pattern decreases ever more slowly as we continue to raise the antenna height. Note that the angle is about  $28^\circ$  when the antenna is  $0.5 \lambda$  high and  $14^\circ$  when the antenna is at  $1 \lambda$ . We might expect an antenna that is  $2 \lambda$  high to show a TO angle of about  $7^\circ$ .

The gain curve is fascinating because it also shows cyclical changes in its value, although at normal heights, we could not notice the changes operationally. We find gain minimums approximately where we also find peak values of the resistive component of the feedpoint impedance. The cycle repeats itself approximately every half wavelength, but like the impedance undulations, the range of values diminishes as we increase the antenna height.

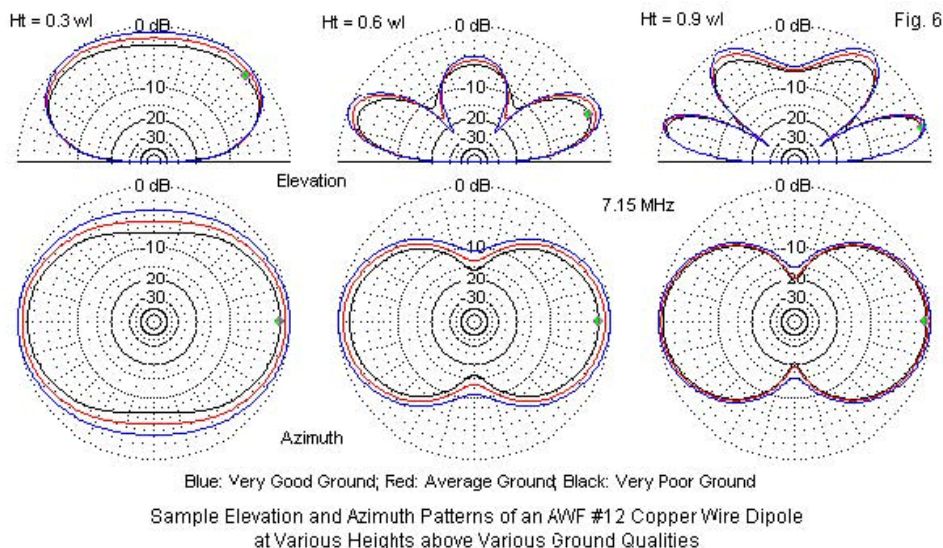
Horizontal antennas of all types do not change their performance properties by a very large amount as we change the quality of ground without altering the antenna height. **Table 3** provides an indication of the amounts of change from very good to very poor ground. Over very good ground, the portion of the radiated energy that reflects from the ground is stronger than over less ground qualities. Ground quality also has a minor but noticeable affect on the TO angle, with better ground qualities producing higher TO angle values.

Table 3. Dipole properties as a function of ground quality: 7.15-MHz AWG #12 copper wire dipole

Height $\lambda$	Ground Quality: Very Good ( $C = 0.0303$ S/m, $DC = 20$ )			Average ( $C = 0.005$ S/m, $DC = 13$ )			Very Poor ( $C = 0.001$ S/m, $DC = 5$ )		
	Gain dBi	TO Deg	Feed Z $R \pm jX \Omega$	Gain dBi	TO Deg	Feed Z $R \pm jX \Omega$	Gain dBi	TO Deg	Feed Z $R \pm jX \Omega$
0.3	6.43	51	$94.5 + j8.4$	5.90	47	$89.3 + j5.4$	5.17	43	$83.3 + j2.8$
0.6	8.60	24	$60.6 + j0.9$	7.97	23	$63.6 + j1.2$	7.11	22	$67.1 + j1.1$
0.9	7.48	16	$80.0 - j5.2$	7.28	15	$71.2 - j5.7$	6.94	15	$76.3 - j2.9$

Note that there seems to be no strict pattern to two factors in the table. The differential between the gain over very good ground and very poor ground does not follow a pattern that tracks height. The differential at  $0.6 \lambda$  is greater than the differential at the other two heights. As well, we find a reversal in the relationship between ground quality and the feedpoint impedance. At  $0.3 \lambda$  and  $0.9 \lambda$ , very good ground shows the highest impedance value, but at  $0.6 \lambda$ , the highest impedance occurs over very poor ground.

**Fig. 6** shows both elevation and azimuth patterns for the dipole at each height over each type of ground. Besides showing the relative gain values over each type of ground—with very good ground showing the marginally highest gain values—the patterns also give us samples of the growth of higher-angle elevation lobes as we increase the antenna height above any quality of ground.



The azimuth pattern shapes show not only the slightly greater gain of the dipole over very good ground, but also an equally slightly greater gain off the ends of the dipole. In contrast to the deeper azimuth nulls over very poor soil, the elevation patterns show deeper nulls between lobes when the soil is very good. Perhaps more significantly, the high-angle elevation lobes change their relative proportions as we change soil and simultaneously raise the antenna. The pattern for  $0.3 \lambda$  shows essentially two lobes (accounting for the slight reduction in gain at  $90^\circ$  elevation), both at high angles. At  $0.9 \lambda$ , the second lobes have grown very large, encompassing more area than the lower lobes. As well, we can see the considerable difference in high-angle lobe strength as we move from very poor to very good soil. At both levels, the impedance is higher over very good soil than over the lesser ground qualities.

At  $0.6 \lambda$ , some aspects of the patterns reverse. The high angle lobe is just emerging, with not much difference in strength regardless of the soil quality. Over

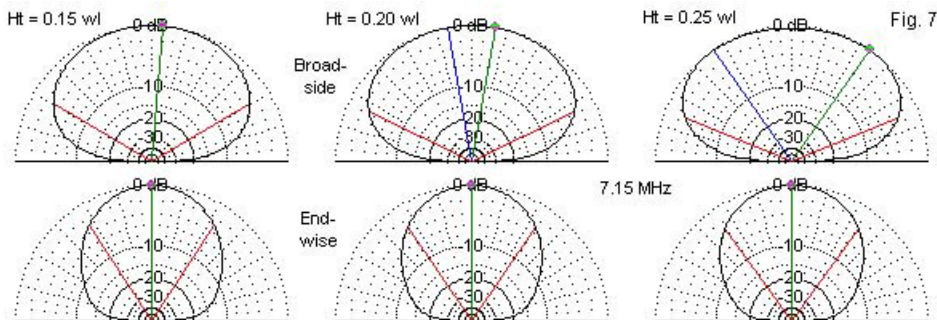
all three soil types, we find that the maximum gain is higher than at  $0.9 \lambda$ , and the gain differential across the three ground quality levels is the greatest. In addition, the impedance is highest for the worst soil rather than for the best. In other words, as we change both the height and the ground quality of an antenna, there are complex cycles of behavior involved.

Before we set aside the current question, we should note the antenna behavior at lower heights, specifically between heights of  $0.15 \lambda$  and  $0.25 \lambda$ . This height range serves near vertical incidence skywave (NVIS) operation. Fig. 7 shows a special set of elevation patterns. We had noticed that as we reduce the antenna height, the azimuth pattern becomes less of a figure-8 and more of an oval. Hence, at the very high TO angles, we find significant radiation both broadside and endwise to the dipole element. Therefore, for evaluating the NVIS potential for the dipole on 40 meters, we look at both broadside and endwise elevation patterns.

If we use the pattern angular lines—the half-power points—as a guide, then the pattern at  $0.15 \lambda$  (about 21') has the greatest circularity for nearly equal omnidirectional coverage. Moving the antenna up to  $0.2 \lambda$  (about 28') yields higher gain, but the broadside pattern now show two peaks, although the gain depression between peaks is almost invisible. At a height of  $0.25 \lambda$  (about 34'), the broadside pattern has two widely separated peaks, but the widest possible elevation beamwidth. The endwise pattern does not change very much over the NVIS-preferred range.

For minimum-range omni-directional coverage, a height between  $0.15 \lambda$  and  $0.2 \lambda$  is best. However, if the NVIS station also doubles for communication with other station at medium distance, the  $0.25 \lambda$  height may be best, with the  $0.2 \lambda$  height coming in second. NVIS operation represents a special application for full-length dipoles, and the proper height depends on the operational needs of the NVIS station.





Broadside and Endwise NVIS Patterns for a 40-Meter AWG #12 Copper Wire Dipole at 3 Typical Heights above Average Ground

For general—usually long-distance—communications, the general rule that applies to the dipole's situation also applies to all horizontal antennas: strive for the greatest height commensurate with antenna durability and periodic maintenance. A practical minimum height is about  $0.35 \lambda$  (about 48'). Although a height between  $0.5 \lambda$  and  $0.65 \lambda$  (69' to 89') is superior, the vertical beamwidth of the low elevation lobe has enough energy at the slightly lower height to allow long-distance communications.

Virtually no amateur 40-meter station places the transceiver at the antenna feedpoint. Therefore, we employ a transmission line to guide energy in both directions between the transceiver and the antenna. Although we can specify a parallel transmission line with a high impedance and use an antenna tuner at the transceiver end of the line, we normally install a coaxial cable. Most amateurs will use a 50- $\Omega$  coaxial cable in preference to a 70-75- $\Omega$  cable. There is a reason for this practice, even though the impedance values at the antenna feedpoint at most heights above ground tend to favor the higher-impedance cable for the closest match between the antenna and feedline impedance values. Feedlines of any sort have losses, and that fact tends to favor the use of 50- $\Omega$  cable. The SWR graph in **Fig. 2** shows that we almost obtain a very usable SWR curve with

50-Ω cable before factoring in the losses, and the losses directly assignable to the SWR will not be significant with a 2:1 value at the band edges.

When we factor in the cable losses, we discover a benefit. Let's assume that we require 100' of coaxial cable to reach between the transceiver and the antenna.

**Table 4** provides some data on what we can expect from three types of 50-Ω cables using three sample antenna heights:  $0.3 \lambda$ ,  $0.6 \lambda$ , and  $0.9 \lambda$ .

Table 4. Dipole properties with 100' of 50-Ω coaxial cable attached

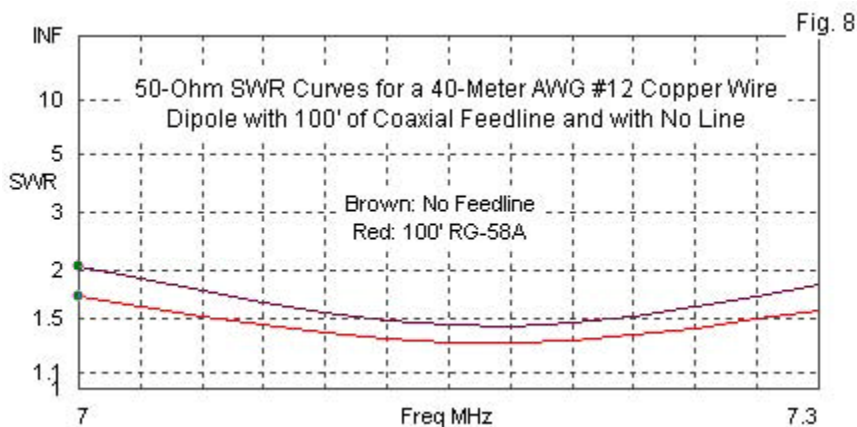
Antenna Height: 0.3 λ				0.6 λ				0.9 λ			
Cable	Gain	TO	Feed Z	Gain	TO	Feed Z	Gain	TO	Feed Z		
Type	dBi	Deg	R+/-jX Ω	dBi	Deg	R+/-jX Ω	dBi	Deg	R+/-jX Ω		
None	5.90	47	89.3 + j5.4	7.97	23	63.6 + j1.2	7.28	15	71.2 - j5.7		
RG-213	5.34	47	53.9 - j27.5	7.46	23	53.2 - j11.4	6.73	15	49.8 - 20.6		
RG-8X	5.00	47	51.9 + j24.2	7.18	23	52.1 + j9.4	6.42	15	56.9 + j18.1		
RG-58A	4.62	47	59.7 + 21.7	6.83	23	54.7 + 7.6	6.06	15	62.1 + j14.0		

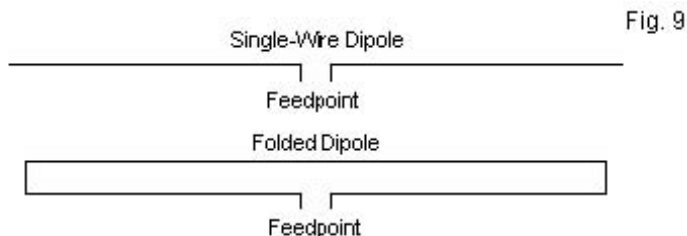
Cable Specification	Zo	VF	Loss/100' @ 10 MHz
RG-213	50	.66	0.6 dB
RG-8X	50	.80	0.9 dB
RG-58A	50	.78	1.3 dB

The table lists values for the hypothetical case of placing the transceiver at the antenna terminals. The three cables are RG-58A, RG8X, and RG-213. RG-58A is among the cheapest, lightest, and most readily available cables around. RG-8X is only slightly heavier, but has considerably lower losses, as indicated by the listings below the table itself. RG-213 is a standard post-World-War-II improved version of RG-8 that uses a solid dielectric. The other cables use a foam dielectric, as indicated by the higher velocity factor (VF) values. The differences in losses per 100' of cable appear in the revised antenna gains in the table. The difference in each case between the listed gain and the "no-cable" gain represents the losses in the cable itself. All values are for 7.15 MHz. Obviously, for the very best results, one should use the cable with the lowest loss, and there are relatively new cables with very low losses indeed, but with a higher price tag. For the antenna builder, the selection of cables is a balance among system efficiency, cost, and weight.

The benefit of using a 50- $\Omega$  cable that has some loss is that the losses tend to reduce the SWR (relative to a 50- $\Omega$  standard) along the length of the line, moving from the antenna toward the transceiver. **Fig. 8** shows the 50- $\Omega$  SWR curves for the no-cable situation and for the situation in which we insert 100' of RG58 when the antenna is  $1\lambda$  above average ground. The resulting 50- $\Omega$  SWR curve is perfectly satisfactory for most operational needs. (An exception is the use of a high-power amplifier with a sensitive fold-back circuit that cuts off with SWR values higher than 1.5:1. Such amplifiers would require the use of cables with higher power handling capabilities than RG-58A.)



There is a misimpression that, if we replace our full-length dipole with a folded dipole for 40 meters, we shall achieve better performance. As shown in **Fig. 9**, a folded dipole uses two long wires connected at the ends. We feed the antenna at the center of only one of the two long wires. If the two wires of the folded dipole have the same diameter, then the distance (up to a point) is not critical and the antenna shows a 4:1 impedance ratio compared to a comparable single-wire dipole. The impedance, but not the performance, of the folded dipole will change if one wire is fatter than the other one.



A Choice: The Single-Wire or the Folded Dipole

As shown by the data in **Table 5** for both a single-wire and a folded dipole in free space, the gain does not change significantly. Both antennas use AWG #12 copper wire. The folded dipole uses a 2" spacing between long wires. Hypothetically, the folded dipole impedance should be almost 293  $\Omega$ . However, let's note a few fine points about the antennas. The two wires of the folded dipole simulate a single wire that is somewhat fatter than the AWG #12 wire in the single-wire version. Fatter wires call for reduced length for resonance. So the folded dipole is noticeably shorter than the single-wire dipole. Shorter antennas generally show lower impedance values, and so the sample folded dipole has a feedpoint impedance slightly under the theoretical 4:1 ratio. Fatter wires—up to a point—show slightly higher gain values, and the folded dipole is no exception.

Table 5. Dimensions and free-space performance of AWG #12 single-wire and folded dipoles

Dipole Type	Length Feet	Length Inches	Feedpoint Z R +/- jX $\Omega$	Max. Gain dBi		
				7.0 MHz	7.15 MHz	7.3 MHz
Single-Wire	66.87	802.4	73.2 - j0.0	2.05	2.07	2.09
Folded Dipole	66.08	793.0	288.7 + j0.0	2.08	2.10	2.12

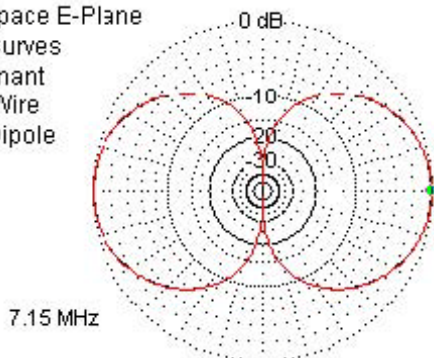
The comparison between the single-wire and the folded dipoles presents an opportune point to note that for any dipole, the gain values does not change significantly across the 40-meter band. In fact, the range of the gain change is the same for both antennas: 0.04 dB, a value that we can only detect in models but never measure by an instruments accessible to amateur radio stations. In

fact the difference in gain between a single-wire dipole and a folded dipole does not even show up in overlaid polar plots for the two antennas. **Fig. 10** presents just such a plot, and the overlapping lines are clearly apparent for their lack of detectable difference.

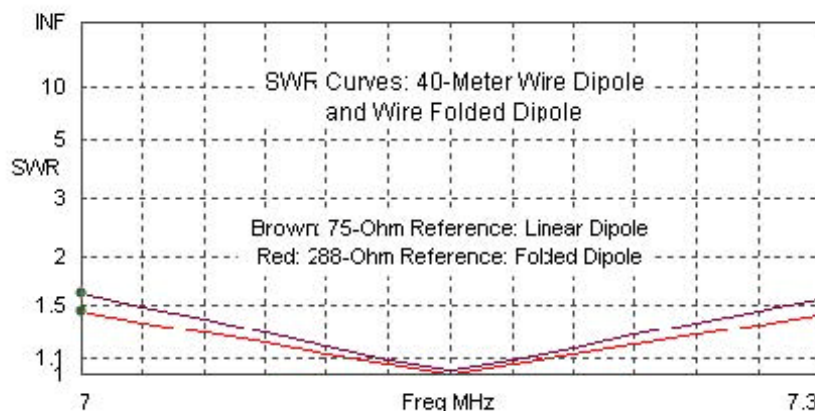
The figure also presents SWR curves for both types of dipoles. The single-wire dipole uses a 75- $\Omega$  reference, while the folded dipole uses a 288- $\Omega$  standard. The folded dipole curve is slightly broader, not as a function of the folded configuration, but rather as a function of the simulated fat wire created by the 2" separation. Had we used a fat element for the single wire version, it, too, would show a broader curve. Likewise, altering the spacing between folded dipole wires (and readjusting the length for resonance) would yield slight changes in its SWR curve. Essentially, the single-wire dipole and the folded dipole are virtually radiation behavior twins.

Comparative Free-Space E-Plane  
Patterns and SWR Curves  
Referenced to Resonant  
Impedance: Single-Wire  
Dipole and Folded Dipole

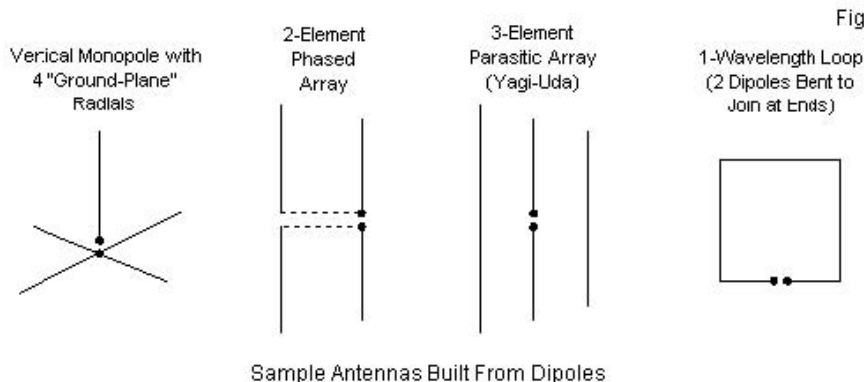
Fig. 10



Both dipoles  
constructed from  
AWG #12 copper  
wire. Folded dipole  
uses a 2" separation  
of wires.



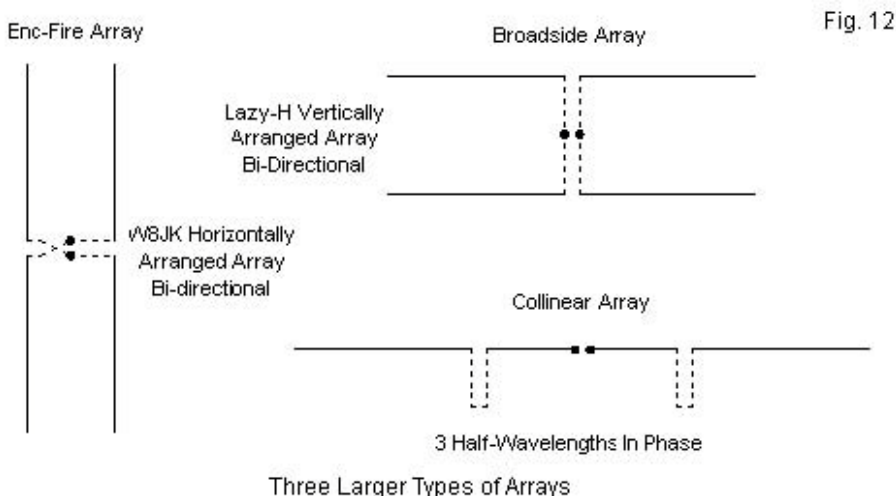
The  $\frac{1}{2} \lambda$  dipole holds a special place in amateur radio antenna technology because it forms a building block for other more complex antennas. **Fig. 11** sketches some of the most common forms of antennas that use the dipole as a foundation.



We normally think of a vertical monopole as half a dipole, that is, as a  $\frac{1}{4} \lambda$  radiating elements. However, the radials create in a distributed form the other half of the dipole. When we elevate the total antenna, as we do in VHF applications, the length of the radials becomes a critical dimension in setting the feedpoint to resonance at a desired impedance value. The current on the vertical element reappears on the radials, with a magnitude that is divided by the number of radials. The symmetry of the radials effectively cancels the potential horizontal radiation from these elements. Without the radials, the  $\frac{1}{4} \lambda$  vertical element will not operate properly.

The second sketch shows two horizontal dipole elements with a phasing (dashed) line between them. We can use various methods to set the relative current magnitude and phase angles on the two elements in order to achieve various directional patterns to enhance communications. An alternative to the use of phasing lines or networks appears in the third sketch of a 3-dipole element Yagi-Uda (usually shortened to Yagi) beam. Careful selection of element length and spacing values can yield highly directional radiation patterns without the use of connecting lines. Among directional antennas used in amateur radio, parasitic arrays are most common.

The last antenna, a  $1\lambda$  loop, may seem surprising. Such loops are used independently as bi-directional antennas with gain over a single dipole or with other loops in parasitic arrays called quad beams. A  $1\lambda$  loop actually consists of two  $\frac{1}{2}\lambda$  dipoles with the ends bent to meet each other to create a continuous wire. The dipole current distribution repeats itself on both the upper and lower halves of the loop, even though we use only a single feedpoint.



In **Fig. 12**, we see even larger arrays, with a sample from each of the three main array categories: end-fire, broadside, and collinear. The W8JK array places two horizontal elements in a line with each phased  $180^\circ$  opposite to the other. The result is a bi-directional pattern in line with the two elements with increased gain over a simple dipole. The Lazy-H array arranges its wires in a vertical plane, although the main pattern is bi-directional and broadside to the plane formed by the wires. We feed the elements in phase to achieve considerable gain over a single dipole.



The last sketch shows three  $\frac{1}{2} \lambda$  element stretched end to end, that is, collinearly. Between each element, we place a phase reversing network or line that sets all three elements in phase with each other. The result is increased bi-directional gain relative to the  $\frac{1}{2} \lambda$  building block out of which we created the array. We can string together any number of element sections and use a wide variety of phase-setting techniques in order to end up with very high gain in a very narrow beam.

Although most of these arrays are incidental to our main project of exploring shortened dipoles, they are fundamental aspects of our understanding and appreciation of the basic  $\frac{1}{2} \lambda$  dipole.

### *Conclusion and Preface*

We have examined the full-size  $\frac{1}{2} \lambda$  center-fed resonant dipole in some (but not exhaustive) detail to set the stage for what comes next as we prepare to tackle half-length dipoles. The tables, graphs, and patterns shown in these initial notes will form a background against which the shorter dipoles and the techniques of making them work will take center stage. The data that we have surveyed gives us clues as to what properties may be important to consider and what adjustments we may have to make in order to create a working short dipole. In addition, the data values give us a baseline against which to measure the half-length dipoles. The numerical comparisons may require some interpretation along the way, but at least we have some basic values to use as touchstones.

## Chapter 21: 1/2-Length 40M-Dipoles - Shorter & Reshaped

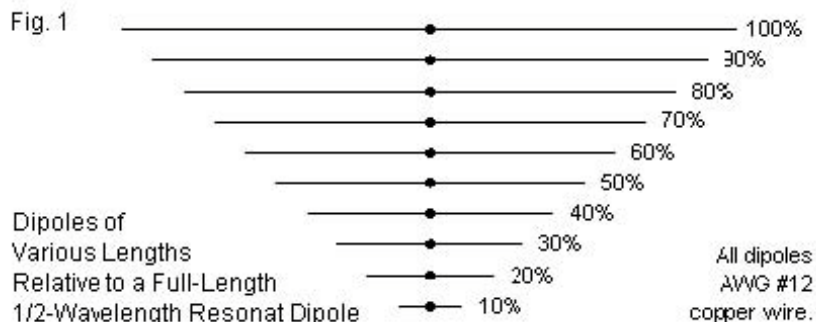
In the previous Chapter, we reviewed in practical depth the properties of a full-length 40-meter dipole. The data in those notes provides both background information on dipole properties in general and specific entries with which we can compare the performance of some shortened antennas. Now the time has come to begin the shortening process.

In this Chapter—with others yet to come—we shall tackle two significant questions. First, what happens when we simply cut an initially resonant full-length dipole to shorter lengths? Second, can we obtain a shorter length while still having at least some of the properties of a full-length dipole? The first question is almost self-explanatory. The second one involves various forms of folding, spindling, and mutilating the linear dipole form to squeeze a full dipole into half-dipole space. We shall evaluate a number of possibilities, even though amateurs are adept at finding new ways to accomplish the task.

As we did in the earlier Chapter, we shall adopt AWG #12 (0.0808" diameter) wire as our standard antenna material. As well, when we set a half-length value for our shortened dipole, we shall use a length of 33.33' (400.0") due to its numerical convenience. A free-space resonant  $\frac{1}{2} \lambda$  dipole using AWG #12 copper wire actually requires 66.87' (802.4"), so our rounding is very slight.

### Shortening the Copper Wire Dipole

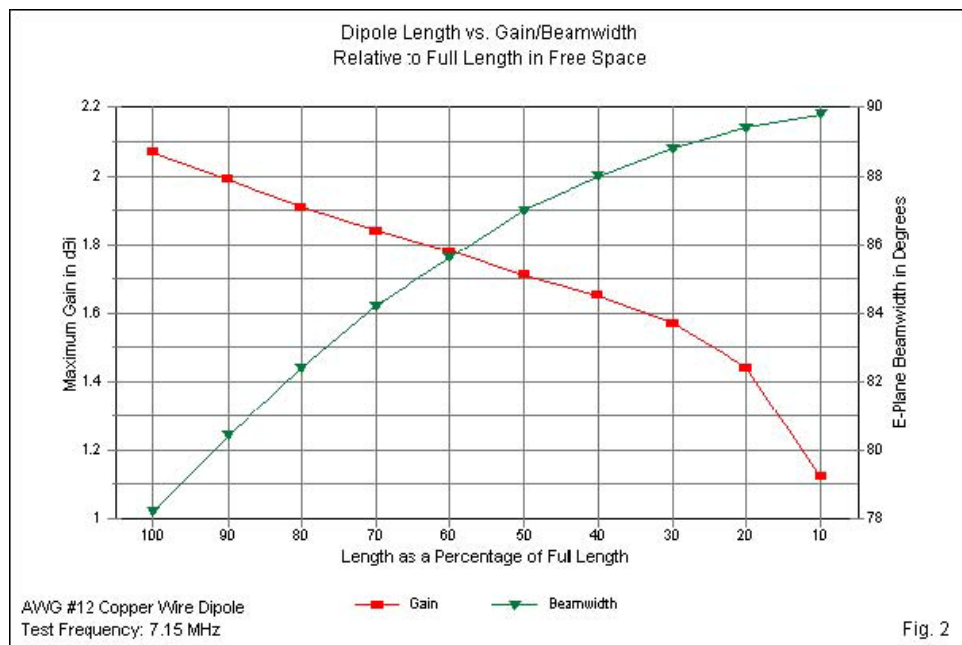
The process of discovering the properties of shortened dipoles is very straightforward. As shown in **Fig. 1**, we simply trim the dipole ends while retaining the center feedpoint position. To create a finite task, let's trim the initially resonant  $\frac{1}{2} \lambda$  dipole in 10% increments down to a final length that is 10% of the original. We can use a free-space environment for convenience, since the properties would transfer easily to any height over any ground that we might use in practice. The information will take both tabular and graphical forms.



**Table 1** provides the numerical overview of the progressions of values for the essential performance characteristics, including maximum bi-directional gain, beamwidth between the half-power points, and the feedpoint impedance, given in the usual series terms of  $R \pm jX \Omega$ . The general progression contains no major surprises, since the gain shows a continuous downward trend, while the beamwidth shows a small but steady progression upward. The feedpoint resistance moves downward from the resonant 73- $\Omega$  value, while the short versions of the dipole show ever-increasing values of capacitive reactance.

Dipole Performance vs. Length as Percentage of 1/2 Wavelength					
AWG #12 Copper Wire			Free Space		7.15 MHz
Length %	Length in	Gain dBi	BW deg	Resist	React
100	802.4	2.07	78.2	73.18	-0
90	722.2	1.99	80.4	53.82	-159
80	641.9	1.91	82.4	39.21	-322
70	561.7	1.84	84.2	28.05	-497
60	481.4	1.78	85.6	19.50	-694
50	401.2	1.71	87.0	12.95	-932
40	321.0	1.65	88.0	8.03	-1244
30	240.7	1.57	88.8	4.43	-1703
20	160.5	1.44	89.4	2.00	-2512
10	80.2	1.12	89.8	0.52	-4595
Notes	Gain dBi: maximum gain in dBi				
	BW deg: E-plane beamwidth in degrees				
	Resist: feedpoint resistance in Ohms				
	React: feedpoint reactance in Ohms				
	Table 1				

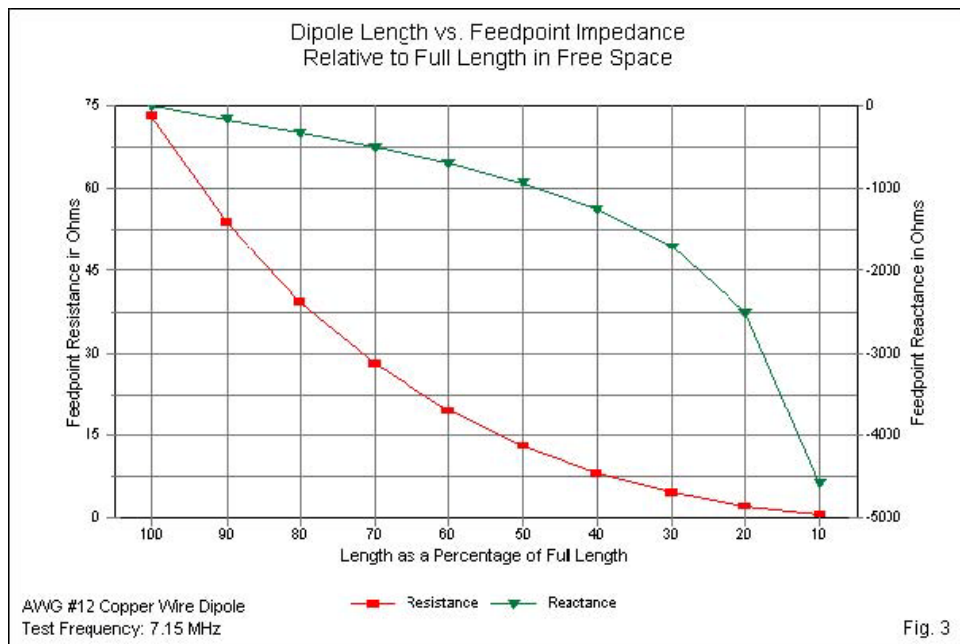
To view more clearly how the progressions proceed, we may graph the results. **Fig. 2** shows the track of the maximum free-space gain and the beamwidth in degrees. Be certain to attend to the values along the proper Y-axis. For example, the beamwidth curve appears very steep, but the axis informs us that the range of values is quite limited: 78° to 90°



The gain curve is interesting because it shows a nearly (but not quite) linear decrease in value per increment of length change until we reach the 30% mark. For shorter lengths the curve becomes steeper with each change of length. Contrary to the intuitive guesses of many new amateurs, the gain of the dipole holds up very well, even at a length that is only 10% of the resonant length (80.24" compared to 802.4"). The gain is only about 1 dB lower at the very short length than it is at full length. Over ground, the same differential would appear. At some height over some ground quality, a full-length dipole might show a maximum gain of 7.0 dBi. The 10% dipole would show a gain of about 6 dBi.

The major practical problem facing users of shortened dipoles is usually not basic performance. Rather, both the resistive and reactive components of the

feedpoint impedance take turns for the worse, as revealed both by the numbers and by the curves in **Fig. 3**. The resistive component drops very rapidly so that lengths below the 70% mark begin to present very difficult matching situations regardless of the value of reactance at the feedpoint.



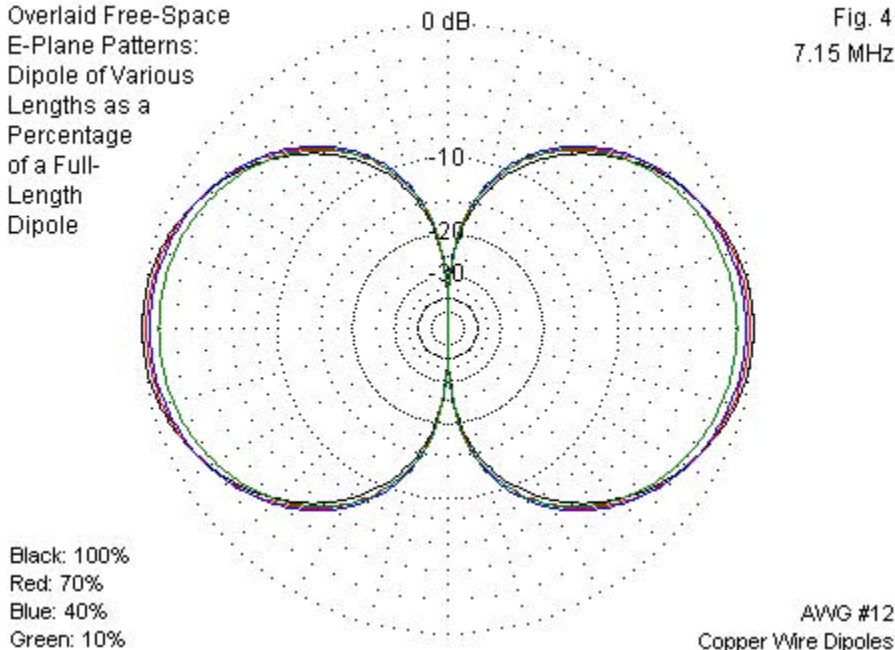
On its own, the feedpoint reactance shows an increasingly steep curve as the capacitive reactance grows with our dipole trimming. The curve may seem initially shallow, but the scale covers a very wide range. A dipole that is 70% of full length has a reactance of nearly  $-j500\ \Omega$ . Reactance conditions grow more troublesome for most types of installations as the antenna length becomes shorter.

Our target length of 50% of full length presents us with a very low resistive component—less than  $13\ \Omega$ —and a very high reactive component—more than  $-j900\ \Omega$ . Under these conditions, even the losses of parallel transmission line become very high. Working with such impedance values will become a daunting challenge for the short antenna builder.

**Fig. 4** shows perhaps the major reason why antenna builders with very limited space tend to try their luck with shortened dipoles. The polar plot shows patterns for dipoles that are 100%, 70%, 40% and 10% of full size. The differences in gain and in beamwidth shown in the table turn out not to make a very large difference in performance, if we read the polar plot as a measure of potential performance. In the end, the key task will be to supply power to the antenna while holding losses to a minimum in the process. Energy that is lost in the transmission line and any matching networks that we might use reduces the gain shown in the ideal plots that contain no lines or networks.

Overlaid Free-Space  
E-Plane Patterns:  
Dipole of Various  
Lengths as a  
Percentage  
of a Full-  
Length  
Dipole

Fig. 4  
7.15 MHz



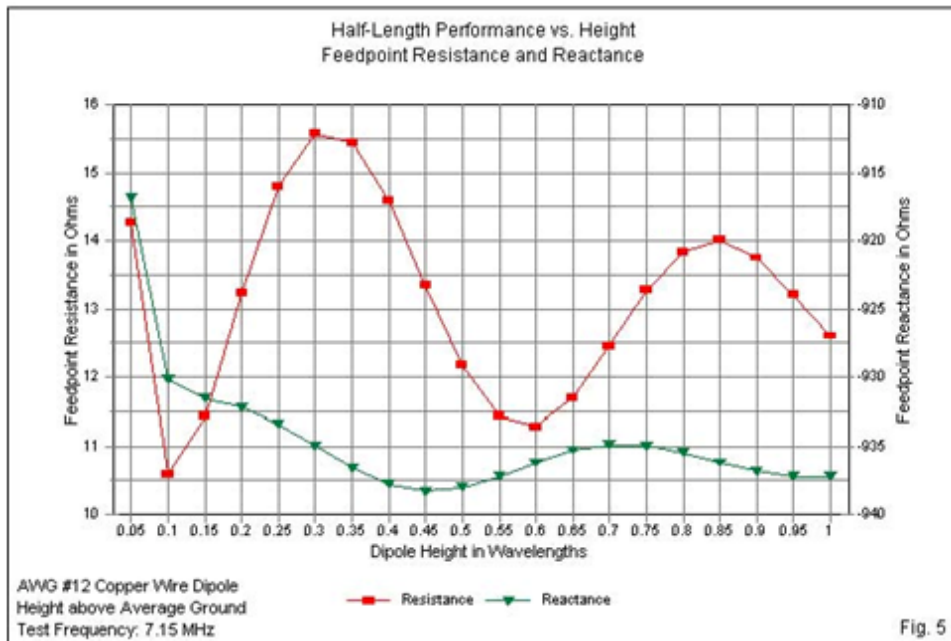
Before we turn to any technique that might let us use a half-length dipole, we should first confirm that the antenna performs over ground in a satisfactory manner. So we should pause to repeat an exercise that we performed with the full-length dipole in Part 1. We shall set the antenna over average ground at different heights and check its performance values. We shall repeat the progression used in the earlier exercise of raising the height from  $0.05 \lambda$  up to  $1.0 \lambda$  in  $0.05 \lambda$  increments. The new dipole is 33.33' or  $0.242 \lambda$  long physically. In free space, it shows a gain of 1.71 dBi, with a beamwidth of  $87.0^\circ$ . The feedpoint impedance is  $12.9 - j936.2 \Omega$ .



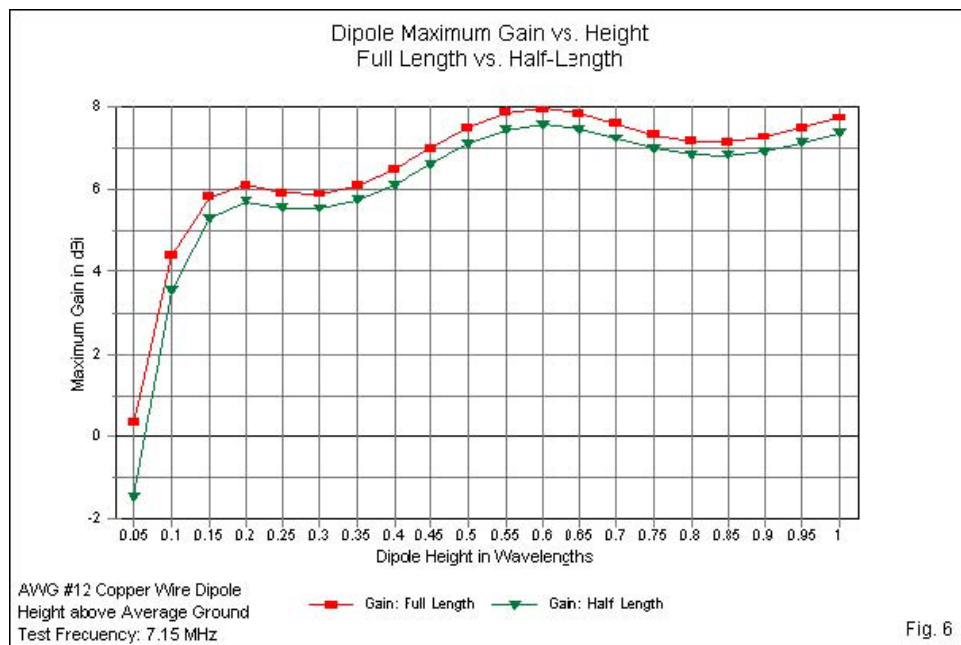
**Table 2** provides the numerical information on the half-length dipole at the listed heights above ground. We can establish that the short dipole has many of the same characteristics as the long one by graphing the feedpoint resistance and reactance values, as shown in **Fig. 5**. Like the full size dipole, the feedpoint resistance and reactance of the 50% version show cycles that vary the values as a function of the height above ground. The resistance reaches peak values at height of about  $0.3 \lambda$  and  $0.85 \lambda$  (close to the  $3/8 \lambda$  and  $7/8 \lambda$  points that are separated by  $1/2 \lambda$ ). Because the reactance is always very capacitive, we have nothing corresponding to a zero-value to coincide with those peaks, as we did with the full-length dipole. However, careful reading of both the numbers and the graph show the reactance to be close to the average value of its swings at peak resistance values.

The graph has a limitation because it cannot show clearly at least two complete cycles of resistance and reactance. As the antenna moves very close to the ground, the feedpoint impedance values show much greater changes than we found to be the case with the full-length dipole. Nevertheless, the tracks are sufficiently parallel at most heights to confirm that the general trends in impedance behavior of a dipole is independent of dipole length.

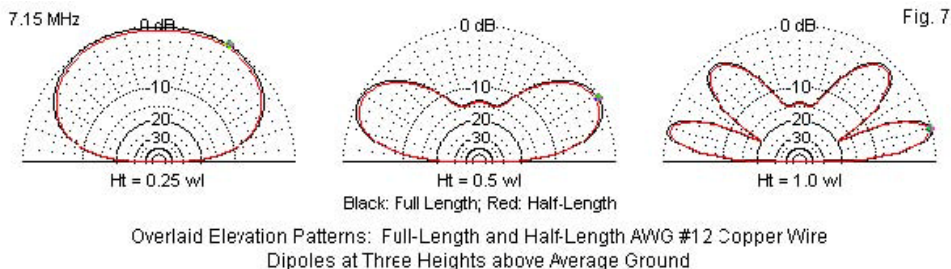
Half-Length Dipole Performance vs. Height above Ground					
AWG #12 Copper Wire			Average Ground		7.15 MHz
Height wl	Height ft	Gain dBi	TO deg	Resist	React
0.05	6.88	-1.47	88	14.3	-916.8
0.10	13.75	3.53	88	10.6	-930.2
0.15	20.61	5.32	88	11.4	-931.6
0.20	27.48	5.72	87	13.2	-932.2
0.25	34.35	5.57	61	14.8	-933.4
0.30	41.22	5.56	48	15.6	-935.0
0.35	48.09	5.76	40	15.5	-936.6
0.40	54.95	6.13	34	14.6	-937.8
0.45	61.82	6.62	31	13.3	-938.3
0.50	68.69	7.11	28	12.2	-938.0
0.55	75.56	7.45	25	11.4	-937.2
0.60	82.43	7.57	23	11.3	-936.2
0.65	89.30	7.47	21	11.7	-935.3
0.70	96.16	7.24	20	12.5	-934.9
0.75	103.03	7.00	18	13.3	-935.0
0.80	109.90	6.85	17	13.8	-935.5
0.85	116.77	6.83	16	14.0	-936.2
0.90	123.64	6.93	15	13.8	-936.8
0.95	130.50	7.13	15	13.2	-937.2
1.00	137.37	7.37	14	12.6	-937.2
Notes:		Gain dBi: maximum gain in dBi at take-off (TO) angle			
		TO deg: elevation of maximum gain in degrees			
		Resist: feedpoint resistance in Ohms			
		React: feedpoint reactance in Ohms			
		Table 2			



The take-off (TO) angle of any horizontal single-wire antenna is a function of height. Therefore, except for the very lowest heights for our half-length dipole, the TO angles are the same for both the present and the past dipoles. More interesting is the comparison of gain curves for full-and half-length dipoles shown in Fig. 6. For all heights, the average gain difference between the two dipoles of 0.47 dB. The value would be slightly less had we excluded the somewhat larger differences at heights of  $0.1\lambda$  and less.



The half-length dipole, then, promises adequate gain and reliable or predictable performance at all practical heights above ground. The sample elevation patterns in **Fig. 7** for various heights above ground show that we can scarcely distinguish between the short and the long dipole. All elevation lobes that apply to the full-size dipole reappear in the plots for the half-length dipole, with no significant changes in proportions. Performance is the least of the problems that we encounter when trying to work with short dipoles.



The most prominent challenge is to be able to supply energy to the antenna with minimal loss, a task that we often characterize as matching the antenna to a standard feedline, such as 50- $\Omega$  coaxial cable. (We shall also encounter some adjunct difficulties along the way.) In most cases, the high capacitive reactance at the feedpoint presents more problems than just converting the resistive portion of the impedance. In fact, the challenge is so great that there are a number of techniques sometimes used to avoid the problem altogether. We may call these “reshaping” strategies.

## Reshaping the Full-Length Dipole

Our basic premise is that we have room in our installation area only for a 40-meter antenna that is about 33.33' long, far short of the size of a full-length dipole. However, a dipole is a linear element with no significant lateral dimension. Suppose that we could reshape a full size dipole so that its longest dimension is 33.33', even if it requires “some” space that gives the antenna an area. There are numerous ways to achieve this goal—some more promising than others. Therefore, let's take another important detour to examine at least some of the major possibilities.

1. *The Zigzag Dipole:* One way to obtain a full size dipole in a smaller space is to create a zigzag shape. The sample antenna shown in **Fig. 8** uses 33.33' of the total as the longest dimension of a rectangle. The center wire section runs from

corner-to-corner of an S (or a Z) shape. The end pieces essentially fold back a bit to create a rectangle that is 27.3' by 19.2'. Because the end pieces are not linear extensions of the center wire section, they must be longer than usual. Thus, the total amount of wire is close to 72', compared to the 66.9' required by the resonant free-space linear dipole.

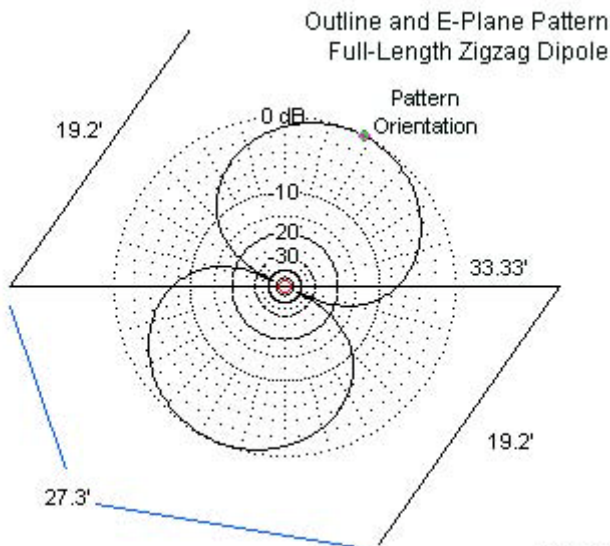


Fig. 8

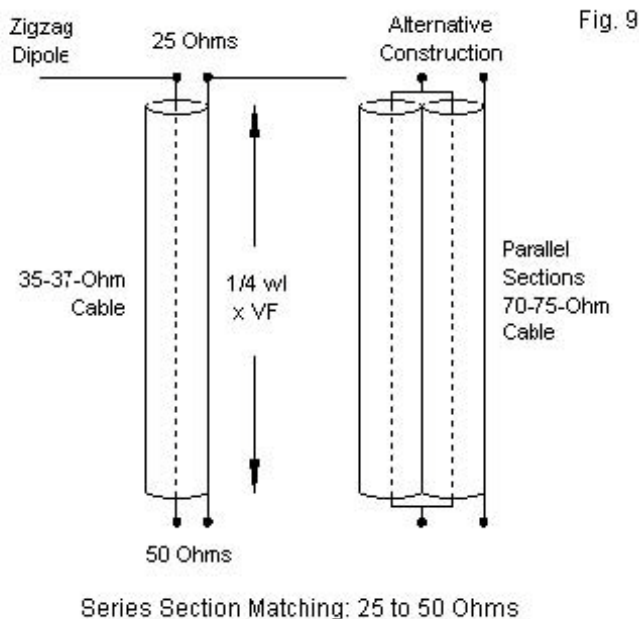
The orientation of the pattern produced by the zigzag dipole is not broadside to the central wire section. Rather it is canted at an angle that is almost parallel to the end wires. Therefore, the zigzag user needs to plan carefully if he has target areas that he wishes to place along the axis of maximum gain. Because the antenna makes use of alternating fold-backs, the maximum gain is only equivalent to the gain of a 30% linear dipole, as shown by the free-space values in **Table 3**. Unlike the 30% dipole, with its low resistance and high capacitive reactance, the zigzag version has a resonant impedance of just above 25  $\Omega$ .

Table 3 Performance of a zigzag dipole with a 33.3' center section

Conditions	Max. Gain	Beamwidth	Feedpoint Z
Free Space	dBi	degrees	$R \pm jX \Omega$
Pre-match	1.54	88.6	$26.5 - j0.2$
Post-match	1.32	88.6	$50.8 - j1.2$
Height	Max. Gain	TO angle	Feedpoint Z
$0.5 \lambda$	dBi	degrees	$R \pm jX \Omega$
Pre-match	6.98	28	$25.0 - j3.8$
Post-match	5.82	28	$52.8 + j3.0$

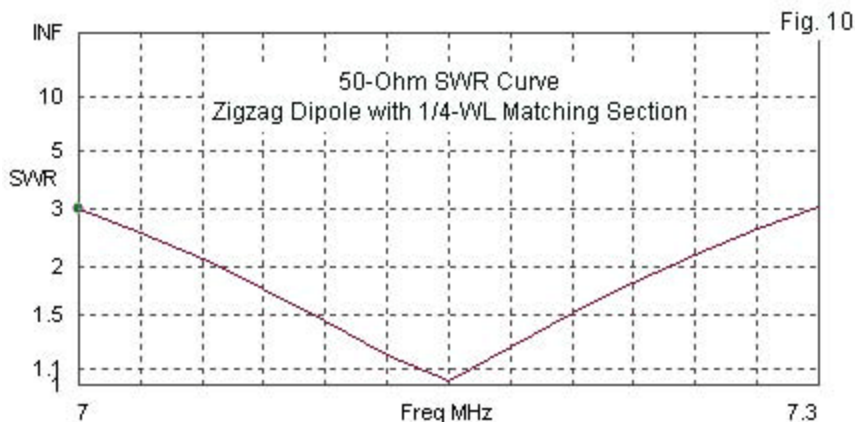
Note: Zigzag dipole forms a rectangle 27.3' by 19.2'.  
 Match consists of a  $\frac{1}{4} \lambda$  section of 35- $\Omega$  cable. Post-match data includes matching section losses.

The table shows both pre-match performance values that assume no transmission line at all and post-match values. The latter assume a  $\frac{1}{4} \lambda$  section of 35-37- $\Omega$  transmission line to transform the 25- $\Omega$  feedpoint impedance to a value close to 50  $\Omega$  for compatibility with a 50- $\Omega$  coaxial cable. **Fig. 9** shows the basic elements of the simple series matching system. Although a 35- $\Omega$  cable does exist, most amateurs simply parallel two lengths of 70-75- $\Omega$  cable, such as RG-59, to obtain the required low impedance. As shown in the sketch, the two center conductors join at both ends, as do the two braids for the cable. Although losses are very low, the numbers in the table show that the gain with the matching system in place does incur some loss, but no more than it would with almost any transmission line of the same length.



Although the matching system produces a very low SWR at the design frequency (7.15 MHz), it cannot significantly increase the operating bandwidth of the total antenna. **Fig. 10** provides the 50-Ω SWR curve for the antenna and matching line. The 2:1 SWR span is about 180 kHz or a little under 2/3 of the band. The narrow operating bandwidth is not a function of the matching system, but of the antenna configuration. Virtually any bent, folded, or otherwise distorted version of a normally linear antenna will show a narrow bandwidth compared to the antenna when laid out in a straight line.





As well, like the zigzag version of the dipole, bending usually results in one or another degree of reduced gain and reduced feedpoint impedance. The two reductions do not track with the succession of reductions in **Table 1**, which shows the values associated with shortened dipoles. The zigzag dipole has the gain of the 30% dipole, but the feedpoint resistance of a dipole closer to 70% of full size.

2. *Fold-back Dipoles*: Some amateurs try more radical fold-back schemes, such as the two sampled in **Fig. 11**. One version folds the elements back at a 30° angle. Any fold-back requires longer tailpieces than we would expect from a linear dipole. The two end pieces—with the standard 33.33' center section—yield a total element length of 71.2'. At the crossing point, the two wires require a few inches of separation.

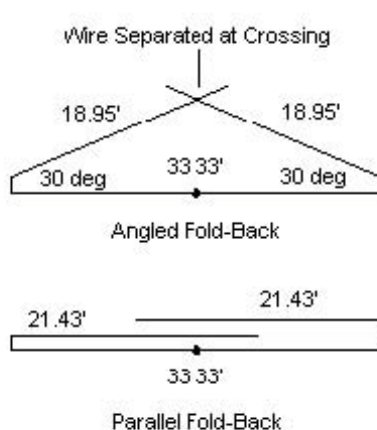


Fig. 11

Two Versions of Fold-Back Dipoles for 40 Meters

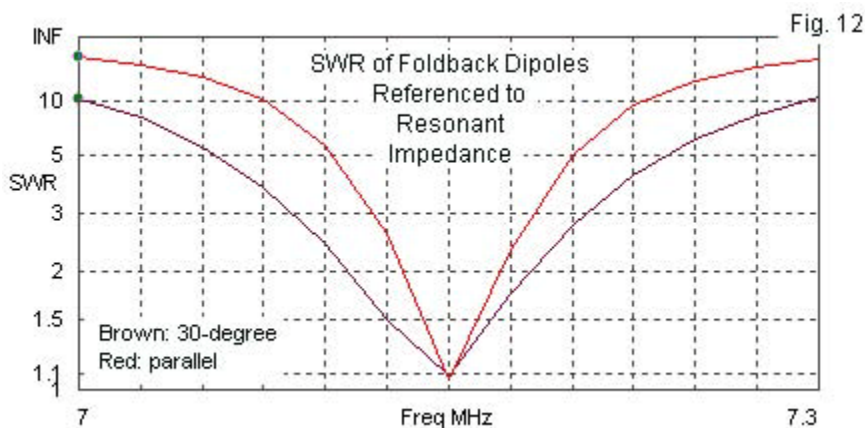
If we try to run the tailpieces parallel to the center section wire, then they grow even longer. The parallel fold-back version of the antenna requires about 76.2' of wire. In both cases, the interaction between the center section and the tailpieces, with opposing current directions, yields a reduced far field as well as longer elements overall. **Table 4** shows the free-space performance numbers for the fold-back dipole samples. The numbers should discourage use of this method of bringing a short-space dipole to resonance.

Table 4. Free-space performance of two fold-back dipoles with 33.3' lengths

Type of Fold Back	Max. Gain dBi	Beamwidth degrees	Feedpoint Z R +/- jX Ω
30° angle	1.00	90.2	10.7 + j0.9
Parallel	-0.18	86.9	4.3 - j0.3

For a fixed center section length, closer spacing of the tailpieces to the center wire yields lower gain and reduced feedpoint resistance values. The combination of the two reductions suggests that there may be better ways to obtain a short dipole. Moreover, the radical folding further reduces the operating bandwidth.

**Fig. 12** shows the free-space SWR curves for the two samples, each using the resonant impedance as the SWR reference value. In both cases, the region in which the SWR is less than 2:1 is so narrow as to require very careful initial adjustment. Even with such care, wind and weather may move the usable frequency span in the normal course of the seasons.

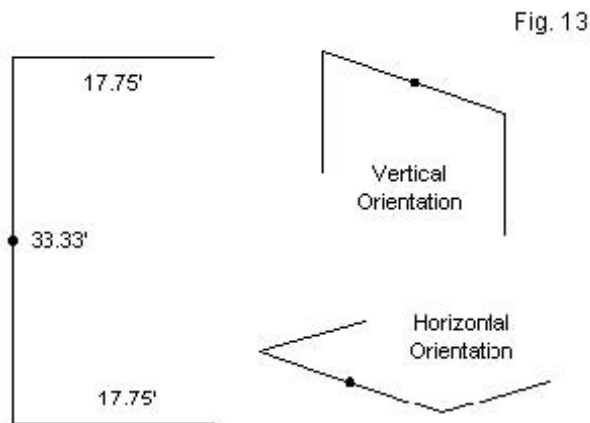


The sample fold-back dipoles function mainly as references, in this case for configurations that are not recommended. However, they do provide vivid examples of the general principle that folding an initially linear structure reduces gain, feedpoint resistance, and operating bandwidth.

**3. The U-Shaped Dipole:** Both the zigzag dipole and the fold-back dipole bent their ends inward beyond the 90° point. A potentially more useful shape is a U in which the tail sections of the dipole form 90° angles with the center section. **Fig.**

13 shows the general idea of the U shape, along with two common versions. In fact, the vertical form of the antenna gives the antenna its name, usually preceded by the term “inverted.” The horizontal form retains the name, although we might see it as a C or something else. We may note in passing that the sketch shows a single set of dimensions that we may use for either the vertical or the horizontal versions of the antenna.

Like all bent forms, the total length of wire required to form the U is greater than the length of a linear dipole. The U's wire total is about 68.8', compared to the linear dipole length of 66.9'. The reduction in length of the U compared to the previous sample bent dipoles that required over 70' of wire promises potential improvements in gain, feedpoint impedance, and bandwidth. Which, if any, of these potentials realizes itself is part of our investigative task.



Two Versions of a U-Shaped Dipole for  
40 Meters Using AWG #12 Copper Wire

**Table 5** provides a sampling of antenna performance in both free-space and over (average) ground. The figures are remarkably similar for both orientations of the antenna. The feedpoint impedance is close to the value for the 90% linear dipole in **Table 1**. However, the maximum bidirectional gain corresponds to a 30% length in the same table. The lower gain is a function of the bent portions of the antenna, since they contribute mainly to the beamwidth. As the tabular values show, the beamwidth is greater than any of the values for the shortened linear dipoles.

Table 5. U-shaped dipoles with a 33.3' center section

Vertical orientation, ends downward

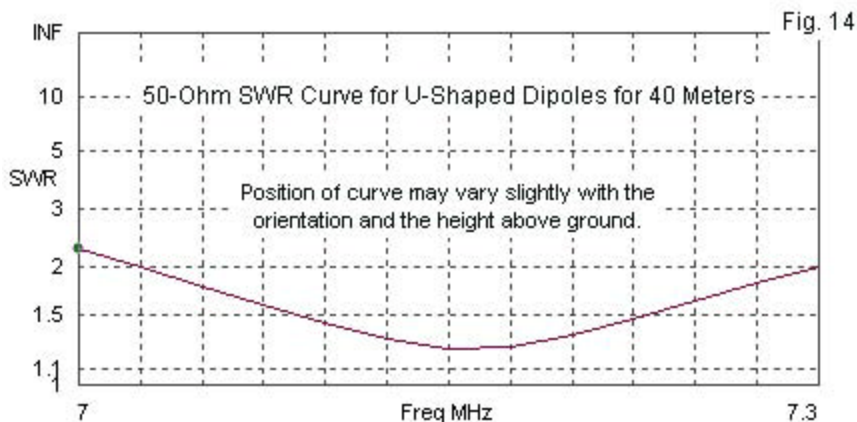
Free Space	Max. Gain dBi	Bearwidth degrees	Feedpoint Z R +/- jX $\Omega$
	1.51	91.8	40.7 - j0.9
Height above Average Ground	Max. Gain dBi	TO angle degrees	Feedpoint Z R +/- jX $\Omega$
0.3 $\lambda$ 41.3'	5.12	48	52.1 - j2.2
0.6 $\lambda$ 82.5'	7.41	23	35.3 - j0.6
0.9 $\lambda$ 123.8'	6.72	15	43.5 - j3.0

Note: wire ends 17.75' below listed height

Horizontal orientation

Free Space	Max. Gain dBi	Bearwidth degrees	Feedpoint Z R +/- jX $\Omega$
	1.51	93.6	40.7 - j0.9
Height above Average Ground	Max. Gain dBi	TO angle degrees	Feedpoint Z R +/- jX $\Omega$
0.3 $\lambda$ 41.3'	5.42	47	48.6 - j2.7
0.6 $\lambda$ 82.5'	7.34	23	35.9 - j0.8
0.9 $\lambda$ 123.8'	6.74	15	43.3 - j2.8

One advantage of the U, however oriented, is the nearly perfect match of the feedpoint impedance with a standard 50 $\Omega$  coaxial cable. At some heights, the impedance may be slightly low. The simplest way to increase the impedance is to lengthen the center section slightly, with corresponding decreases in the length of tailpieces.

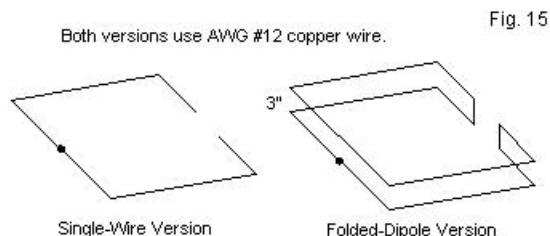
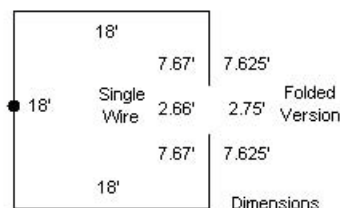


**Fig. 14** shows the wisdom of lengthening the center section to more closely approximate a 50- $\Omega$  impedance at the center frequency of the SWR sweep. The SWR does not quite remain below the standard 2:1 limit if we insist upon using the 33.33' center section. Since the impedance fluctuates just like it does for a full-length dipole as we change the height above ground when measured as a fraction of a wavelength, the required amount of lengthening will vary with each specific installation.

Of the modified full-length dipoles with 33.33' center section that we have so far surveyed, the U version may be the most promising in terms of operating bandwidth and ease of matching. The beamwidth offsets the somewhat lower gain. In fact, one might set up crossed inverted-U (vertically oriented) antennas and obtain virtually full horizon coverage with a remote switch.

4. *The Square "Interrupted-Loop" Dipole:* A more extreme form of the U shape is the so-called interrupted loop configuration. As shown in **Fig. 15**, it provides perhaps the most compact form of a full size dipole at only 18' per side. The total

size is comparable to a 1  $\lambda$  quad element on a 20-meter beam, but laid on its side.



General Outline and Dimensions of a Square Interrupted-Loop Dipole for 40 Meters

The idea of an interrupted loop is something of a misnomer, since the gap between ends is so wide. Although there is a modicum of interaction between ends, the antenna is still a dipole and uses about 69.3' of wire for the single-element version. The sketch provides dimensions for a folded-dipole version of the antenna using a 3" separation of the upper and lower wires. Besides using twice as much wire and needing a slightly wider gap (or a shorter total tip-to-tip length), the key reason for considering the folded version appears in the data in **Table 6**.



Table 6. Square dipole (interrupted loop) 18' per side

Single AWG #12 wire version; 2.66' gap

Free Space	Max. Gain dBi	Beamwidth degrees	Feedpoint Z R +/- jX $\Omega$
	0.81	131.4	12.7 - j0.3
Height above Average Ground	Max. Gain dBi	TO angle degrees	Feedpoint Z R +/- jX $\Omega$
0.3 $\lambda$ 41.3'	4.63	45	14.4 - j0.9
0.6 $\lambda$ 82.5'	6.40	23	11.6 - j0.4
0.9 $\lambda$ 123.8'	6.07	15	13.4 - j0.7

Folded dipole (AWG #12 wire, 3" separation) version; 2.75' gap

Free Space	Max. Gain dBi	Beamwidth degrees	Feedpoint Z R +/- jX $\Omega$
	1.01	134.6	48.0 - j0.1
Height above Average Ground	Max. Gain dBi	TO angle degrees	Feedpoint Z R +/- jX $\Omega$
0.3 $\lambda$ 41.3'	4.80	45	54.4 - j4.6
0.6 $\lambda$ 82.5'	6.61	23	43.7 - j0.1
0.9 $\lambda$ 123.8'	6.26	15	50.4 - j1.4

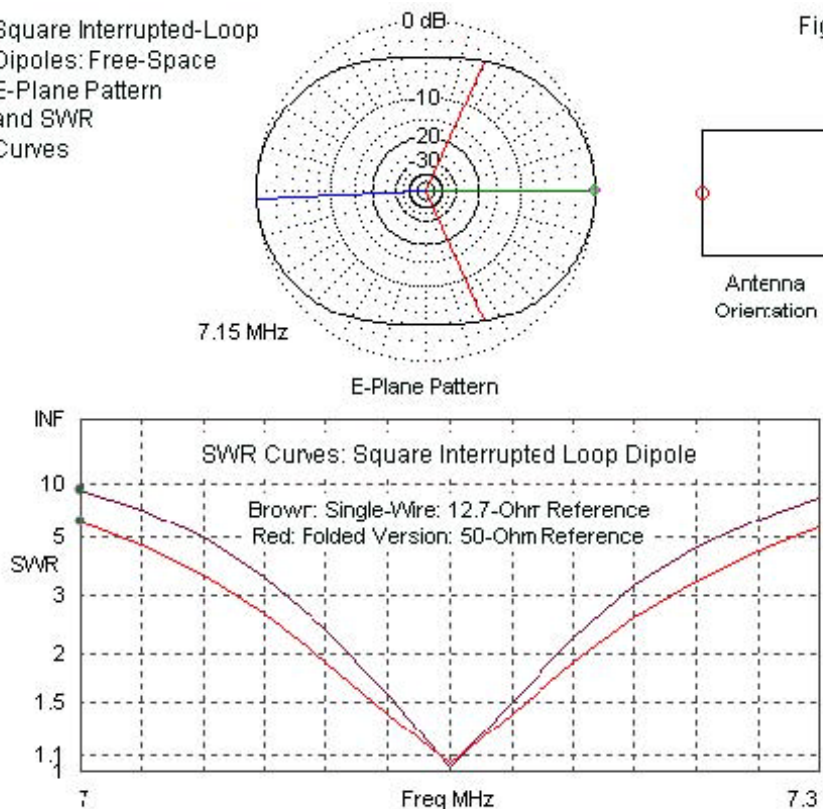
The free-space impedance of the single-wire squared dipole is about 12.5  $\Omega$ . One way to obtain a better match with a 50- $\Omega$  coaxial cable is to install a 1:4 balun at the feedpoint. Transmission-line transformer baluns with a 4:1 impedance ratio are designed for antenna impedance values close to 200  $\Omega$  and may not be efficient when reversed. The folded version of the antenna provides a 4:1 step-up of the feedpoint impedance within the antenna design and requires no further impedance matching.

The gain and beamwidth numbers for the antenna extend the progression of values that we encountered for the U antennas. Gain decreases, but beamwidth increases, as shown at the top of **Fig. 16**. It is possible to use a single version of the squared dipole in a fixed mounting and to obtain reasonable result in all directions. In fact, it is possible to nest squared dipoles for several bands with a single support system. Commercial versions of this antenna do exist in both mono-band and multi-band forms.

One of the key limitations of the squared dipole is the operating bandwidth. The SWR sweeps in **Fig. 16** show the curves for each version of the antenna in free-space, with each curve referenced to the resonant impedance of the antenna. Neither version of the antenna covers a full 50% of the 40-meter band. (Any commercial version of the single-wire version of the antenna that advertises a wider bandwidth is most likely relying upon impedance transformer losses and possible transmission-line losses to broaden the bandwidth, with a consequential reduction in available gain.) The folded version of the antenna shows marginally higher gain values in the tabular data and a wider SWR bandwidth in the sweep as a result of its two-wire construction. Relative to radiating currents, the double wire simulates a single fat wire from which we expect a slightly shorter overall length and a wider operating bandwidth.

Square Interrupted-Loop  
Dipoles: Free-Space  
E-Plane Pattern  
and SWR  
Curves

Fig. 16



For a home-built version of the squared dipole, the folded version may be preferable. Despite its operating bandwidth limitation, the squared dipole interrupted loop is perhaps the most compact 40-meter dipole design available.

5. *The Helical Dipole*: The helical dipole, sometimes called a slinky after a toy of the same name, consists of many turns of wire in an Archimedes (uniform pitch)

spiral. Normally, we place the feedpoint at the center. In practice, amateurs obtain a pre-made spiral of springy wire and stretch the assembly until it arrives at resonance at a desired frequency. For our preliminary assessment, we shall construct a free-space model with about 12 segments per turn, a 6" diameter, and a 400" (33.33') total length to meet our half-length standard while remaining well within NEC limitations. The wire will be AWG #12 copper, although actual slinkys used in practice are often composed of spring steel having relatively indeterminate properties.

As shown in **Fig. 17**, the resonant helical dipole requires 65.2 turns for the specified wire, length, and diameter. The antenna acts like a closed loop rather than like a linear wire. Therefore, increasing the wire diameter has the effect of reducing the electrical length, and the dipole requires more turns within the same length to achieve resonance. Doubling the wire diameter from 0.08" to 0.16" requires 70 turns for resonance at 7.15 MHz. The greater the number of turns in a helical dipole with a fixed diameter, the more wire we need to achieve the overall length. As specified, the sample helical dipole requires about 106.5' (1278") of wire, over 1.5 times the wire needed for a full-size  $\frac{1}{2} \lambda$  dipole.

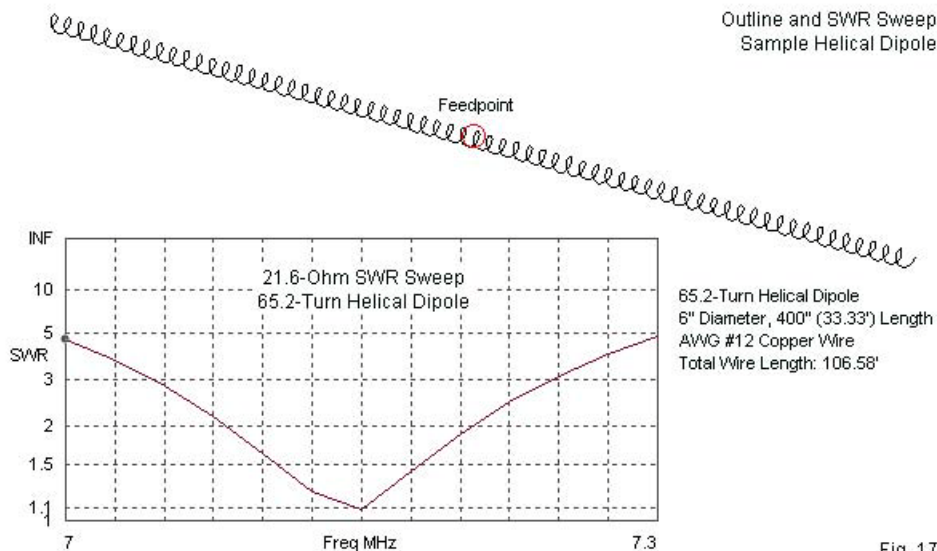


Fig. 17

Like any shortened dipole, the helix has lower gain than a full-length dipole: about 1.48 dBi or the equivalent of a 20% dipole. The resonant impedance is about 21.6  $\Omega$ , with an SWR bandwidth of 125 kHz or only 40% of the total 40-meter band. The efficiency of the sample helix is based upon the large loop diameter and the highly conductive wire. Actual toy slinkys pressed into antenna service tend to have smaller loop diameters and use less conductive material. Hence, the figures given for the sample are operationally optimistic. Users of toy slinkys often find that the feedpoint impedance is close to 50  $\Omega$ , an indication of the greater losses of using the smaller diameter spring-steel devices. Perhaps service as an emergency field antenna remains the best use of the helical dipole.

## **Conclusion and Preface**

We have included only some of the major variations on folding up a dipole to stuff it into a small linear space. For example, we have omitted the center-fed inverted-L antenna, although it is a feasible alternative if we stretch our basic orientation to include vertical antennas. Nevertheless, the samples have shown the general trends of what is possible in the avoidance of directly tackling the impedance matching problems associated with the use of a half-length dipole. In the next episode, we shall look at several techniques of compensating for the very high capacitive reactance of a linear 33.33' wire dipole.

## Chapter 22: 1/2-Length 40M-Dipoles - EI-Loading for Dipole Resonance

**W**e have set the half-length 40-meter dipole (using AWG #12 copper wire) at 33.33' (400"), which is within 1% of the modeled free-space length for such an antenna. We discovered that the precise length of a half-size dipole will actually vary with the height of the element above ground. So our arbitrary limit is useful in giving us a ready reference throughout these notes.

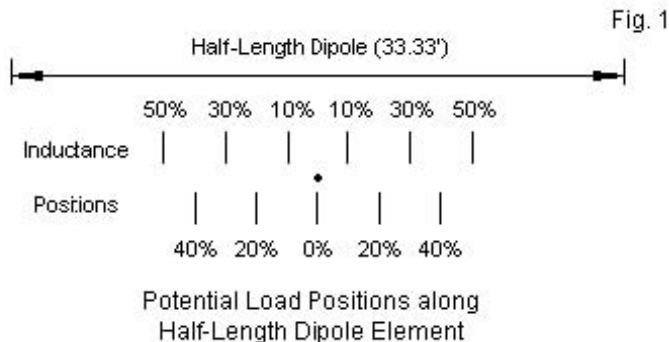
The first set of attempts to deal with this length involved reshaping a full-length dipole to fit this linear dimension. Of the distorted dipoles, the U shape proved most promising, since it provided usable gain and a feedpoint impedance value close to 50  $\Omega$ . However, the zigzag and the square interrupted loop versions may also have applications if we apply appropriate impedance matching techniques. However, only the U (in either an inverted vertical position or a horizontal orientation) held promise of covering the entire 40-meter band with less than a 2:1 SWR value.

In this episode, we shall examine the linear half-length element as a one-dimensional object, that is, one having only length without vertical or horizontal width. The challenge is to deal with the low feedpoint resistance (less than 13  $\Omega$ ) and the high capacitive reactance (more than 900  $\Omega$ ). The two operations are normally separate. We have noted—and shall note again—methods of transforming the feedpoint resistance to a usable (normally 50- $\Omega$ ) value. First, we must compensate for the high reactance. The common expression for the techniques used reduce the reactance to zero and to thereby achieve resonance at the design frequency (7.15 MHz in this exercise) is element loading. If we introduce into the element a reactance of the same effective value, but of the opposite type, as the problematical reactance we measure at the feedpoint, the net effect will be a purely resistive feedpoint impedance, at least at the design frequency. We shall survey some of the variables associated with loading elements. In fact, before we close, we shall look at an additional method that also

bears the name of loading, but which is in principle an entirely different technique altogether.

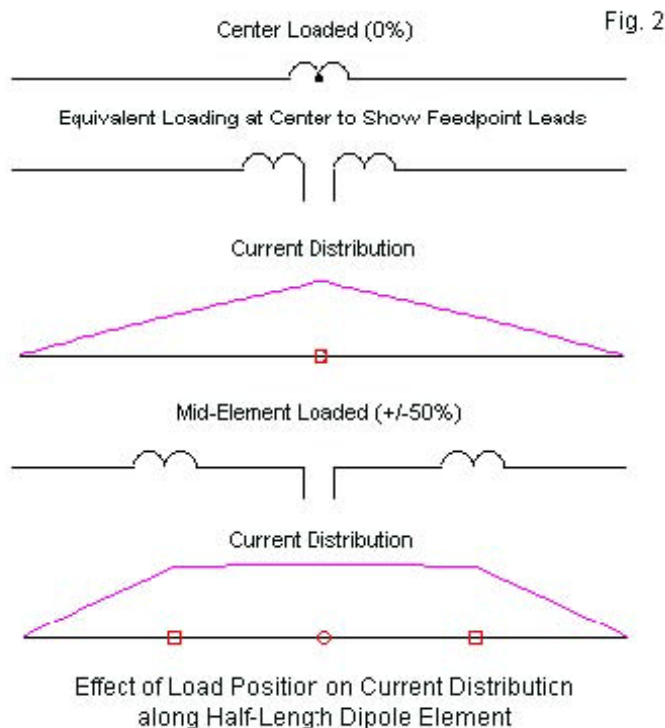
### Inductive Loading

As we shorten the length of a dipole, the feedpoint reactance increases, slowly at first, but at an increasing rate with each additional increment of length reduction. Our half-length dipole intercepts this curve at a challenging point, just where the rate of reactance change begins to increase very rapidly with only small length changes. For reasons that will become very apparent, for most amateur installations half-length is about the limit of shortening.



**Fig. 1** gives us a bit of important information. We may place the opposite type of reactance (inductive) at the element center, or we may place it in the form of two equal inductances away from the element center. For tubular elements, the center position is often mechanically convenient, but outer positions or mid-element loading is often used. If we think of the center inductance as actually two solenoid inductors (coils) in series with the feedpoint at their junction, then we discover that mid-element loading is simply an extension of center loading. **Fig. 2** provides a glimpse into the process.





With a center-loading coil, the current is at peak value only at the very center of the element. A full-length dipole would show a broad region of high current before the current tapers to the element-end value of zero. A center loading coil substitutes for the part of the antenna that is normally at high current. Since the coil has almost no radiation, we lose much of the radiation that the high current would yield, with a resulting gain reduction. In contrast, if we place the coils further away from the feedpoint, we retain part of the element with the high current level. The lower part of the figure shows the current distribution with the

loading coils at the middle or 50% point of each half element on either side of the feedpoint.

Unfortunately, we do not gain as much as the current distribution curve might suggest. Let's install loading coils at various points along the dipole in 10% increments, where 10% means a distance away from the feedpoint toward the element end. Initially, we shall treat the coils as pure inductances with no resistive losses. The results of our small experiment in modeling appear in **Table 1**. In the table, we treat the center-loading coil as a series combination of two coils so that the progression of required inductance values is clear. The farther outward from the center that we place the loading coils, the higher must be the individual inductance values. At the 50% mark, each individual coil has an inductance that is almost double the series center coil. The rate of inductance increase rises steadily as we move away from the center position. For this reason, the 50% mark represents a practical limit to loading inductor placement.

Half-Length Dipole with Inductive Loading				Table 1	
Load Position and Required Reactance and Inductance					
Pos: %	Ld React	Ld Induct	Gain dBi	Resist	React
0	464.85	10.35	1.71	12.7	-0.03
10	513	11.42	1.71	15.32	-0.46
20	570	12.69	1.72	17.81	-0.67
30	645	14.36	1.72	20.31	-0.75
40	748	16.65	1.73	22.86	0.11
50	894	19.9	1.74	25.44	-0.27
Notes:	Pos. %: Position measured from element center to				
	element end as a percentage of distance				
	Ld React: Load reactance in Ohms required to				
	resonate element				
	Ld Induct: Inductance in uH required to yield Ld React				
	Gain dBi: Free-space gain in dBi				
	Resist: Feedpoint resistance in Ohms				
	React: Feedpoint reactance in Ohms				
	Center (0%) load treated as 2 inductances in series				

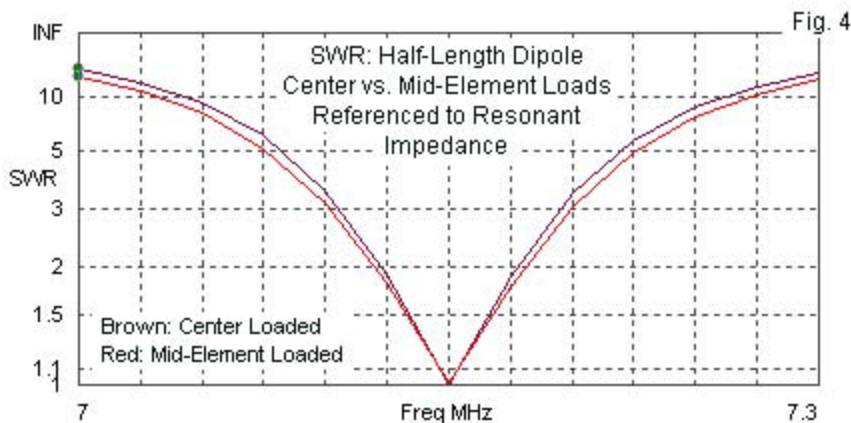
**Fig. 3** graphs the progression of required inductive reactance and inductance values that apply to the loads in the table. The chart allows us to sense more vividly the rate of increase in values with increasing distance between the loading component and the feedpoint.



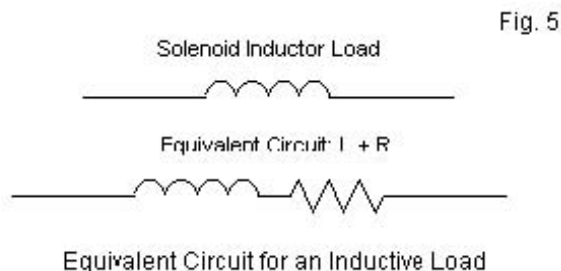
Surprisingly, the element gain does not increase significantly as we move the loading coils outward from the center position (0%). (Mobile vertical monopole antennas have special circumstances that may call for loading-coil placement away from the feedpoint, but our horizontal dipole—here in free space—does not share in those circumstances.) The net difference in gain between center loading and 50% mid-element loading is only 0.03 dB, far short of a difference that we could detect in operation.

The table does reveal a different reason why some antenna builders prefer mid-element loading over center loading. As we move the coil outward, the resonant impedance rises. The center loading value of under  $13\ \Omega$  calls for some form of impedance transformer at the feedpoint if we use a  $50\text{-}\Omega$  cable. In the previous set of notes, we noted some limitations of 1:4 transmission-line transformers. Before such transformers became readily available, antenna builders would employ second coil so that the turns-ratio of the two closely coupled coils created a 1:4 impedance transformer. The 50% mid-element coil placement yields a resonant impedance of about  $25\ \Omega$ . We examined in the earlier notes a single series transformer composed of transmission line sections for converting this impedance to  $50\ \Omega$ .

Regardless of the coil placement, inductive loading has one very negative consequence: very limited SWR bandwidth. **Fig. 4** provides curves for a center-loading coil and for a pair of mid-element loading coils. Coils at all other positions would yield curves that fit between these two limiting cases. The 2:1 SWR bandwidth of the inductively loaded is less than 1/5 of the entire band. (Longer elements with less loading would show wider SWR bandwidth values.)



In our examination of the basic properties of inductive loading with solenoid coils, we have purposely set aside an important aspect of loading: coil  $Q$ . The  $Q$  of a solenoid coil is simply the coil's inductive reactance divided by the series resistance, as shown by the equivalent circuit in **Fig. 5**. Since coil wire is subject to skin effect, the RF resistance of a coil is higher than the simple DC resistance of the wire. As well, the value of  $Q$  and the resulting resistive losses depend on the coil shape.



Let's begin with the center-loading coil, which has a total inductance of over 20  $\mu\text{H}$  to obtain a reactance of over 900  $\Omega$ . Practical values of  $Q$  may range from a low of 100 to perhaps 600 for a coil with a high ratio of diameter to length. Most practical coils tend to fall in the range of 250 to 350. **Table 2** shows the consequences for performance for  $Q$  values between 600 and 100 in steps of 100.

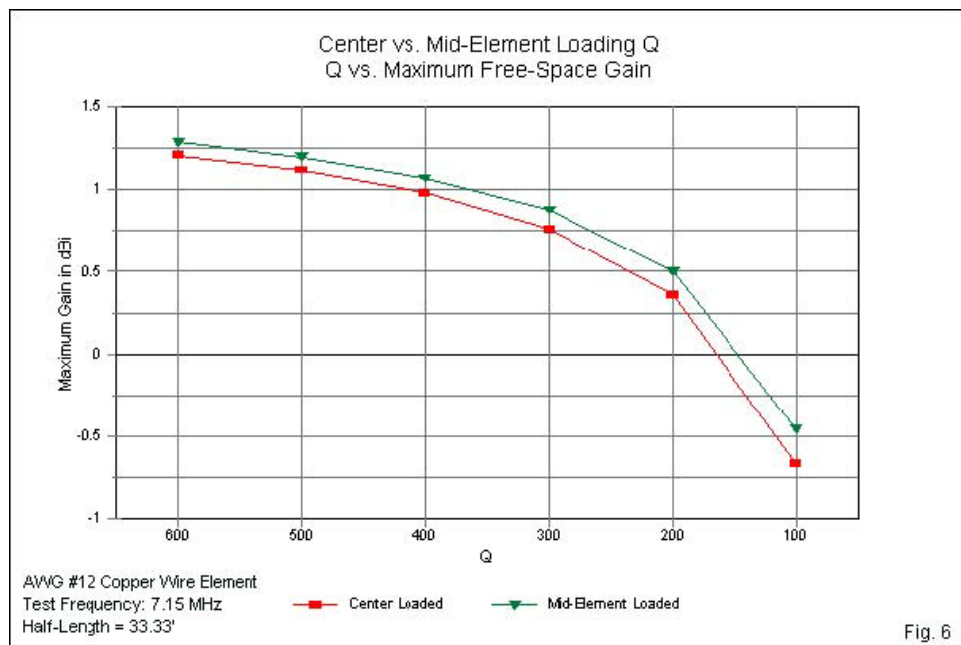
Center-Loaded Half-Length Dipole: Q				Table 2
Reactance: 929.7 Ohms			Inductance: 20.69 $\mu$ H	
Q	Ind Res	Gain dBi	Resist	React
Infinity	0	1.71	12.7	-0.03
600	1.55	1.21	14.3	-0.03
500	1.86	1.12	14.6	-0.03
400	2.32	0.98	15	-0.03
300	3.1	0.76	15.8	-0.03
200	4.65	0.36	17.4	-0.03
100	9.3	-0.67	22	-0.03
Notes:	Q: Loading coil Q			
	Ind Res: Loading coil series resistance			
	Gain dBi: Free-space gain in dBi			
	Resist: Feedpoint resistance in Ohms			
	React: Feedpoint reactance in Ohms			
	Values for a single solenoid inductor			

As we lower the value of Q and thereby increase the resistive losses, we discover a further reduction in dipole gain. The values are still usable, if we remember that the free-space gain of a full-length AWG #12 copper wire dipole is only about 2.05 dBi. However, for low values of Q, the difference is operationally noticeable. In the process of lowering the gain due to resistive losses in the loading coil, we rediscover the resistance in the feedpoint impedance, which is now the sum of the radiation resistance and the loss resistance. By itself, the impedance with a Q of 100 seems promising until we remember that nearly half of it represents lost energy.

Mid-Element-Loaded Half-Length Dipole: Q Table 3				
Reactance: 894 Ohms			Inductance: 19.90 $\mu$ H	
Q	Ind Res	Gain dBi	Resist	React
Infinity	0	1.74	25.4	-0.27
600	1.49	1.29	28.3	-0.31
500	1.79	1.2	28.8	-0.32
400	2.24	1.07	29.7	-0.34
300	2.98	0.88	31.1	-0.37
200	4.47	0.5	33.9	-0.43
100	8.94	-0.46	42.3	-0.67
Notes:	Q: Loading coil Q			
	Ind Res: Loading coil series resistance			
	Gain dBi: Free-space gain in dBi			
	Resist: Feedpoint resistance in Ohms			
	React: Feedpoint reactance in Ohms			
	Values for each of two solenoid inductors			

We can repeat the exercise with loading coils placed at the mid-element (50%) position. When separated from the feedpoint, neither the coil inductance nor its impedance impact the feedpoint resistance directly. Therefore, we find a small variation in the feedpoint reactance column that was absent from the center-load table. However, the trends are identical. The lower the value of coil Q, the lower will be the overall antenna gain, but with a rise in feedpoint resistance that reflects the increased losses in the coils. The gain values may seem to be higher for the mid-element loading case than for the center loading situation, but **Fig. 6** shows just how little that difference is. Moreover, the curves almost exactly parallel each other across the sampled span of Q values.

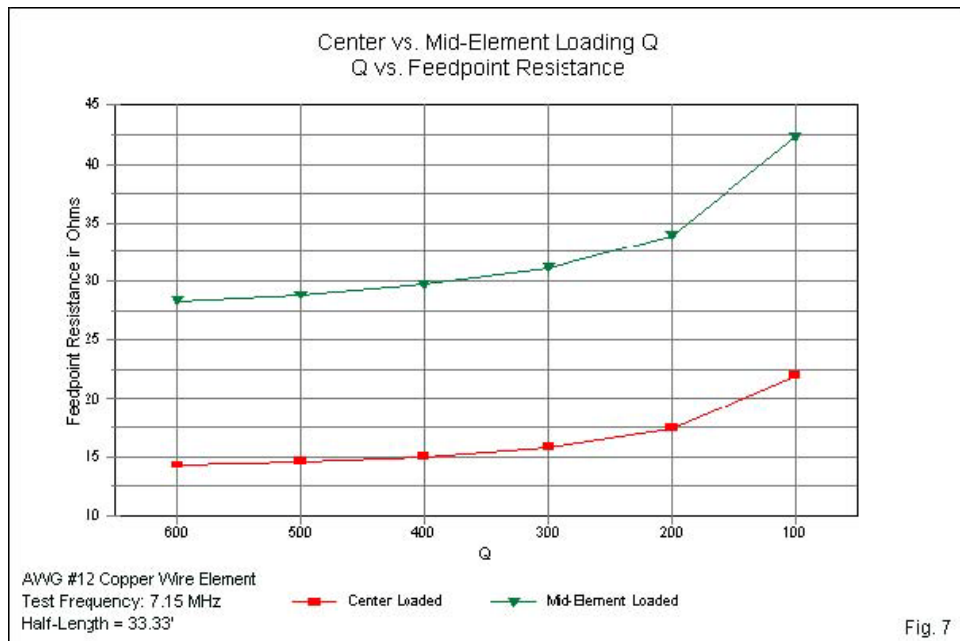
The trends for the resonant feedpoint resistance show a comparable set of parallel curves, even though the initial values for the curves are more widely separated. **Fig. 7** shows the two data sets. A high-Q loading coil set for mid-element loading provides a matchable situation relative a 50- $\Omega$  transmission line. The low-Q situation may in fact allow a direct match to the cable, although at the cost of considerable gain from the antenna element.



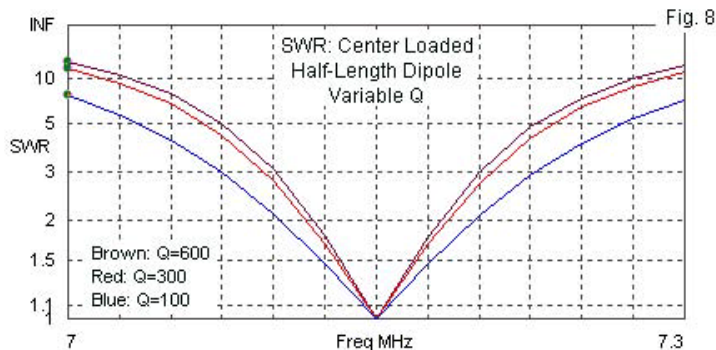
Of course, the mid-element loading coils, with their high inductive values, also present special support problems not fully shared by the center-loading coil. Each mid-element coil is nearly the same weight (given a fixed construction method for a fixed level of  $Q$ ) as the single center-loading coil. For a wire element, such as our copper wire half-length dipole, the coils can create significant sag. In antennas using tubular aluminum as the desired material, a center-loading coil is in line with the normal single support for the element. In contrast, mid-element loading coils place the weight away from the supporting mast, increasing gravity's stress on the element and also increasing the element's wind load. The use of mid-element loading coils for a 33' aluminum element (about the length of a 20-meter full-length dipole) may call for increased tubing sizes, with some sections doubled, to support the coils effectively for the



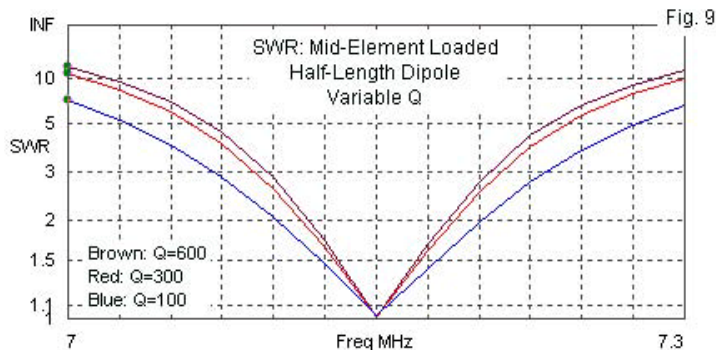
same all-weather, all-season survivability as a single center-loading coil. The knowledgeable antenna builder will take these factors into consideration long before actual antenna construction begins.



Loading coil Q has an affect upon the SWR bandwidth of a half-length dipole. However, the broadening of the bandwidth does not become significant until the Q drops below about 300. **Fig. 8** shows the SWR bandwidth (referenced to the resonant impedance of each sample) of a center-loaded dipole for Q values of 600, 300, and 100. Only in the last case do we find a bandwidth that approaches 100 kHz, at the cost of appreciable gain, of course. For the two higher values of Q, we find bandwidths ranging from a little under 50 kHz to a little over 50 kHz.

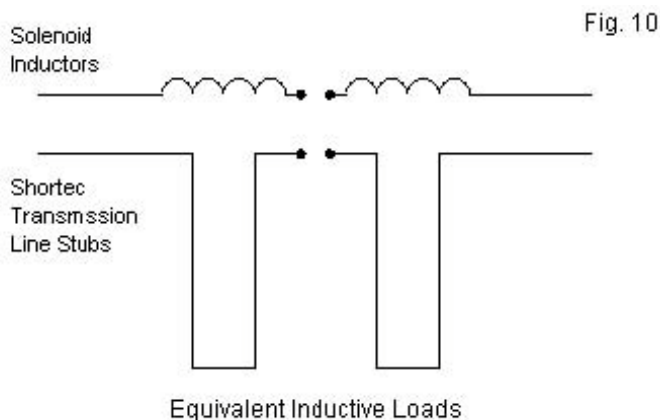


Moving the loading coils outward to the mid-element (50%) position does not improve the bandwidth beyond the very slight advantage shown by the initial lossless coils, as revealed by the SWR curves in **Fig. 9**. High values of  $Q$  yield a bandwidth of about 70 kHz, while a  $Q$  of 100 yields a 100-kHz bandwidth. One of the severe limitations of inductive loading is always the limited coverage of an amateur band as wide as 40 meters compared to a full-length dipole, however, we may implement the required element loading.



## Linear Loading

In the history of amateur radio's experimentation with loaded elements, beyond the range of direct recall, an alternative system of loading emerged. Called "linear loading" by its early users (and some present-day users), the scheme used lengths of wire, usually paralleling the main element, to effect the required loading. Because the scheme did not use inductors with known loss sources, early proponents claimed that linear loading was lossless. Once we began to understand exactly what was going on—besides adding a set of wires to an element—the claim of no losses began to disappear. As shown in **Fig. 10**, the wires actually form shorted transmission line stubs that replace solenoid inductors as the source of loading reactance for an element. Unfortunately, shorted transmission line stubs do exhibit losses.

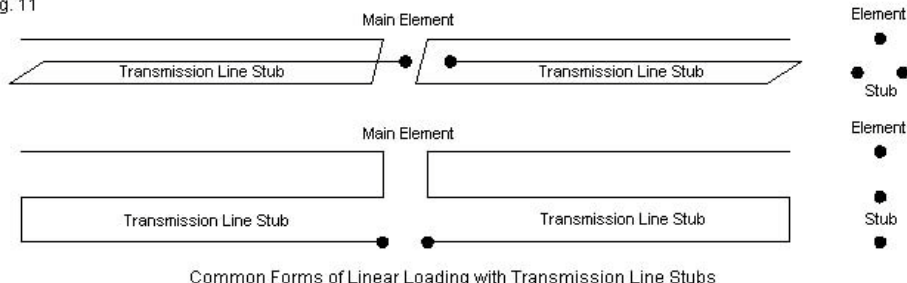


The calculation of stub length requires a two-step process. First, we can calculate the likely characteristic impedance ( $Z_0$ ) of the stubs by knowing the wire diameter and the spacing (center-to-center) between wires, using any of several utility programs or a calculator. Then the inductive reactance of a

shorted stub that is less than  $\frac{1}{4} \lambda$  long is simply the product of the  $Z_0$  times the tangent of the electrical length of the stub in degrees (or radians). If we know the desired reactance, we can always back out the electrical length in degrees and then the physical length as a fraction of a wavelength, and finally, the physical length in inches or feet.

There are two general implementations of linear loads for an element, both of which are applicable to our 40-meter half-length dipole. **Fig. 11** provides an outline of both forms. First, in both cases, the linear load or transmission-line stubs do not hang at right angles to the element, although the hanging configuration is possible, however impractical. Instead, we parallel the stubs, one on each side of the feedpoint, to the main element. In the first case, the shorted stub lines are equidistant from the element and form a triangle when taken together with the main element. Under these conditions, the lines act most like a pure transmission-line stub, since coupling with the main element is equal on both lines.

Fig. 11



The second case that places the stubs in a linear row beneath the main element is more common to home built wire antennas than to commercial implementations of linear loading. In this scheme, the differential coupling between the two wires and the main element creates a small imbalance in the currents in the load lines. The system will still work perfectly well, but usually requires a longer stub length on each side of the feedpoint.

Unfortunately, if we restrict ourselves to a main element with a total length of 400", the stub lengths will slightly exceed the element length. The antenna will still work, but for the sake of aesthetics, I set each type of linear load so that the load lengths and the element length were all the same. All AWG #12 wires in each scheme are two inches apart. **Table 4** shows the differences in the free-space models. The table also includes a special entry that uses NEC transmission lines with the same total length as the element. I assigned the lines a typical ladder-line loss factor of 0.06 dB/100' at 10 MHz to sample potential line losses.

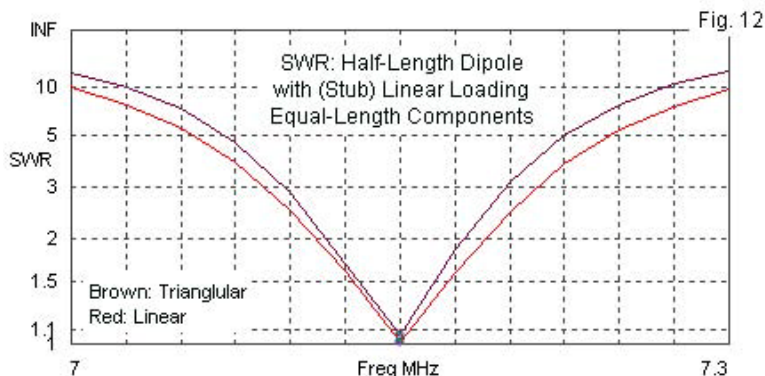
Table 4. Linear loading using shorted transmission line stubs

Model Type	Half Length Inches	Max Gain dBi	Feedpoint Z R +/- jX $\Omega$
NEC Xmsn Lines	204.2	0.86	16.8 - j0.0
Triangular Wires	205.0	0.49	17.1 + j0.9
Linear Wires	210.4	0.77	17.0 - j0.1

Notes: Transmission-line stubs and main elements are the same length.  
Total dipole length is twice the length shown.  
Each of two shorted stubs is the length shown.  
All wire assemblies use AWG #12 copper wire.  
Wire Spacing: 2".  
Model environment: free space.

The first notable item in the table is the similarity of antenna lengths when using non-interactive NEC transmission lines and when constructing the lines from copper wires in a triangular formation allowing equal interaction of the main element with each stub wire. The gain suggests an overly optimistic assignment of losses to the NEC lines. The triangular version of the wire loads shows increased gain if we move both stub wires farther from the main element. At a distance of 4", the level of the lowest wire in the linear system, the gain rises to about 0.7 dBi. The gain is similar to the value that we obtain from the linear system, which requires about 5" of additional length at both ends of the element-stub combination.

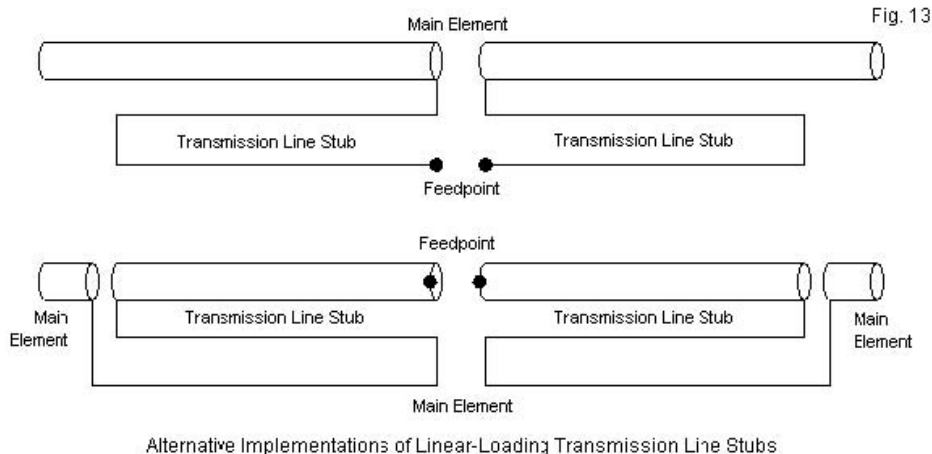
The gain values are consistent with a center-loading system with a  $Q$  of about 300. Since the loads are electrically about 1% to 2% off center, the feedpoint impedance values are also consistent for  $Q$  values of about 300. We may note in passing that all three impedance values are sufficiently alike to confirm the equality of the three schemes shown.



As shown in **Fig. 12**, the SWR bandwidth of a linear loaded system is only marginally broader than the curves for the center-loaded dipole with a  $Q$  of 300. The linear system is slightly broader than the triangular system, but again in the margins of significant improvement. The curves also establish the limited  $Q$ -equivalence of linear loading, since a very high  $Q$  or very low loss value for the linear loads would yield a narrower SWR operating bandwidth.

Perhaps the chief reason for using linear loading has little to do with the performance of the element. Rather, by distributing the weight of the loading element along the entire length of the antenna, we generally remove many of the support problems that accompany the use of coils in a wire antenna that we intend to support only at the ends. Linear loads in some circumstances offer a mechanical advantage in antenna construction.

One perennial matter of perspective sometimes clouds the eyes of less experienced antenna builders. Suppose that we intend to use a tubular main element, with wires or rods for the linear loading elements. We might end up with an assembly like the upper half of **Fig. 13**, shown in linear form for pictorial clarity. The feedpoint clearly goes to the pair of transmission-line stubs. However, numerous commercial linear-loaded elements (usually for 20 meters and higher) bring the feedpoint to the tubular element and use a set of wires or rods that seem to begin at a point further outward on the element. It appears that the antenna is using a form of linear loading that is a version of mid-element loading. For whatever reason, the antenna builder has bent the linear loading stubs back toward the center of the element. Unfortunately, this view of the lower element sketch can deceive us.



The lower sketch is electrically identical to the upper sketch. In this case, the loading element is composed of two wires with different diameters, a situation that slightly complicates the calculation of the stub characteristic impedance. The main element employs one of the thinner lines as part of its structure until

that line intersects with the tubular material beyond the end of the stub. (There are cases in which one may employ mid-element loading with a transmission-line stub, but they require elements longer than the half-length dipole that we have set as our project limit. With element lengths about 70% of full size, one may install a mid-element stub and bend it outward toward the element end—or let it hang in the wind.)

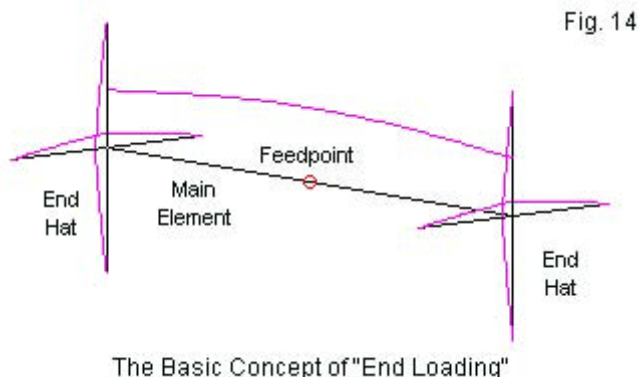
Linear-loading, then, is simply a form of inductive loading that makes use of shorted transmission-line stubs to create the necessary inductive reactance to bring an element to resonance. The stubs are substitutes for the solenoid inductors that we most commonly think of when the subject of loading arises.

### *End-Hat Loading*

For many decades, an alternative form of bringing a shortened element to resonance has gone under a misleading label: end capacity-hat loading. The name derives from an early method of approximating the hat size on low and medium frequencies. The calculation scheme breaks down in the HF region into a complex of factors that include the relative sizes of the wires making up the hat and the main element, and capacity has little if anything to do with the method of resonating a short element. The “hat” portion of the name has some visual validity, since the system requires the installation of a symmetrical set of wires on and at right angles to the ends of the shortened main element. It is dubious whether the system of resonating a short element even deserves the name “loading.”

**Fig. 14** shows the outline of a simple short dipole. On each end, we find a set of four equal length wires symmetrically arranged. Under these conditions—using the correct lengths for the spokes in the hat wheels—we can obtain resonance and the current distribution pattern shown in the sketch. Up to the point at which the hats begin, the shortened dipole shows a current distribution curve that is virtually identical to one that would occur over the same central length of a full-length dipole.

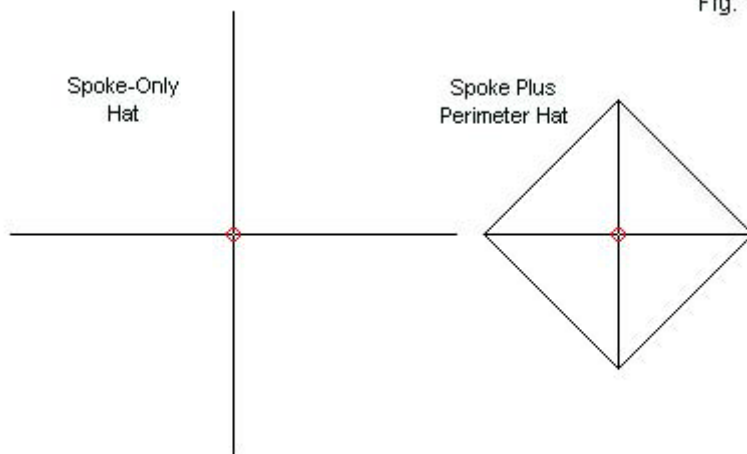




At the junction of the main element and the hat wires or spokes, the current divides equally into four branches. It continues to decrease toward the spoke tips, just as it would in a full size dipole. However, any radiation from a given spoke is offset by the radiation from the other spokes so that there is virtually no far-field radiation from the spoke assembly. Hence, the central section of the dipole controls the far-field pattern with respect to both the pattern shape and strength.

There are two general forms of constructing end hats that provide resonance in a shortened dipole of some specific central length. One system uses only radial spokes. The other system uses spokes plus a perimeter wire. **Fig. 15** shows the relative sizes of such assemblies with 4 spokes and applied to the half-length (33.33') dipole with which we have been working. With a perimeter wires, we can reduce the spoke length significantly (by 40% or more). In the spoke+perimeter wire system, we can think of the spoke length as consisting of the spoke itself plus half the length of the perimeter wire that connects one tip to the next.

Fig. 15



Relative Hat Sizes: Spoke-Only vs. Spoke + Perimeter

The two systems are electrically equivalent. Adding intermediate wires circling the spokes generally adds almost nothing electrically to the hat, although such wires might be useful in large hats to help brace the spokes. For our 400" AWG #12 copper wire dipole with hats composed of the same material in alternative spoke-only and spoke+perimeter wire configurations, we can sample the free-space performance in **Table 5**.

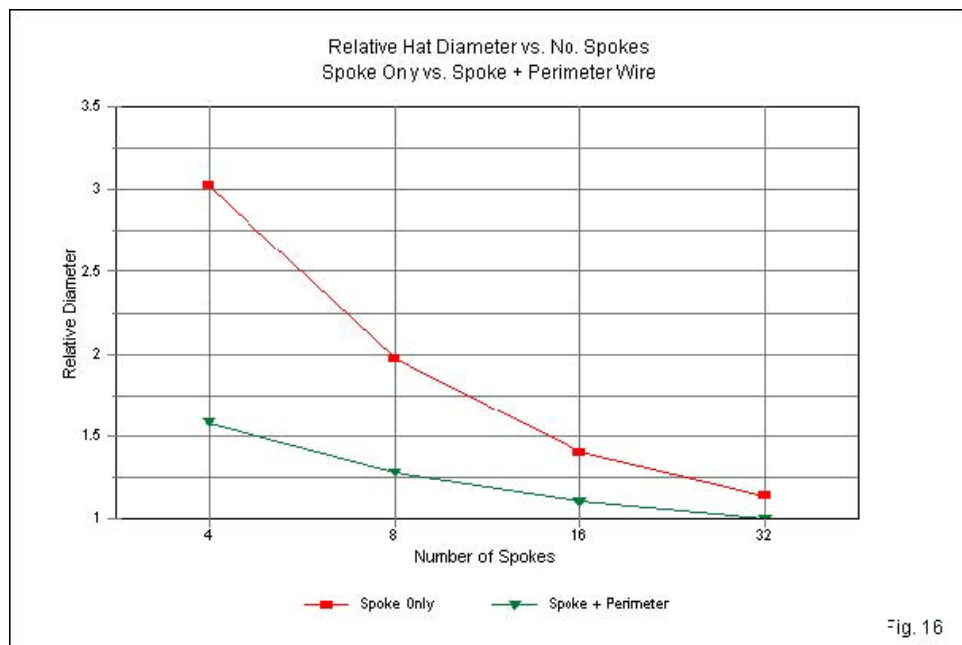
Table 5. Performance of half-length dipole with two types of end hats

Hat Type	Spoke Length Inches	Max. Gain dBi	Feedpoint Z
Spokes only	31.5	1.79	$38.9 - j0.1$
Spokes plus perimeter wire	46.5	1.80	$39.0 + j0.8$

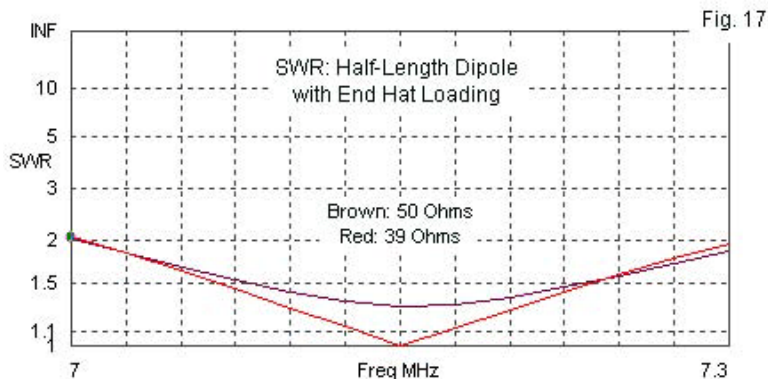
Notes: Element length 400" (33.33').  
Element and hat wires: AWG #12 copper wire.  
Samples use 4 spokes per end hat.

The table establishes the electrical identity of the two systems. We can further shorten the length of the spokes in either system by adding more spokes. **Fig. 16** provides a sample of modeled systems using 4 through 32 spokes and records the relative spoke length using the shortest spoke as the base line. As we increase the number of spokes, the two curves gradually converge. Somewhere in the vicinity of 60 spokes or more, the two lines come together as the assembly effectively simulates a solid or a wire-mesh surface.

We should not pass over the data in **Table 5** only noticing the similarity of the numerical entries. The gain of the hatted half-length dipole does not show the decrease that marked all forms of inductive loading, since the primary radiating portion of the element has no loss other than the resistivity of its copper wire. In fact, the gain values are up (by less than 0.1 dB) because the hat structure does narrow the dipole beamwidth by about 2°. Despite its mechanical inconvenience, a hatted short dipole delivers all of the gain possible from an element of the given length.



In addition, the hatted dipole shows the highest resonant impedance of any of the versions of the half-length dipole where the impedance is not artificially raised by loss resistance. The test frequency value of  $39\ \Omega$  would increase to a value closer to  $50\ \Omega$  without much further lengthening of the main element (along with accompanying shorter spoke lengths in the hat).



The feedpoint impedance shows a further advantage of hat loading: the SWR curve is virtually as broad as the curve for a full-length dipole. The sample antenna offers full-band coverage with less than a 2:1 50- $\Omega$  SWR even though the test-frequency impedance is a bit lower than optimal. Despite all of these advantages, the physical difficulty of implementing end hats on shortened elements tends to discourage the use of this technique, especially in the lower HF region.

There are many variations on the hat theme. Among true (symmetrical) hats, perhaps the most promising is the double concentric spiral that can include a considerable quantity of wire in a smaller space than even the spoke+perimeter wire system. A tight single spiral works well, but due to its asymmetry, the SWR bandwidth tends to be smaller.

**Fig. 18** provides a sample of a half-length dipole equipped with end extensions composed of single spirals. All parts of the assembly are AWG #12 copper wire. Like the hat-loaded dipole, the main element is 400" (33.33'). The spirals consist of 5 equally spaced turns of wire with an outer or limiting diameter of 46.46" (3.87'). This value is virtually identical to the spoke length required for the hats

that used a perimeter wire. Hence, the spiral would require about half the space of the 4-spoke hat, although we might shrink the hat by adding more spokes.

The single spiral, however, is not a true hat with virtually complete cancellation of radiation from the end assembly. There is a small component of radiation at right angles to the main element. The free-space gain is 1.73 dBi, a small amount below the level of the hatted assembly (about 0.07 dB). This difference is operationally insignificant. The feedpoint impedance at the test frequency (7.15MHz) is  $40.0 + j0.9 \Omega$ , almost identical to the value derived from the hatted half-length dipoles.

The shortcoming of the single-spiral end extension shows up in the 40- $\Omega$  SWR sweep in the lower portion of **Fig. 18**. The true end hat allowed full band coverage with an SWR of 2:1 or less. In contrast, the single spiral provides the same level of SWR performance over only about 60% of the band, for the sample, from about 7.06 to 7.23 MHz. In addition, the support requirements for the spiral may prove to be more complex than those needed by the hat.

Nevertheless, for some applications, the single spiral may be an attractive alternative to a true hat. As a further alternative, one may create a double opposed spiral on each end of the dipole and achieve the symmetry required for true hat performance.

Fig. 18

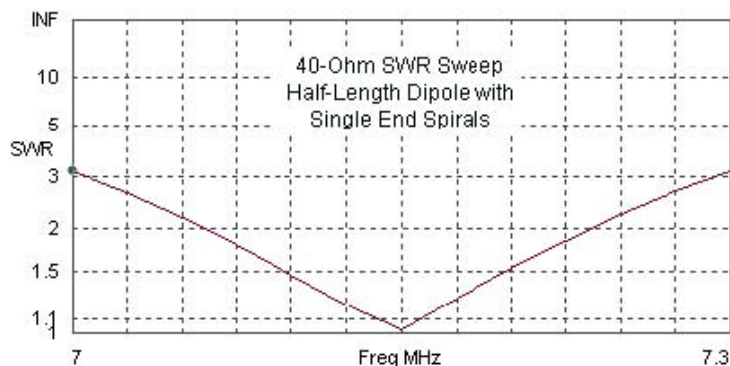
Outline and SWR Sweep  
Half-Length Dipole with  
Single Spiral End Extensions

Spirals: 5 Turns  
Diameter: 46.5" (3.87')  
Equal Spacing Between Turns

Feedpoint

Main Element:  
400" (33.33')

All parts of the spiral-loaded  
dipole are AWG #12 copper wire.



### Conclusion and Preface

In one sense, we have completed our task of examining the half-length dipole and the main ways of utilizing the antenna. Among reshaped full-length dipoles,

the U form proved most promising. Turning to loaded elements, the hat system preserved the greatest performance and operating bandwidth of the full-size element. These conclusions do not overrule the use of other techniques as circumstances dictate.

Perhaps we should consider one more episode before we close the book on the half-length dipole. There are many antenna arrays based on the dipole, most notably the parasitic array that we call the Yagi-Uda (or Yagi for short). We might find something interesting in exploring that antenna—and variants—using our half-length copper wire 40-meter element.



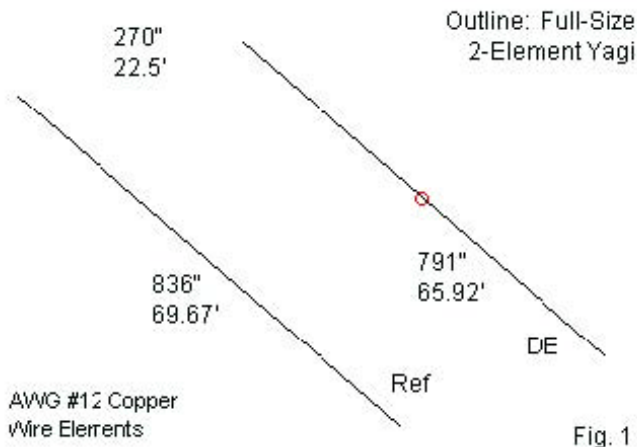
## Chapter 23: 1/2-Length 40M-Dipoles - Basic Loaded-El Parasitic Beams

**T**he two major strategies that we have used in shortening the linear span of a 40-meter dipole have been reshaping the full-length dipole and loading the half-length version. Of the various shapes used, the U configuration may have some application to more complex antenna arrays. Since the loaded elements are still essentially linear, they may have more direct application. Nevertheless, both reshaping and loading have significant consequences for the performance of more complex multi-element antennas.

Our final exercise in this series of notes will examine some of the consequences. The focal array will be a 2-element Yagi-Uda parasitic beam composed of a driver or driven element and a reflector element. We shall begin with a review of a full-size Yagi and then proceed to various alternatives that use shortened elements that we have previously explored. As in past episodes, we shall employ AWG #12 copper wire throughout, even though the 400" (33.33') main elements lend themselves to construction using aluminum tubing in sizes similar to those used in full-size 20-meter beams.

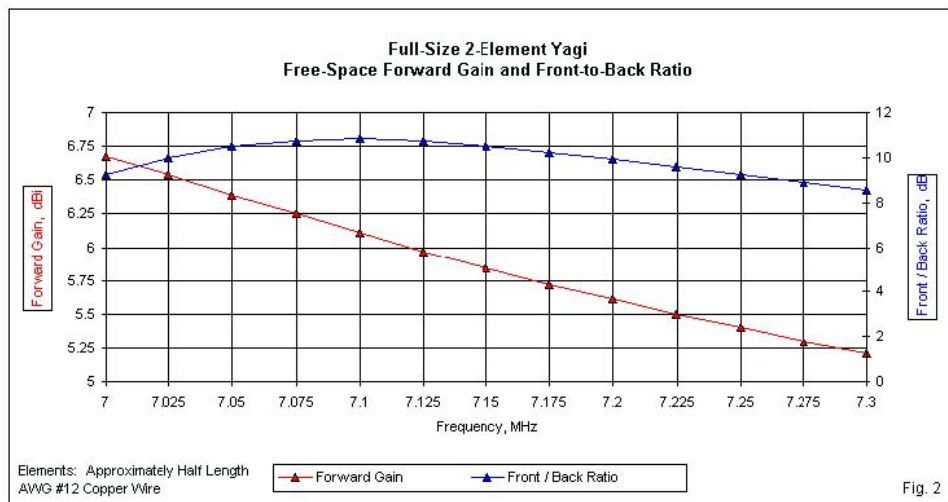
### *A Full-Size 40-Meter 2-Element Yagi*

Two-element driver-reflector Yagis may use a variety of element spacing values. Although peak front-to-back ratio tends to occur with a spacing of  $0.125 \lambda$ , the feedpoint impedance tends to be only about half the value at resonance (about  $35 \Omega$ ) as the impedance of a single dipole (about  $70 \Omega$ ). However, we may increase the spacing between elements to raise the impedance to a desirable level (usually  $50 \Omega$ ) with only a few tenths of a dB loss in gain and less than 1 dB loss in front-to-back ratio. The exact spacing value depends upon the element diameter and the resulting level of mutual coupling between the two elements in the array.

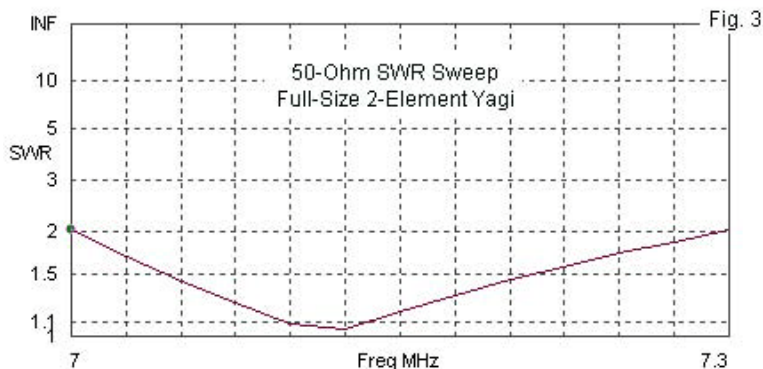


**Fig. 1** shows the outline of a full-size 2-element Yagi with a spacing of 270", about  $0.145 \lambda$ . The element lengths reflect values necessary for relatively peak front-to-back performance and resonance at 7.115 MHz, slightly below the center of the band. We shall soon discover the reasons for moving the resonant frequency downward from the value used for single dipole elements. The overall performance of the Yagi in terms of free-space gain and front-to-back ratio appears in **Fig. 2**.

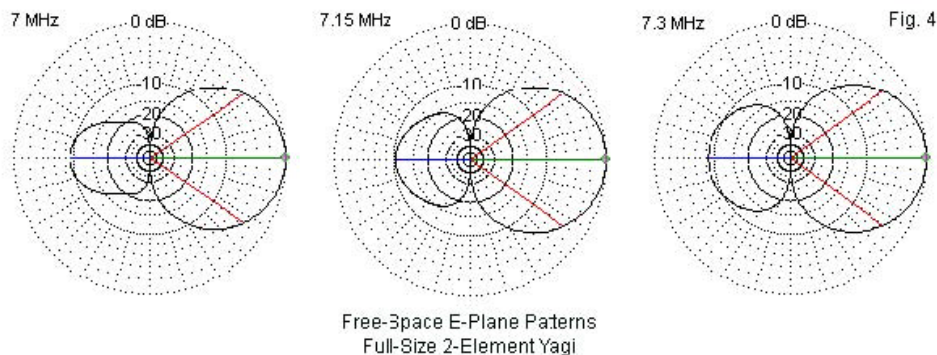
Like all 2-element driver-reflector Yagis, the gain shows a continuously decreasing value across the passband. Fatter elements decrease the rate of descent, but the trend is endemic to this element configuration. In contrast, the front-to-back curve shows only modest value decreases as we move away from the peak value. Note that the front-to-back ratio decreases more rapidly below the design frequency than above it. With closer element spacing, the overall curve would be steeper: wider spacing tends to increase the operating bandwidth of the antenna in terms of basic performance parameters.



We find a similar pattern in the 50- $\Omega$  SWR sweep for the full-size Yagi. At 7.115 MHz, the impedance is  $50.5 - j0.3 \Omega$ . The impedance is about 70% of the value for a single dipole and handy for directly matching the antenna feedpoint impedance to the characteristic impedance of 50- $\Omega$  coaxial cable. Using a design frequency lower than the arithmetic band center allows the antenna to achieve a 2:1 SWR or better across the entire band. Like the front-to-back curve, the SWR curve is steeper below the design frequency than above it. Wider spacing would raise the resonant impedance and broaden further both the SWR and the front-to-back ratio curves.



The full-size Yagi provides relatively even performance across the entire band, as suggested by the free-space E-plane pattern in **Fig. 4**. The only exception, of course, is the forward gain, which decreases by a total of about 1.5 dB across the 300 kHz of the 40-meter band.



The 2-element full-size driver-reflector Yagi is a very serviceable array on almost any amateur band. The front-to-back ratio is never outstanding in this configuration due to limitations of how the relative element geometry affects the current magnitude and phasing on the rear element for spacing values greater than  $0.1 \lambda$ . We may obtain better results with closer spacing or by using a driver-director configuration, but the feedpoint impedance tends to drop to very low values and the operating bandwidth for all the performance parameters becomes very narrow.

The full-size Yagi provides a baseline of data to which we compare corresponding data for short-element Yagis that use one or another form of loading. Specifically, we shall examine Yagis with half-length elements that use center loading, mid-element loading, and hat loading. One general error that is common to less experienced attempts to create short-element Yagis is the tendency also to shrink the element spacing. The basic rules of element spacing do not change when we shorten elements. Wider spacing increases operating bandwidth, especially with respect to the front-to-back ratio and the SWR coverage. As well wider spacing yields higher feedpoint impedance values than closer spacing. Since many of our loaded dipoles already show low impedances, sustaining a usable feedpoint impedance value is significant to a successful short-element beam.

### *A Half-Size 40-Meter 2-Element Yagi with Center-Loaded Elements*

The first of our Yagis using half-length (400") elements employs center loading. The outline, roughly in scale to the sketch of the full-size Yagi, appears in **Fig. 5**. The first notable feature is the fact that neither element is precisely 400" long. In general, we can usually obtain slightly better performance from a center-loaded pair of elements by setting the load values at the same level on each element and then making small adjustments to the element length. This practice also corresponds to actual antenna construction. We can usually more easily change the two element lengths than we can change the loading inductors. The required loading inductors for the sample beam are close to but not identical with the inductors used in the preceding episode with a single dipole element. When

constructing a 2-element driver-reflector beam—with or without loading—fine adjustment is a normal procedure.

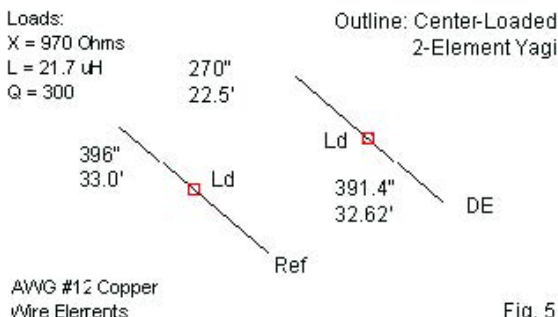
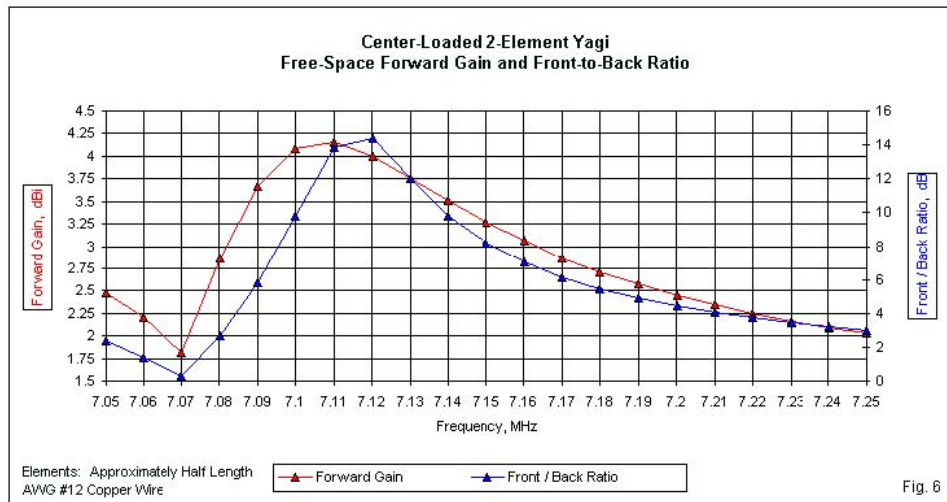


Fig. 5

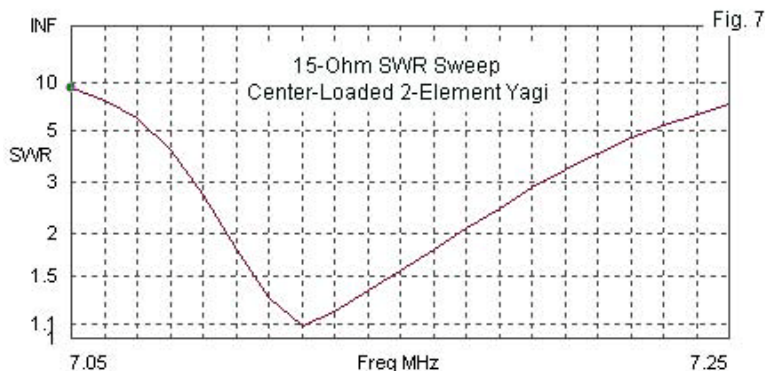
Center loading severely reduces the operating bandwidth of a Yagi, even with loads with  $Q$  values of 300, as used in the sample array. The performance sweep for the center-loaded Yagi extends only from 7.05 to 7.25 MHz, but the operating range is even more restrictive. At the low end of the gain and front-to-back graph in **Fig. 6**, we see a pair of minimum values for gain and for the front-to-back ratio. At the frequency of minimum value, we find a pattern reversal.

Like the full-size Yagi, the center-loaded Yagi with half-length elements shows much steeper curves for both gain and front-to-back ratio below the design frequency (7.115 MHz) than above it. As well, the peak values of both curves are notable. Element loading with a finite value of  $Q$  (and hence with losses associated with the loading element resistance) reduces the maximum gain that we can achieve from the array. The full-size Yagi obtains a peak gain of well over 6 dBi, but the maximum gain for the center-loaded short-element Yagi is about 4.15 dBi. By the upper end of the frequency sweep, the gain has decreased to simple dipole levels.



In contrast, the peak front-to-back ratio improves with element loading. The full-size Yagi achieves a peak front-to-back ratio of slightly less than 11 dB, but the center-loaded version reaches almost 15 dB. The 4-dB difference is operationally noticeable and has led new beam users to mistake rearward quieting for forward gain. The front-to-back ratio aids reception by attenuating signal strength away from the desired communications target, but only forward gain provides that target with a stronger signal from one's transmitter.

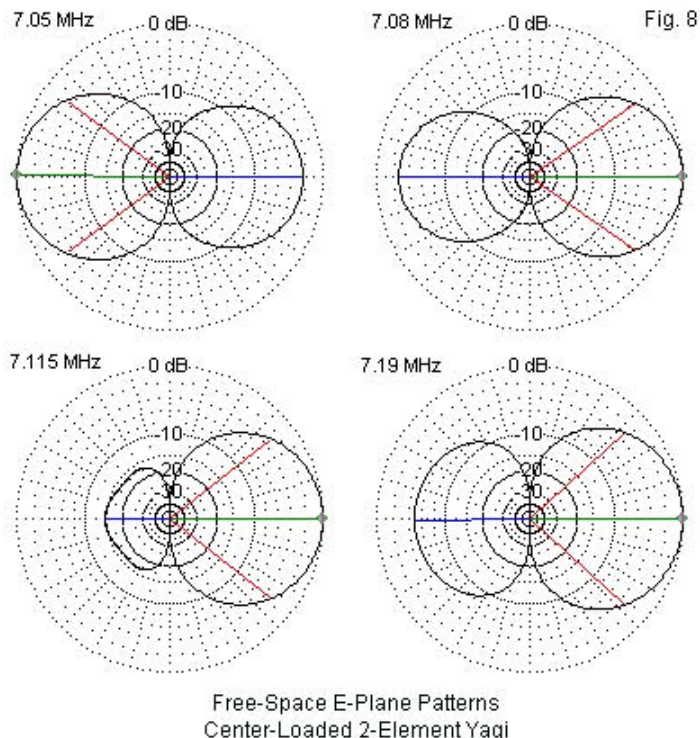
Many of the points about gain and front-to-back ratio at frequencies away from the design frequency become moot when we examine the SWR curve in **Fig. 7**. Assuming that we have a suitable low-loss means of transforming the 15- $\Omega$  resonant feedpoint impedance to match the impedance of our feedline, the SWR bandwidth remains very narrow. The center-loaded short-element Yagi covers only about 70 kHz with less than a 2:1 SWR referenced to the resonant impedance.



The free-space E-plane patterns in **Fig. 8** are also revealing. The set includes a pattern for 7.05 MHz, a frequency below the minimum gain and front-to-back values that we saw in **Fig. 6**. The pattern direction reversal is very evident, indicating a useless portion of the band for this particular beam design. The remaining patterns include an optimal pattern at the design frequency. Both above and below the design frequency, the patterns quickly degrade. The normalized plots show the rapid reduction in the front-to-back ratio, as the rearward lobe quickly grows. To see the reduction in forward gain, read these plots in conjunction with the gain and front-to-back graph.

In practical terms, adjusting this type of beam so that the most significant performance parameters (gain, front-to-back ratio, and SWR) roughly coincide in frequency can be a somewhat daunting task, since small changes of dimension can yield large changes in the peak frequency for a given performance specification. Designing and constructing a center-loaded short-element Yagi is not a task for the newer antenna builder.





### *A Half-Size 40-Meter 2-Element Yagi with Mid-Element-Loaded Elements*

With adjustments to the feedpoint impedance, the mid-element loaded dipole performance is similar to the center-load version. Therefore, we would expect that a short-element driver-reflector Yagi using mid-element loading should perform similarly to its center-loaded counterpart. Our expectation will not be disappointed.

**Fig. 9** outlines the sample mid-element loaded Yagi. The element lengths are identical to those used with the center-loaded antenna. As a result, the required load values are slightly higher than those used in the dipole that we examined in the preceding episode. The present beam also retains the same 22.5' element spacing as the full-size and center-load Yagi beams. The element spacing results in a beam that is, with shortened elements, still under square by a ratio of 3:2. (A version of the beam using tubular elements might have slightly wider spacing, but not to a significant degree that would change the ratio of element length to element spacing.)

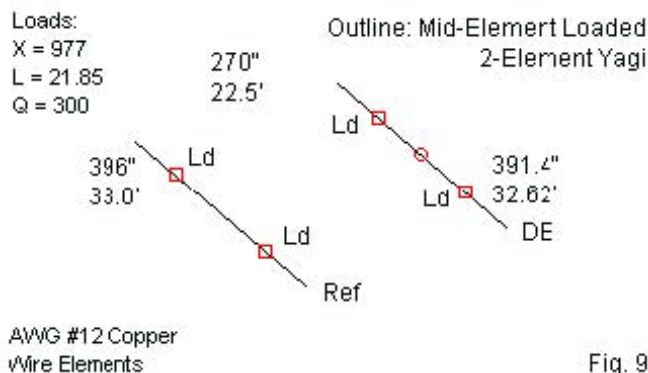
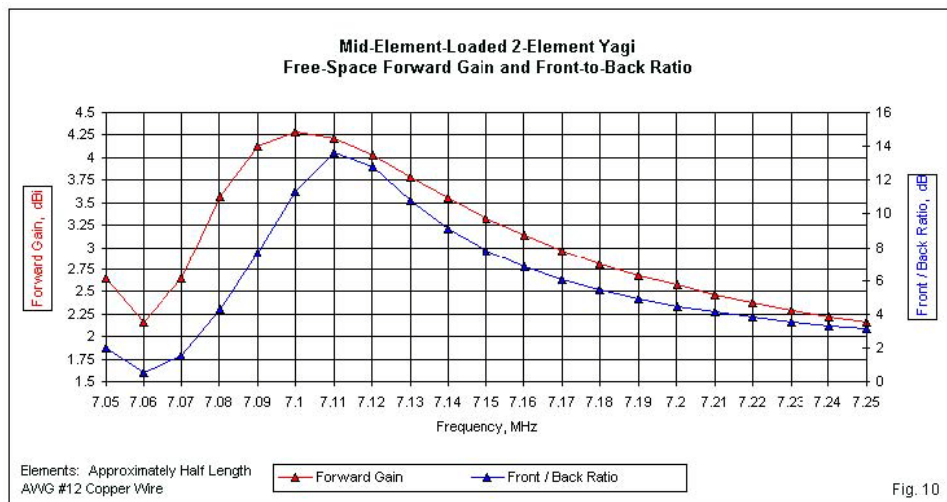
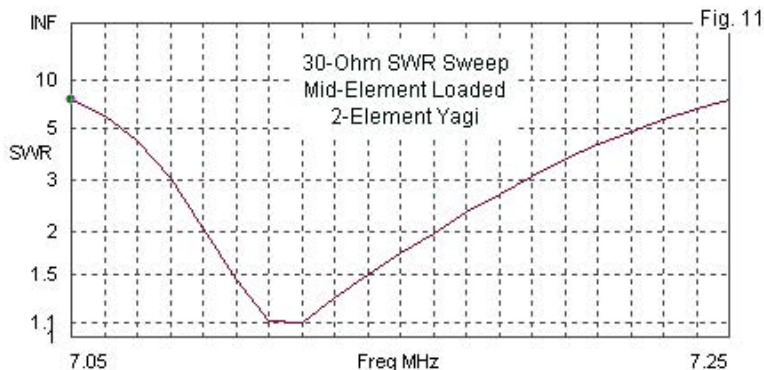


Fig. 9

The performance of the mid-element loaded Yagi follows the trends set by the center-loaded version, although some details differ. **Fig. 10** graphs the free-space gain and the front-to-back ratio from 7.05 to 7.25 MHz. The gain exceeds that of the center-loaded Yagi by a few hundredths of a dB, obviously a trivial amount. Contrarily, the front-to-back ratio does not quite reach the same peak values, but again, not by an amount that would register operationally. The gain and front-to-back ratio reach minimum values near the lower limits of the frequency sweep. As well, the upper end of the sweep shows values that decrease nearly to simple dipole levels.

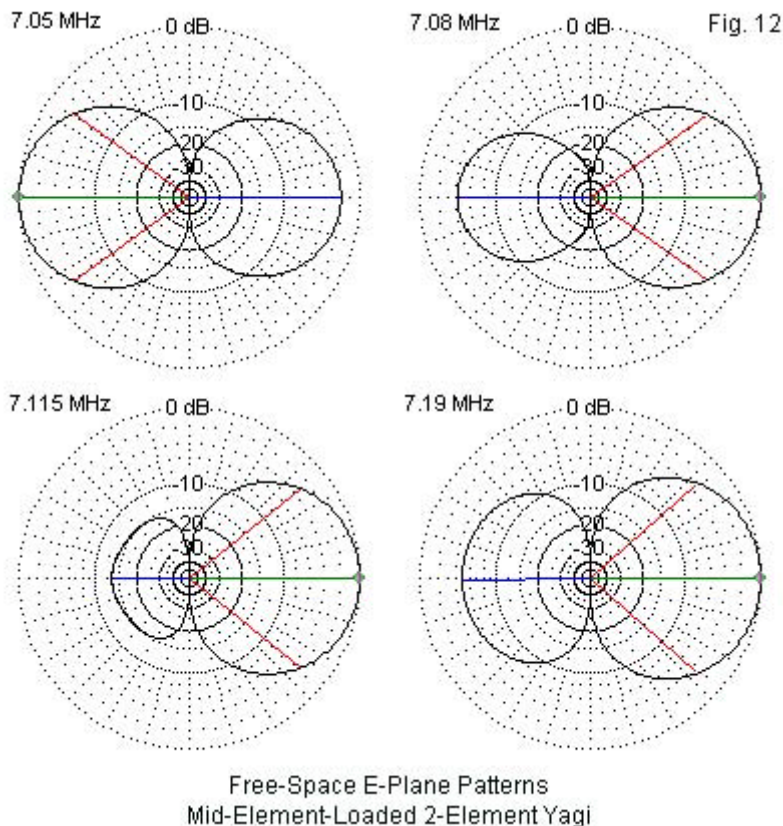


The resonant feedpoint impedance of the sample mid-element loaded Yagi is very close to  $30\ \Omega$ . The SWR curve referenced to this value appears in **Fig. 11**. The 2:1 SWR passband extends from about 7.09 to 7.16 MHz, a 70-kHz span that matches the narrow passband of the center-loaded Yagi. Nevertheless, a matching system designed to transform  $30\ \Omega$  to  $50\ \Omega$ , rather than going from  $15\ \Omega$  to  $50\ \Omega$ , might show lower losses under most circumstances. However, the exact results would depend in part on the precise matching system used.



Further evidence for the practical operational equivalence of the center-loaded and the mid-element loaded short-element Yagis appears in the collection of free-space E-plane patterns in **Fig. 12**. The pattern for the low end of the frequency sweep shows a clear direction reversal. For both loaded Yagis, the front-to-back ratio at 7.05 MHz is in the vicinity of 2 dB. The remaining three patterns replicate those of the center-loaded Yagi, with differences only in minor detail. As the gain graph shows, the forward performance for 7.08 and 7.19 MHz is well below the peak value at the design frequency. The mid-element loading Yagi is a performance twin to its center-loaded brother in every category except the basic feedpoint impedance.

Mid-element loading of the half-length elements does add a structural complication to the beam structure. It not only offsets the weight of the loading solenoids from the support boom, but as well multiplies by 2 the numbers of loading elements that may one day suffer from the effects of daily and seasonal weather. In addition, mid-element loading precludes the use of inductively link coupling between the driver element and the feedline.



### *A Half-Size 40-Meter 2-Element Yagi with Hat-Loaded Elements*

One interesting feature of both inductively loaded Yagis is the fact that their respective feedpoint impedance values are very close to the values obtained from single dipole antennas with the same systems of loading. The impedance

values stand in contrast to the full-size 2element Yagi, which showed a feedpoint impedance about  $20\ \Omega$  below the value we would obtain from a single full-length resonant wire dipole. Our interest in this difference emerges as we turn to a hat-loaded short-element Yagi.

For a sample hat or end-loaded Yagi, let's use elements that employ a spoke+perimeter wire. The outline of the sample array appears in **Fig. 13**. The hat spokes are 46.5" long (93.0" from tip to tip). We can reduce the length of the spokes by adding more of them, although the performance of the resulting beam would not change. The change from inductive loading to the use of end hats also requires different element dimensions, with a shorter driver and a longer reflector. The reflector-to-driver length differential is 22", compared to 4.5" for the loaded Yagis and to 35" for the full-size Yagi. As was the case for the inductively loaded Yagi elements, the hat size remained constant, and the element lengths underwent adjustment to bring the array to its peak performance. The model used 7.115 MHz as the design frequency.

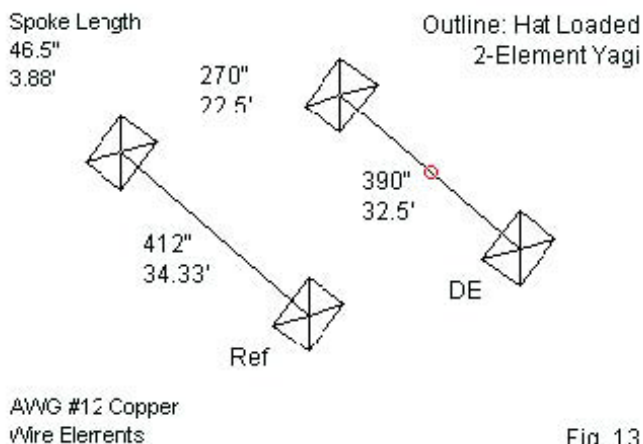
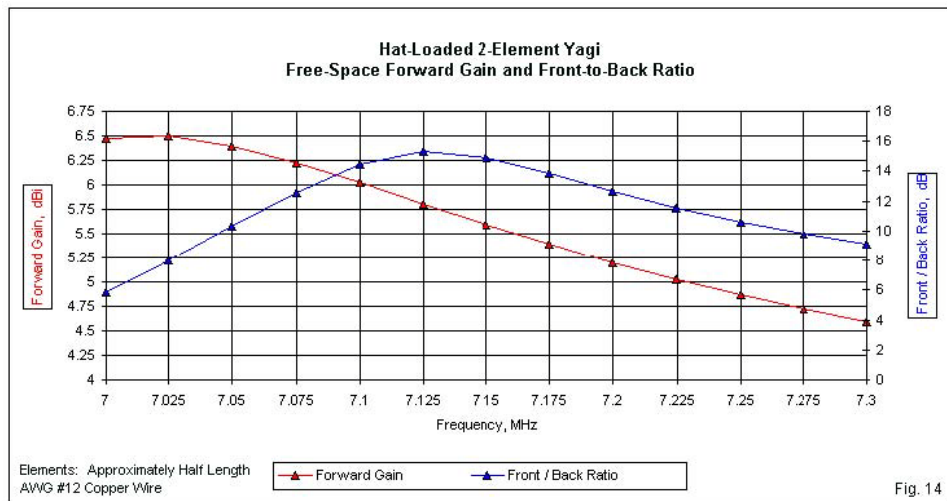


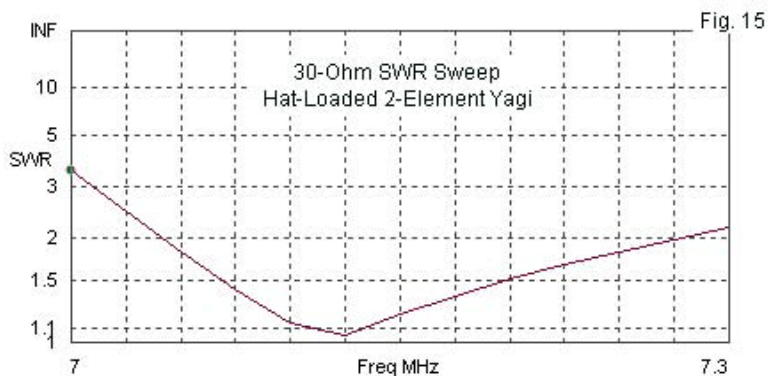
Fig. 13

Despite being somewhat ungainly, the use of end hats on the shortened elements increases the operating bandwidth of both the gain and front-to-back curves, as shown in **Fig. 14**. However, the curves do not match those of the full-size Yagi. For example, the full-size Yagi peak gain occurs below the lowest frequency in the sweep. For the hat-loaded Yagi, the peak gain is within the passband, although near the low end. As well, the hat-loaded Yagi gain curve is steeper, with the gain at the upper end about 0.7 dB lower than for the full-size Yagi. At the design frequency (7.115 MHz), the gain is about 5.9 dB, only about 0.1 dB less than we obtained from the full-size version and far above the values that emerge from the inductively loaded Yagis.



The SWR curve also is much steeper on both sides of the peak value. The peak value is close 15.5 dB and occurs close to the design frequency. This value exceeds the peak value of the full-size Yagi by over 4.5 dB. However, the band-edge values are between 6 dB and 9 dB, while the full-size Yagi yield values close to 8 dB at both ends of the band. Even though the hatted Yagi does not

fully match the performance of the full-size Yagi, it exceeds the performance of the inductively load Yagis with similar element length by a wide margin, especially when we move away from the design frequency.

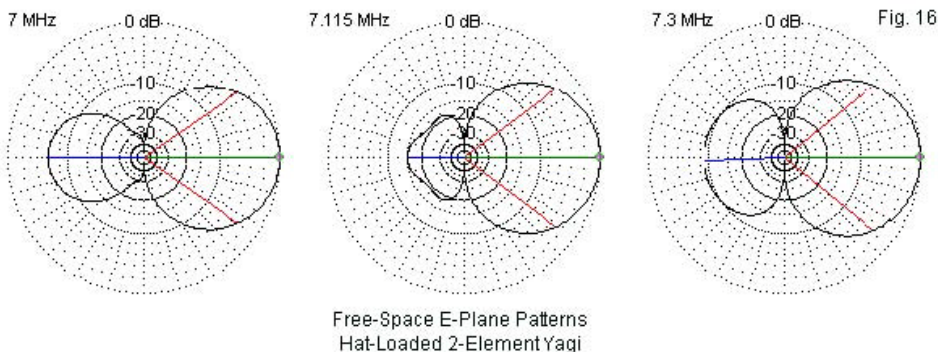


The resonant impedance of the hatted short-element Yagi is just over  $30\ \Omega$ . The hatted dipole showed a value close to  $50\ \Omega$ . Hence, the feedpoint behavior of the hatted Yagi is similar to that of its full-size counterpart. In fact, the loadless driver element might be amenable to the use of a gamma match, as well as beta and series matching techniques to transform the antenna impedance to the usual  $50\text{-}\Omega$  value. **Fig. 15** displays the SWR sweep for the Yagi design. The 2:1 SWR passband extends from about 7.04 to 7.25 MHz, a 210 kHz spread that is three times wider than for either inductively loaded Yagi. As usual, the SWR curve below the design frequency is steeper than above it, but both partial curves are steeper than the corresponding segments of the SWR curves for the full-size Yagi.

As we would expect, the sample free-space E-plane plots in **Fig. 16** do not show the uniformity of the comparable plots for the full-size Yagi. Nevertheless, they are far superior, especially at the band edges, to the plots for the inductively loaded Yagis. The hatted short-element Yagi provides the improved front-to-back



ratio at the design frequency without the severe reductions in gain and operating bandwidth suffered by the inductively loaded versions.

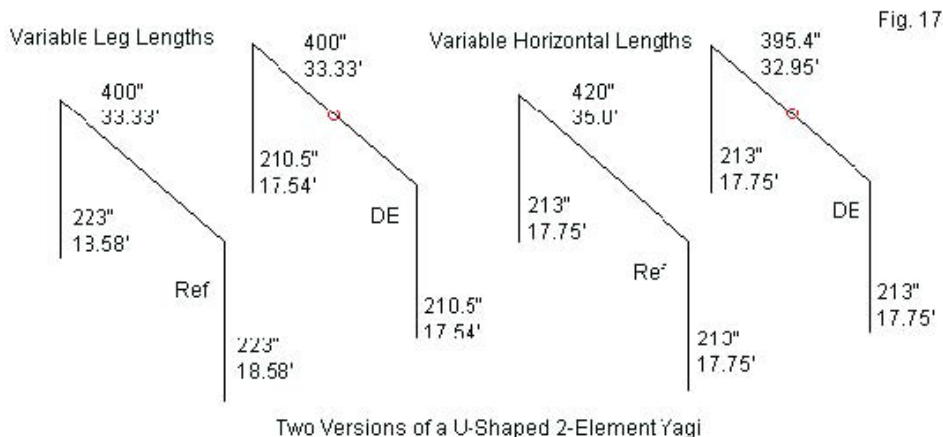


Of all the half-length element Yagis, the hatted version holds the highest performance potential. At the same time, it offers the greatest mechanical challenge: the requirement for substantial structures at the element ends. As a consequence, the history of amateur Yagi design contains many examples of inductively loaded Yagis (and the counterpart linear-loaded Yagis), but few examples of hatted element versions.

### *A Half-Size 40-Meter 2-Element Yagi with U-Shaped Elements*

While reviewing the methods of reshaping full-length dipole element to fit the linear space of a half-length installation space, we noted the potential of the U-shaped element. It supplied fairly good gain and maintained a feedpoint impedance close to  $40\ \Omega$ . The element might be useful as an alternative to the low-impedance inductively loaded elements and present fewer structural problems than end hatting the elements of a beam.

If we use our standard element spacing of 270", we can form a U-shaped Yagi in two ways. As sketched on the left in **Fig. 17**, we can maintain 400" center horizontal sections and allow the driver-reflector length variations to show up in the length of the vertical legs. Alternatively, as shown on the right, we can maintain equal vertical leg lengths and vary the length of the horizontal center section. In both cases, the total driver wire is 821" (68.42'), while the total reflector length is 846" (70.5').



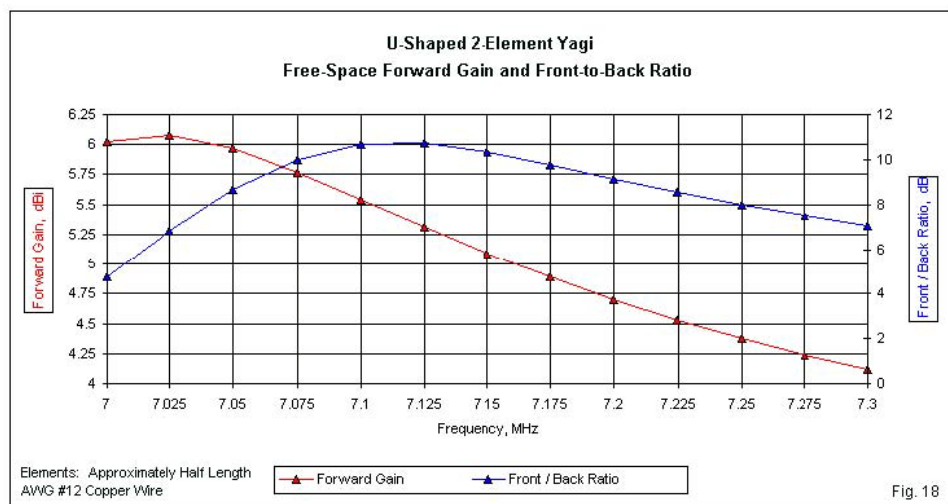
Two Versions of a U-Shaped 2-Element Yagi

Regardless of which technique we use, the performance of the resulting 2-element Yagi is virtually identical. **Fig. 18** graphs the gain and the front-to-back ratio across the entire 40-meter band. Between the two versions of the beam, the maximum difference in gain is less than 0.1 dB. The variation in front-to-back ratio is less than 0.4 dB. Both of the maximum variations occur at band edges. At the design frequency, the reported gain values are 6.06 and 6.08 dBi, with front-to-back values of 10.6 and 10.7 dB.

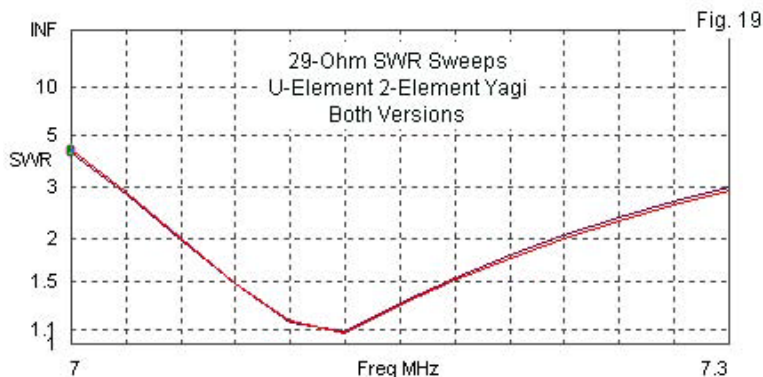
In many ways, the gain curve resembles the corresponding curve for the hatted Yagi. The peak gain value occurs just within the 40-meter band. The slope is also

similar as we increase the operating frequency. The key difference is that the average gain across the band is about 0.5 dB lower with the U-shaped elements.

With the U-shaped Yagi elements, the front-to-back ratio is 3 to 4 dB lower than with end hats. The peak value is only about the same as for the full-size Yagi. However, unlike the full-size Yagi, the U-shaped Yagi shows front-to-back values that decrease relatively rapidly both above and below the peak frequency.

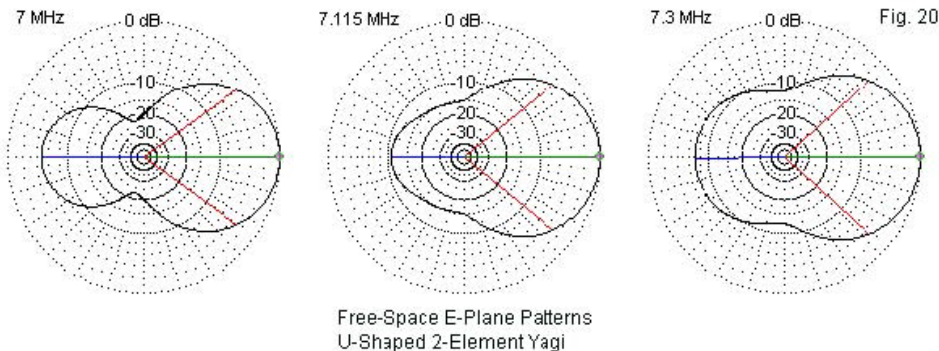


The vertical legs of the U-shaped elements provide the key reason why the Yagi does not reach the peak front-to-back values of the other beam with shortened main elements. In the end-hatted Yagi, there is almost no radiation from the end assembly. However, the vertical legs of the U-shaped Yagi show considerable current. The legs therefore radiate to some degree endwise to the element center sections, reducing both the front-to-side nulls and the overall beam front-to-back ratio.



To confirm the electrical identity of the two versions of the U-shaped Yagi, **Fig. 19** overlays the 30- $\Omega$  SWR sweeps for both versions. The curves are very similar to those for the end-hatted Yagi, but the 2:1 SWR passband extends only from 7.05 to 7.225 MHz. This 175-kHz span covers about 58% of the band, as it is defined for U.S. operation. The passband is certainly wide enough to cover the smaller European version of the 40-meter band.

The consequences of radiation from the vertical legs of the U-shaped Yagi appear clearly in the gallery of free-space E-plane patterns in **Fig. 20**. As we increase the operating frequency across the band, the front-to-side ratio steadily decreases from about 22 dB down to barely 12 dB. There is no significant difference between the pattern shapes for the two different versions of the array, since the differences in leg length are relatively small.



Although limited in performance relative to the end-hatted Yagi, the U-shaped parasitic array has a key advantage: structural simplicity. The vertical legs require some form of pinning to hold them in position and their tips must be well above a height that anyone can reach under any circumstances. Nevertheless, they add no support requirements, since the single-wire legs add very little weight to the two elements.

### *The VK2ABQ Square*

There is a way to employ U-shaped elements horizontally and to remain close to the specified half-length center sections. The Moxon rectangle has become one of the standard monoband 2-element parasitic beams over the last 2 decades. The Moxon has, when properly designed, a direct 50- $\Omega$  feedpoint and would cover 40 meters with less than a 2:1 SWR ratio. The Moxon consists of two elements folded so that the tails of each element point toward a common point, with a precise gap between the ends of the tails. It makes use of the parallel (inductive) coupling between the long sections of the elements and the tip-to-tip (capacitive) coupling between the ends of the tails. While a Moxon rectangle is always a useful wire beam to consider, it violates our basic requirement that restricts us to elements about half as long as a linear full-size element. Moxon

elements are about 70% of full-size when measured from one side of the beam to the other.

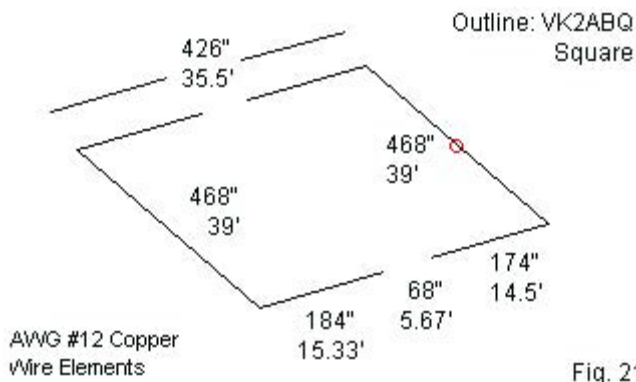
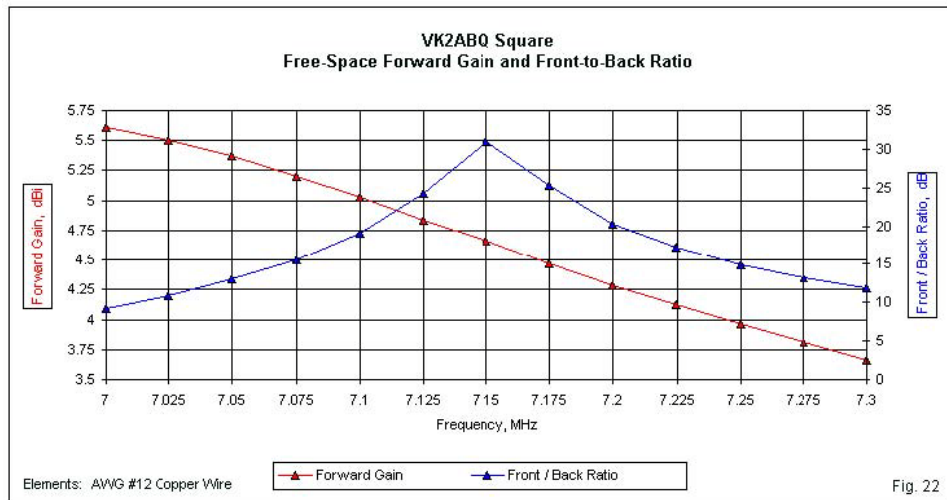


Fig. 21

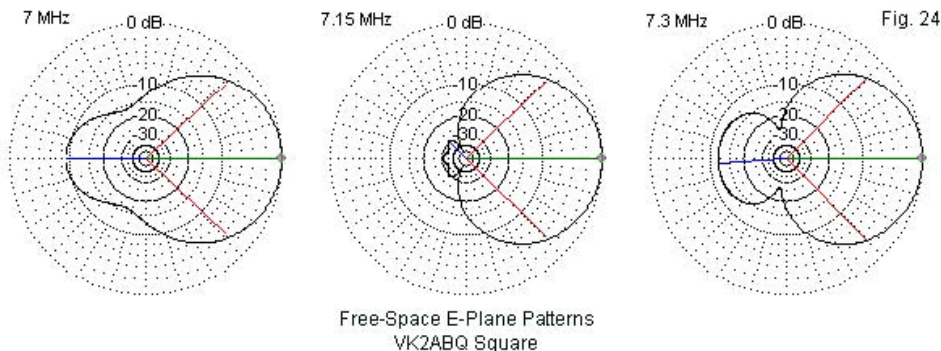
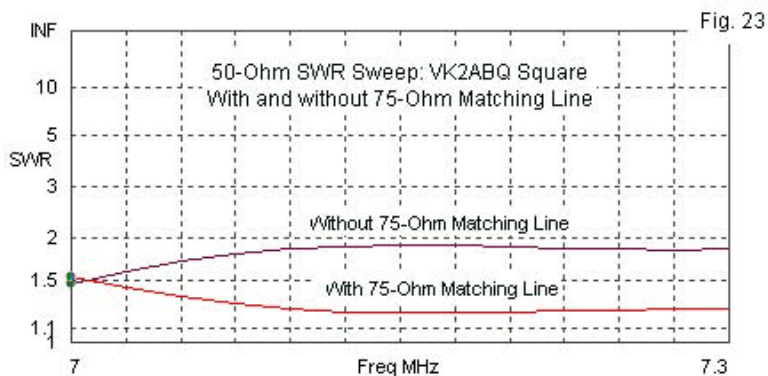
**Fig. 21** presents an alternative to the standard Moxon rectangle in the form of a beam that actually provided the foundation for the rectangle. The VK2ABQ square uses the same general principles as the Moxon, but with a shape that is more nearly square. The dimensions show the imperfection of the square shape necessitated by the process of optimizing the array for maximum performance. The foundation of the array in two U-shaped elements is clearly apparent.



Like any 2-element driver-reflector array, the square shows a descending gain curve, traced in **Fig. 22**. The square shape yields less gain than the rectangular Moxon shape in which the parallel high-current sections of the elements are more closely spaced. Like the Moxon, the square exhibits the very high peak front-to-back ratio at the design frequency. Although the values fall sharply both above and below the design frequency, the values are fairly good at both ends of the band

The SWR sweep in **Fig. 23** provides two 50- $\Omega$  curves. One line tracks the SWR at the antenna feedpoint, which shows a 95- $\Omega$  impedance at the design frequency. However, the square shape demonstrates one of its key advantages. The impedance does not change significantly from one end of the band to the other. Hence, the curve is very flat. The lower curve results from adding a 75- $\Omega$  matching section that transforms the somewhat high antenna feedpoint impedance to a lower value. At the 7.15-MHz design frequency, the transformed impedance is about 60  $\Omega$  using a  $\lambda/4$  section of 75- $\Omega$  cable. Any odd multiple of

a quarter wavelength (accounting for the line's velocity factor) will perform the necessary transformation.



**Fig. 24** provides a selection of free-space E-plane patterns across the 40-meter band. The evolution of the rearward lobe structure is clearly apparent. In all cases, radiation from the tails of the horizontal U-shaped elements is apparent. It shows up in the displacement of the side null. Even inductively loaded Yagis



show a side null at about 90° to the main forward direction. However, the side null for the VK2ABQ square is closer to 120° away from the main forward heading of the array. Be certain to read the patterns in conjunction with the graph of gain levels, since each pattern is normalized.

Although the VK2ABQ square has lesser gain than either the hatted Yagi or the U-shaped Yagi, it offers full-band coverage with significant directivity and a very tame SWR curve. It requires 4-corner support, but a similar requirement attaches to virtually all of the wire beams that we have examined in these notes.

### *Conclusion*

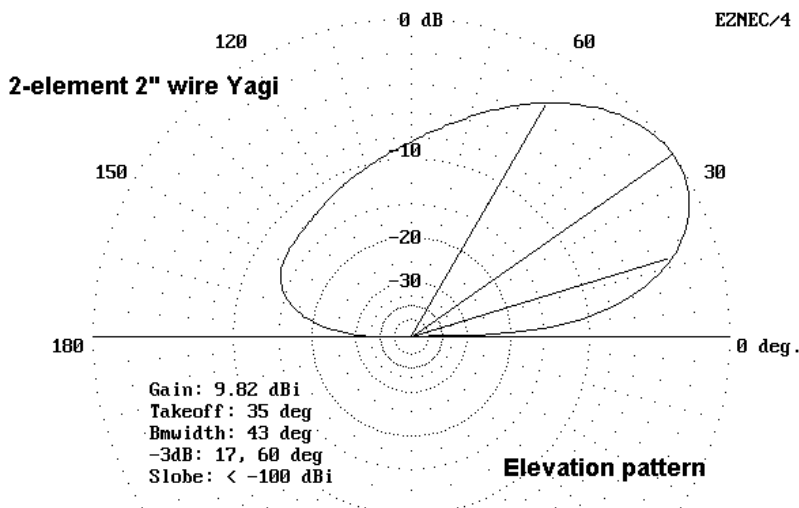
We have explored a fair sample—but certainly not all possible—parasitic beams using a driven element and a reflector that meet our basic requirement of needing only about half the linear space of a full-size Yagi. Each version has some advantages and disadvantages, but the weight that we assign them depends upon our operating needs and desires. More significantly, as we varied the technique for forming a directive beam, we discovered that we could overcome many limitations of using half-length elements. Unfortunately, we cannot overcome all of the limitations within a single design. The more familiar that we are with the variations, the better chance that we have to make the correct selection for our particular installation site and operating goals.

## Chapter 24: Lower HF Wire Beams

**F**ixed position wire beams still have a place in amateur communications from 40 through 160 meters. However, I am not certain we always make the right and patient choices in selecting and building wire beams. We tend to treat them as Field Day temporary antennas rather than really building them to do a job.

### The Wire Yagi

Consider the 2-element wire 40 meter beam. It is an improvement over the dipole in several ways. 1. It provides forward gain; 2. It provides rear attenuation; and 3. It lowers the elevation angle of maximum radiation by a few degrees. Most of these advantages are captured in the elevation plot below: Gain = 9.5 dBi; Front-to-back ratio = 14 dB; TO angle = 35 degrees; Feedpoint Z = about 50 ohms, all at a height of 50' over average ground, centered at 7.15 MHz.



For reasons that appear below, let me give the performance figures for an elevation angle of 18 degrees, near the lower -3 dB point. Gain = 7.5 dB; F-B = 12.7 dB.

Here are the dimensions that will yield this performance. Driven element = 66'; reflector = 70'; spacing = 20' with #12 or #14 copper wire. However, the 2:1 SWR bandwidth of the antenna covers only about 2/3rds of the 40 meter band. Moreover, especially on the low end of the band, the pattern goes to pot.

Let's redesign the antenna by making one simple change: increase the wire size to 2" in diameter. The dimensions for this fat wire Yagi are these: Driven element = 64'; reflector = 70'; spacing = 20'. Now the 2:1 SWR bandwidth of the beam exceeds the limits of 40 meters, as the following table demonstrates:

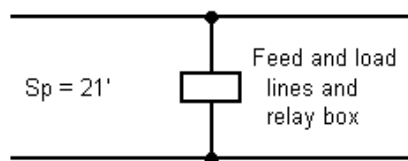
Frequency MHz	Gain dBi	Front-to-Back dB	Feedpoint Impedance R +/- jX ohms	SWR
7.0	7.9	11.1	36.4 - 13.4	1.6:1
7.1	7.6	12.5	45.3 + 3.3	1.1:1
7.2	7.4	12.6	54.0 + 18.3	1.4:1
7.3	7.3	11.9	62.2 + 32.0	1.8:1

Of course, 2" wire is impractical, and 2" diameter tubing is too heavy for any installation. So the antenna is impractical--unless we remember that we can simulate fat wire with an array of thin wires spaced apart. The simplest scheme to achieve most of the benefits is to use two wires making a flat wire about twice the diameter of the wire used in the model. This 2:1 rule of thumb is not precise, but adequate for most simple design cases. Take two wires and a bunch of spacers (1/2" thin wall CPVC is an adequate substitute for varnished or parafinned wooden dowels) and make lengths of flat 4" wide wire. Not only connect the ends, but as well solder shorts across the wire periodically. Now we have the material for a wide-band 40-meter beam.

## **Reversible Wire Beams**

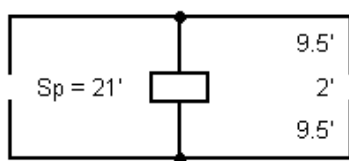
Carrol Allen, AA2NN, has allowed me to share a pair of designs that take the wire beam process one step further. He developed 40-meter models of reversible wire Yagis and Moxon rectangles using a sound technique of employing identical elements and loading the reflector with a length of transmission line. He modeled his beams at 55' over medium earth to fit his location, but his designs are widely applicable.

Below are outlines of the two beams. Taking the Yagi first, he uses 2 65' long #12 wires, spaced 21' apart. From each, he hangs a length of 50-ohm transmission line (9914 with a velocity factor of 0.78). The lines go to a switch, whose common terminal goes to the coax coming from the shack. Carrol switches in one direction, making the hanging line in that direction an extension of the shack coax and hence, the line to the driven element. The remaining line is not connected and becomes the load for the reflector.



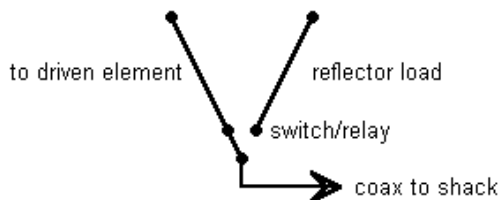
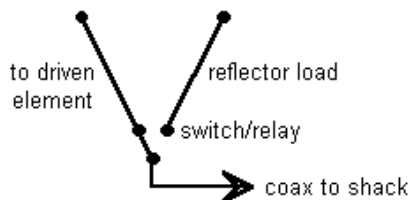
$L = 65'$  (#12 wire)

Reversible Yagi



$L = 46' 1"$  (#12 wire)

Reversible Moxon



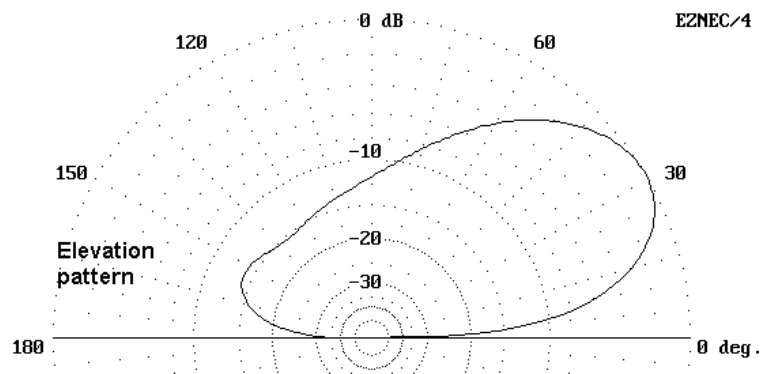
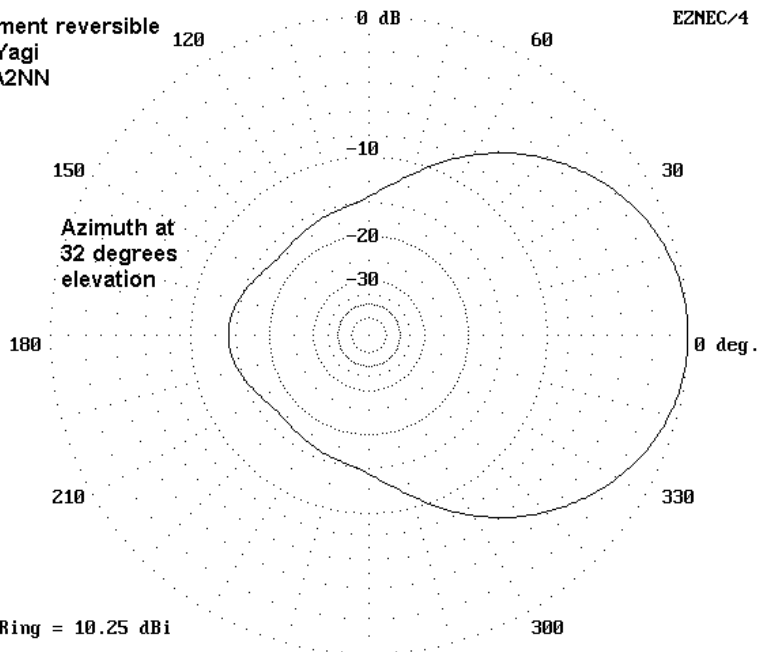
**Reversible wire beams by AA2NN**

For this Yagi design, to maximize the performance pattern, the reflector needed an inductively reactive load of about 75 ohms. Transmission lines between 0 and 90 degrees long, when shorted, provide inductive reactance. Between 90 and 180 degrees, transmission lines provide inductive reactance when open circuited. Carrol chose open-circuit 146-degree lines (43' 4") to suit his situation. However, you can also use shorted lines of 56.5 degrees (16' 8.7") to do the job. If you need to bring the line near the ground for switching, you can add 180 degrees (53' 2.3") for a total shorted line length of 70'. If you use shorted lines, just be sure that the "unused" switch or relay positions go to ground; if you use open circuit lengths, leave the contacts open.

The next figure provides azimuth and elevation patterns of the beam at its projected 55' height.

2-Element reversible  
wire Yagi  
by AA2NN

EZNEC/4

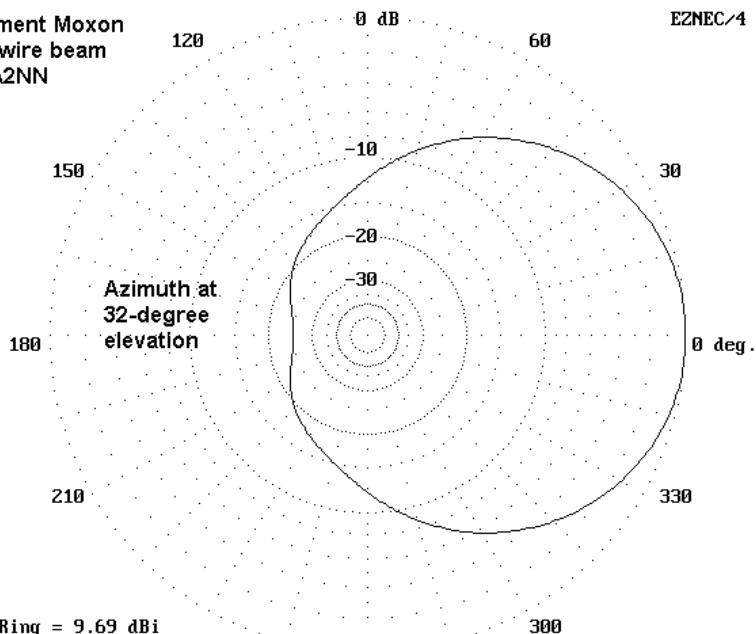


Note the gain--a little over 10 dBi--and the front-to-back ratio--a little over 14 dB. Although not astounding when compared to highly elevated many-element 20 meter beams, the antenna will enhance 40 meter operations very nicely--and in two directions.

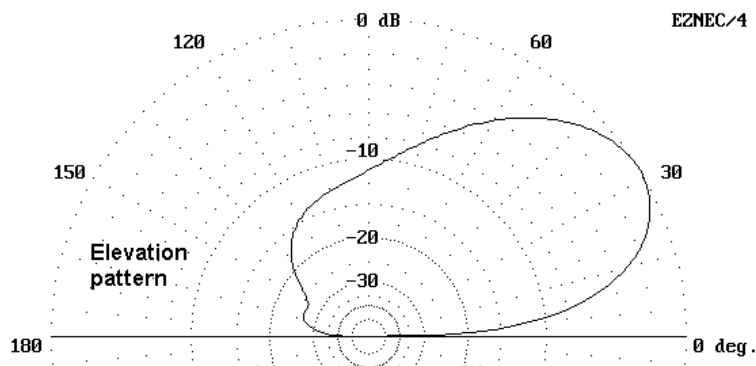
Searching for a little better front-to-back ratio, AA2NN adapted the Moxon rectangle for reversible operation. The sketch provides the dimensions of Carrol's #12 copper wire model. Because the equalized Moxon rectangle optimized for front-to-back ratio has a slightly higher feedpoint impedance, Carrol used 70-75 ohm cable as his projected feedline. The "hanging" feed-load lines are 75-ohm, 0.83 velocity factor coax. Carrol used 42' 7" lengths of open circuit line for this antenna, although corresponding shorted lines might also have been used. AA2NN does remind us that coax loading lines are not lossless and may be lower in Q than we may initially think, especially when we use them in longer lengths for convenience. The resistive losses will decrease gain by a small amount.

2-Element Moxon  
40-M wire beam  
by AA2NN

EZNEC/4



EZNEC/4





The projected performance of the Moxon version of the reversible beam shows clearly the enhanced front-to-back ratio and the reduced gain relative to the reversible Yagi. Which of these two very usable antennas one might select will depend both on the needs of one's operating situation and on how much high horizontal space one can give to the antenna. The Moxon is almost 20' shorter than the Yagi.

My thanks to AA2NN for letting me add these antennas to this note.

### **The Parasitical Half-Square**

The wire Yagi is the ultimate in simplicity for a directional antenna, but it may not be the best for all types of operating goals. We often forget that we can add parasitical elements to almost any wire antenna. Parasitical extended double Zepps were known back in 1938. More practically, a half square will fit the half wavelength horizontal space of our Yagi, with vertical wires dangling from the 50' high point to about 12 to 14 feet or so above ground. Can we add a reflector about 20' or so behind a half square and change the bi-directional pattern to a mono-directional one? Yes, as the plot below demonstrates. The operating performance of a #12 wire parasitical half square is given by these numbers: Gain = 6.6 dBi; F-B = 23 dB; TO-angle = 18 degrees; Feedpoint impedance =  $56.9 + 3.4$  ohms. The reason for giving the 18-degree performance figures of the Yagi is now apparent.

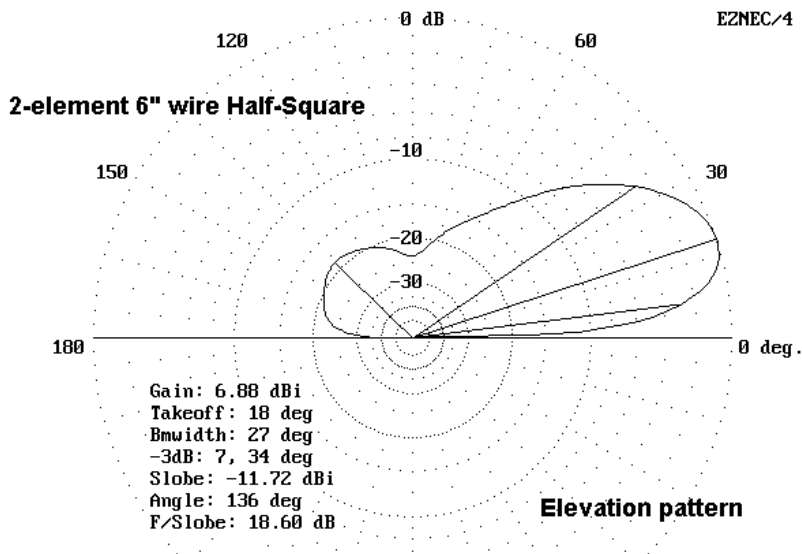
The dimensions of this wire parasitical half-square are these: Horizontal length of both elements = 68'; driven element vertical length = 34.8'; reflector vertical length = 35.9'; spacing = 20.4'.

The advantage of the half-square is that at elevation angles below 18 degrees, its gain drops off much more slowly than does the Yagi gain. In addition, it lacks significant gain above 35 degrees, reducing incoming high angle QRM and QRN. These are, of course, advantages to the DX operator; the Field Day and

Sweepstakes operator may prefer the Yagi precisely because of its higher angle radiation pattern.

One distinct disadvantage of the wire parasitical half-square is narrow bandwidth-about 100 kHz on 40 meters. To increase the bandwidth both in terms of 2:1 SWR and pattern retention, we must increase the wire size to about 6" in diameter. Then we obtain these dimensions: horizontal length of both elements = 68'; driven element vertical length = 35.2'; reflector vertical length = 37.6'; spacing = 20.4'. Some may find it odd that we increase the element lengths as we fatten the wire of the half-square. However, remember that the half square belongs to the family of 1 wl loop antennas, and like a quad, lengths grows with wire diameter.

With these dimensions, we can achieve the elevation plot below.

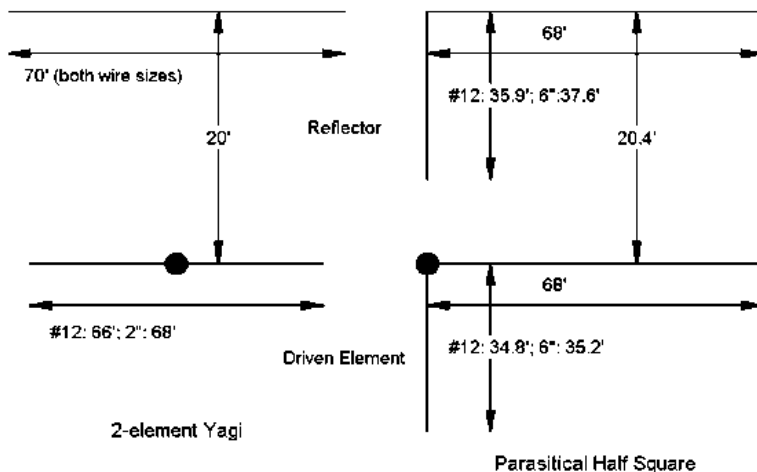


Here is a chart of performance checkpoints through the 40-meter band:

Frequency MHz	Gain dBi	Front-to-Back dB	Feedpoint Impedance R +/- jX ohms	SWR
7.0	6.9	10.1	37.5 - 21.8	1.8:1
7.1	6.9	21.2	60.5 + 4.6	1.2:1
7.2	6.5	18.6	79.3 + 15.1	1.7:1
7.3	6.1	10.0	85.9 + 23.1	1.9:1

The design center of the fat-wire half square was 7.07 MHz. Selecting this lower frequency was necessary to preserve a directional pattern across the band with a reasonable SWR figure at both band edges.

Like the fat-wire Yagi, the fat-wire parasitical half-square requires construction of the antenna wires using the same principles, but this time with a spacing of about 12". The figure below compares the shapes of the two antennas and summarizes both #12 and fat-wire dimensions.



## The Parasitical Right-Angle Delta

As with the half-square, it is also possible with delta loops to derive well above 3 dB forward gain (relative to a single loop) and a front-to-back ratio of 10-15 dB by placing two vertical loops about 0.15 wl apart. The result is a parasitical 2-element beam with the same low TO angle. The beamwidth will be fairly wide: 80-90 degrees, without the side nulls we are used to with upper HF high altitude Yagis. Feedpoint impedance will be to the 60-65 ohms range at resonance.

Expect both the driven loop and the reflector to be a bit shorter than a resonated single loop, with the driven element shorter than the reflector.

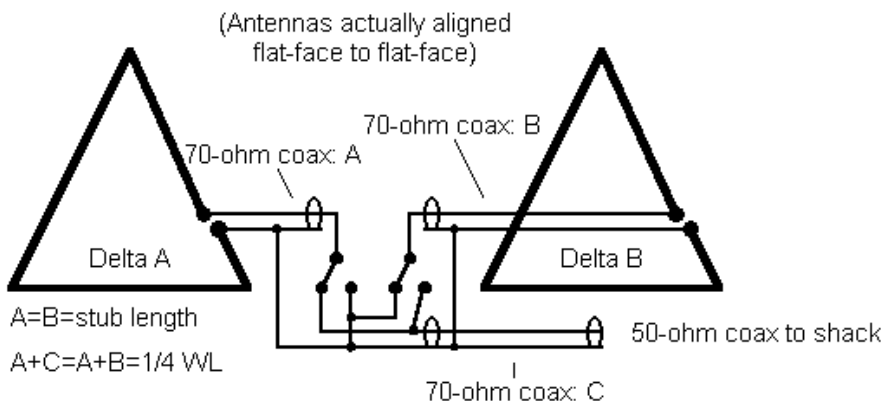
If you care to scale some numbers from 7.15 MHz, here is a right angle delta loop and its 2-element counterpart. Given are the baseline and height (one is twice the other), and the sides are about 1.414 the height. This model had a maximum height of 60.4' which was held constant for the 2-element version to achieve comparable TO angles (17 degrees for the model)

Antenna	Baseline	Height	Spacing
single ra delta	60.8'	30.4'	---
2-el ra delta			
driv. el.	59.3'	29.65'	
reflector	60.6'	30.3'	20.5'

When made into a parasitical beam, the deltas also show reduced 2:1 SWR bandwidth (relative to their resonant impedance). At 40 meters, both SWR and pattern begin disintegrating somewhere around +/- 50 kHz from the design point with #12 wire. Widening that bandwidth depends upon using truly fat wires with equivalent diameters of about 6" at 40 meters for full band coverage with reasonable gain and F-B (arbitrarily defined here as 3 dB gain over a single loop, greater than 10 dB F-B, and less than 2:1 SWR).

K1KP uses a simplified version of the ON4UN feed for his 80 meter delta loops, which have their apices up at 70 feet and base legs about 8 feet off the ground.

The apices are spaced 20 feet apart, with the bases spread to a distance of about 50 feet. He reports that the feedpoint impedance is close to 100 ohms. Each feedpoint runs to a central switch, roughly as sketched in the drawing. (Not shown in the drawing are baluns at each loop feedpoint to isolate each antenna. Also not shown is the tilt of each loop toward the other.)



### The K1KP Parasitical Delta Feed System

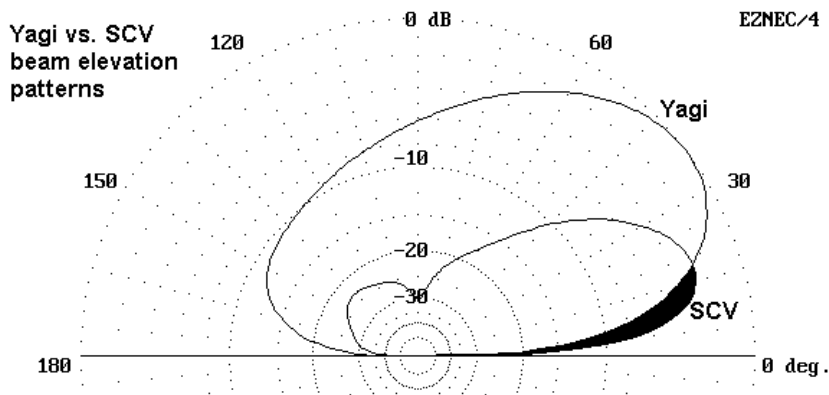
Coax sections A and B to the switches are lengths of RG-11/U foam (with a higher velocity factor than non-foam coax) coax, 36 feet long. The switch is a relay that selects one feed as the driven element. 16 more feet of RG-11/U foam coax adds to the 36 feet on the driven element to form a quarter wave matching section, yielding a 50-ohm impedance for the coax to the shack.

The relay also shorts out the end of the other line forming the reflector. The shorted 36 foot coax line functions as a loading inductance to lengthen the electrical size of the loop in use as a reflector.

K1KP reports reasonable flat SWR and detectable gain over the single loop with this system, which is fairly close-spaced (average distance = about  $1/8$  wl) as parasitical systems go. It represents an ingenious way to switch beam directions and simplify feedline requirements without sacrificing performance from the wire array.

Incidentally, models of the half square and the single loop DMS (otherwise known as a side-fed rectangle) show about a dB gain advantage over the delta loops, and this gain also transfers to parasitical arrays of them. Of the antennas investigated, the half-square has the highest gain and front-to-back potential at more than 6.5 dBi and more than 23 dB respectively. The side-fed rectangle shows nearly comparable figures, but is among the most narrow-banded of the SCV configurations in parasitical application. The side-fed rectangle should be used in a single-loop configuration for parasitical use, since the feedpoint impedance reaches about 40 ohms at a spacing of 25' on 40 meters, while the double loop variety has a feedpoint impedance of over 120 ohms at the same spacing.

Moreover, it is feasible to electrically tune the reflector of any of the SCV parasitical arrays with no significant change of beam performance. This fact makes it possible to design two identical loops/half squares for resonance in the beam configuration and lengthen the reflector with a coaxial stub. The stub can become part of the feed cable when the loop serves as a driven element and can function as an inductive reactance when the loop is a reflector. Using a switching system similar to the one used by K1KP, but designed for direct 50-ohm feed and reflector stub, a reversible beam results with excellent front-to-back ratio and about 3.2 dB greater forward gain than a single loop/half square. Remember that if the required reactance is low, calling for a short stub that will not reach the switch in the center of the two loops, you can use at least two means of getting a longer stub. First, you can add a half-wavelength of coax (remembering velocity factor) to the stub. Second, an open ended stub, which is capacitive at less than  $1/4$  wl become inductive over  $1/4$  wl. This latter technique will likely be the most useful for these applications.



As the figure shows, a 2-element wire Yagi may give the same or slightly more gain at 17 degrees elevation when mounted at the apex height of the delta. However, its elevation angle of maximum radiation is about double that of the SCV group, and the SCVs have higher gain below the 17 degree mark, with 1/2 power points ranging from 7-10 degrees elevation, depending on the actual antenna height. Hence, the choice of antenna types depends on the user's operating goals.

The 70' by 21' rectangular area necessary for these antennas is about the same. If the concept of a fixed position wire beam is useful, then the decision as to which antenna to build may rest on which performance characteristics one prefers relative to one's operating goals. However, whichever you build, it is wise to take the added pains of fattening the wires to give good performance across the band.

## **Chapter 25: A Starter Antenna for 160**

The following notes rest on a small set of assumptions.

1. You want to get on 160 meters for the first time (or perhaps, for the first time in a long time).
2. You want to set up the simplest possible effective antenna using all wire construction. In fact, all of the antennas will be made from AWG #14 or AWG #12 wire. 2-mm (0.0787") diameter wire falls right between these sizes, so all of the data will use that value. However, nothing much changes by reducing the diameter to AWG #14 (0.0641") or increasing the diameter to AWG #12 (0.0808").
3. You do not have unlimited vertical space for your antenna. In these notes, the limit will be about 70'. In fact, I shall use 21 m (68.9') as the standard top height for all antennas.

I have set these limits so that we can compare the performance of a collection of relatively simple antennas.

For all comparisons, we shall use average ground with a conductivity of 0.005 S/m and a relative permittivity (dielectric constant) of 13. For vertical antennas especially, you should expect lesser performance from worse ground and better performance from better ground--but not radically worse or better. Horizontal antennas are less affected by ground quality, but the top height is so low (about 1/8 wavelength) that the ground will influence performance much more than for the antennas you place 1 wavelength above ground for the upper HF region.

160-meter antennas are naturally much larger (longer, taller) than antennas for the other HF amateur bands. Therefore, be prepared to spend a little more money for quality wire and insulators to durably bear the antenna weight. Copperweld is desirable. Supporting structures--whether natural or constructed--



need to be stronger and taller than the average sorts of things that populate a backyard. How you handle the support structures I shall leave to you, since every yard is different, as are the locally available materials and the construction skills at hand.

With those qualifications, let's get started in our work, starting with some vertical antennas.

### 160-Meter Wire Verticals

We shall begin with an antenna that violates the upper height limit of our task: the full-size 1/4-wavelength vertical monopole. A wire version of this antenna needs to be about 39 m (128') tall. The convenience of the vertical monopole is that we can feed it at the base--at or near ground level. The inconvenience is that we must install radials. The radials should be about 1/4-wavelength long and placed as symmetrically as the yard space allows. To see how many radials we might need, I modeled the vertical using 4, 16, and 64 1/4-wavelength radials, each 6" (0.15 m) below the surface. **Fig. 1** shows the outlines of the 3 models.

1/4-Wavelength Wire Vertical with 4, 16, and 64 Buried Radials

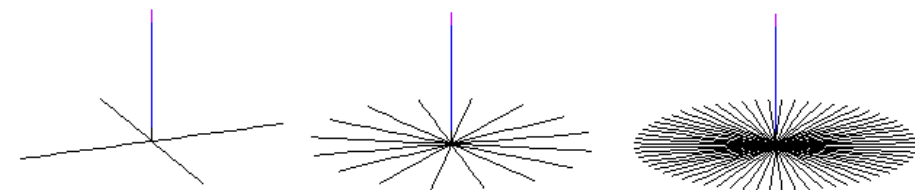


Fig. 1

The following table shows the anticipated results, assuming that the vicinity of the antenna is not filled with RF-eating ground clutter. Conductive objects--even semi-conducting trees and shrubs--can distort antenna patterns and absorb

some RF energy, so keeping the antenna area as clean as possible is important to getting the most out of any vertical antenna.

#### 1/4-Wavelength Vertical Monopole with Variable Radial Systems

Average Ground

No. of Radials	Maximum Gain dBi	TO Angle degrees	Feedpoint Z R +/- jX Ohms
4	-0.72	23	57 + j 1
16	0.48	23	44 - j 8
64	1.14	23	37 - j12

Note that we gain about 1.2 dB by increasing the radial field from 4 to 16 wires, with another increase of about 0.7 dB by raising the count to 64. **Fig. 2** shows the relative radiation pattern strengths. The radiation plot also shows that a vertical antenna is best for lower-angle long-distance skip signals, but almost unusable for NVIS (Near Vertical Incidence Skywave) very short distance communications. Many vertical users also find a vertical less noisy than a horizontal antenna in terms of QRN from lightning, but more susceptible to local man-made noise sources. As well, as we increase the number of radials, the impedance decreases, indicating a reduction in energy lost to the ground.

1/4-Wavelength Wire Vertical  
with 4, 16, and 64 Buried Radials

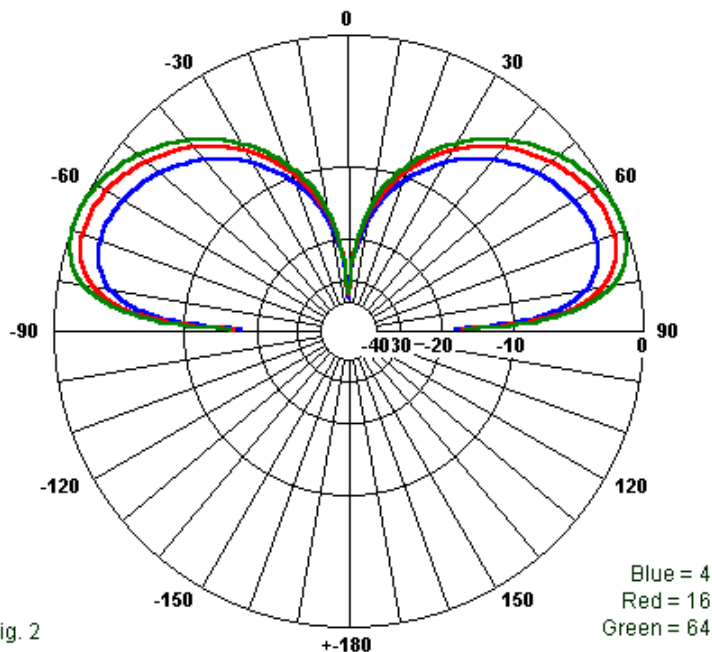


Fig. 2

As the impedance decreases due either to the number of radials or ground quality, a number of operators use a simple means of obtaining a good match for coaxial cable. By making the vertical longer, they increase the resistive component of the impedance and the reactance moves from being slightly capacitive to being more definitely inductive. Adding a series capacitor at the feedpoint between the cable center conductor and the feedpoint itself allows them to compensate for the reactance, leaving a nearly perfect match for the 50-Ohm cable. A fixed capacitor may work if you have a specific operating frequency, but a remotely tuned variable is necessary for obtaining a low SWR

over a wider operating bandwidth. Since we want the antenna to be at least slightly inductively reactive at all operating frequencies, setting up the antenna for the low edge of the band is the usual practice.

The full-size vertical monopole is useful as a reference for comparing other vertically polarized antenna candidates. With that data, we can see what we gain or lose from each one. We shall look at 2 candidates, each no more than 70' tall.

*The Tee-Vertical:* If we must limit the height to a certain level--70' in our case--but still desire a perfectly circular pattern, we need to create a shorter vertical antenna. Many vertical users opt for inductively loading the vertical either at its base or higher up on the wire. However, inductive loading has two disadvantages. First, the inductor always has a series resistance that reduces the radiated energy. Second, inductive loading reduces the feedpoint impedance faster, the closer the inductor is to the feedpoint.

One of the simplest and most efficient ways to shorten a vertical monopole is to create a hat at the top. The usual vision of a hat consists of several hat wires radiating from the top of the vertical wire. However, we actually need only 2 wires to effect a hat. (The more wires that we have in a symmetrical arrangement, the shorter that each must be to set the antenna at resonance. However, any wires not in the same line as the supports for the top of the vertical section require additional supports.)

We shall look at 3 versions of a Tee-vertical: with 4, 16, and 64 radials. **Fig. 3** shows the relative complexity of each version. The vertical wire is 21 m (68.9'), and each leg of the Tee is 11.6 m (38') long.

1/4-Wavelength T with 4, 16, and 64 Radials

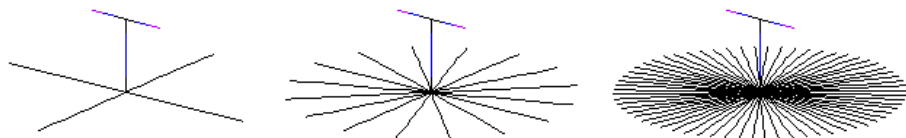


Fig. 3

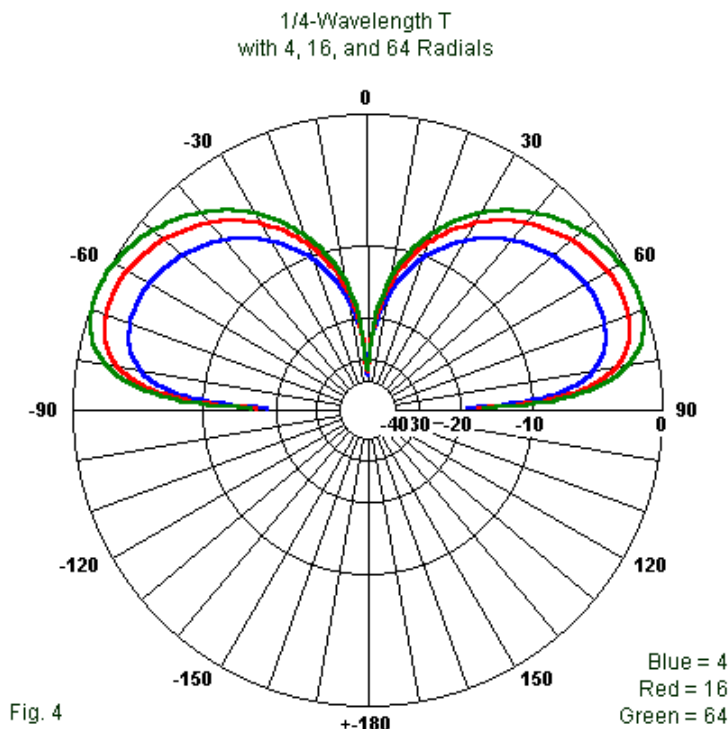
For the same set of conditions used to model the full-size vertical monopole, the shortened Tee-vertical shows the following performance values.

#### Shortened Tee-Vertical Monopole with Variable Radial Systems

##### Average Ground

No. of Radials	Maximum Gain dBi	TO Angle degrees	Feedpoint Z R +/- jX Ohms
4	-1.45	25	42 + j 2
16	0.20	25	29 - j 6
64	1.11	25	23 - j11

The fewer the radials, the more that Tee-vertical performance lags behind the performance of the full-size vertical monopole. With 64 radials, there is almost no difference in performance with respect to gain. The Shorter vertical section of the Tee version does show a 2-degree increase in the TO angle. As well, the impedance at the feedpoint is only about 70% of the value for the full-size vertical. **Fig. 4** shows the relative radiation patterns. We do not need azimuth patterns because, like the full size vertical, the Tee-vertical provides virtually a perfect circle of radiation (assuming that there are no nearby objects to distort that pattern).



The Tee-vertical is amenable to the use of lengthening techniques to raise the feedpoint impedance with a series capacitor to compensate for the inductive reactance. Lengthening the Tee legs (in equal amounts to preserve symmetry) saves you the trouble of increasing the height. However, you will need more horizontal space for the increased Tee-top. If you use a series capacitor at the base of the antenna, I recommend a double waterproofing case system, along with regular preventive maintenance. As well, be sure that you use a beefy capacitor able to handle the high current level at a 50-Ohm impedance.

*The 1/4-Wavelength Inverted-L:* A second alternative for our 70' height limitation is the inverted-L. As shown in **Fig. 5**, the L does not worry about symmetry, but simply uses a horizontal extension of the vertical wire to reach resonance on 160 meters. Because the top is not symmetrical, the horizontal wire radiates. However, the current is lower in the horizontal part of the antenna and the pattern is not seriously distorted on 160 meters. In the model for 1.85 MHz over average ground, the horizontal wire is 19 m (62.3') for the same vertical wire used in the Tee-vertical.

1/4-Wavelength Inverted-L with 4, 16, and 64 Radials

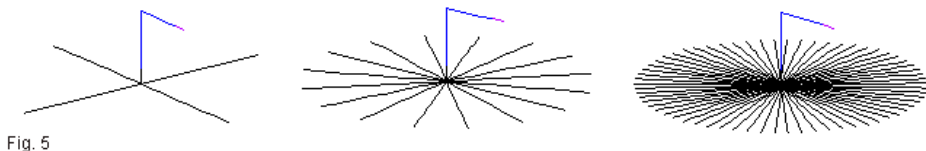


Fig. 5

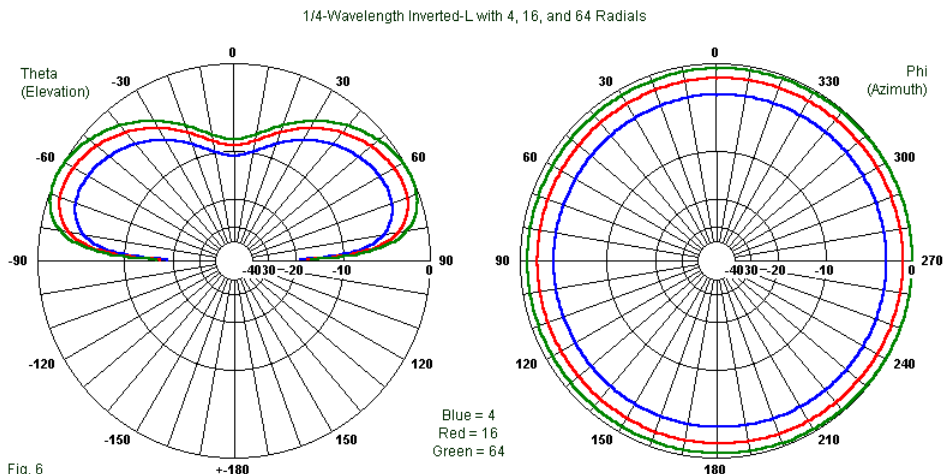
The performance of the inverted-L is not significantly different from the Tee, as shown by the following performance figures.

#### Shortened Tee-Vertical Monopole with Variable Radial Systems Average Ground

No. of Radials	Maximum Gain dBi	TO Angle degrees	Feedpoint Z R +/- jX Ohms
4	-1.53	26	43 + j 3
16	0.08	26	30 - j 6
64	0.98	26	24 - j11

Due to the small horizontal component of the radiation patterns, the elevation angle has increase by another degree. However, the impedance values are almost identical to the corresponding values for the Tee-vertical. **Fig. 6** shows the elevation and the azimuth patterns for the inverted-L. Note that the presence of a non-symmetrical horizontal section does not allow the pattern overhead to go to nearly zero, although the level is not strong enough for effective NVIS communications. The azimuth pattern shows a slight push in the direction of the

top section of the L. However, the differential is not large enough to be noticed during operation.



The 160-m 1/4-wavelength inverted-L has another advantage. With a wide-range tuner at the feedpoint (perhaps one of the remote tuners on today's market), the antenna is usable for general communications on virtually all of the amateur bands. Above 160-meters, the radial system acts like a good RF ground between the operating position and the antenna base, since the antenna is 1/2-wavelength or longer on all bands above 160 meters. If you choose to use a remote tuner for such an inverted-L system, add another layer of water-proofing as an additional guard against weather penetration of the tuner and the connection.

There is one temptation to avoid with the 160-meter 1/4-wavelength inverted-L. Many operators obtain rather poor results because they place the vertical section of the antenna too close to a natural or man-made support. The vertical section



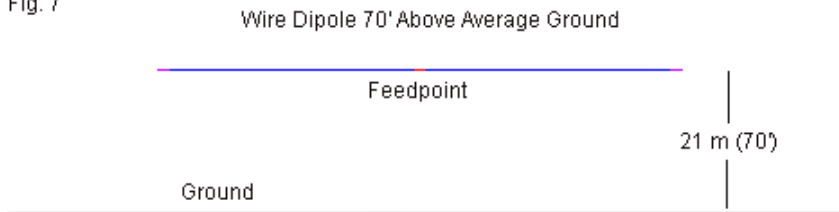
needs as much clearance from other objects as the corresponding part of the full-size and the Tee verticals.

### 160-Meter Wire Horizontal Antennas

We have examined the main candidates for vertical wire antennas, although there are many variations on the basic designs that we have used as examples. We should also look at some horizontal basic wire antennas. Any horizontal antenna will be severely limited by the 70' height restriction that we placed on the exercise. 70' is only about 1/8-wavelength above ground, a height that is even below optimum for NVIS operation--although it will work quite well in this service. One advantage of the horizontal wire is that it does not require any radials. A second advantage--at least for our work--is that horizontal wires do not change performance characteristics very much as we change ground quality. Therefore, the use of average ground provides a good indication of operation over any soil type. Finally, there are only 2 important horizontal variations that are possible within our height restriction: linear wires and closed horizontal loops.

*The 1/2-Wavelength Dipole:* There is no magic about the 1/2-wavelength dipole except that at resonance, it is a reasonably good match for coaxial cable. If we wish to use parallel feedline and a tuner, we can be less critical about the exact length without changing the pattern in any detectable way. **Fig. 7** shows the details of our model set-up. The wire is 78 m (256') long.

Fig. 7



Since we have only a single model with which to deal, our performance table is simplified.

1/2-Wavelength Horizontal Dipole 70' above Average Ground

Maximum	TO Angle	Feedpoint Z
Gain dBi	degrees	R +/- jX Ohms
6.72	90	49 + j 0

Theta (Elevation) Pattern Comparison  
Dipole at 70' vs. Inverted-L with 16 Radials

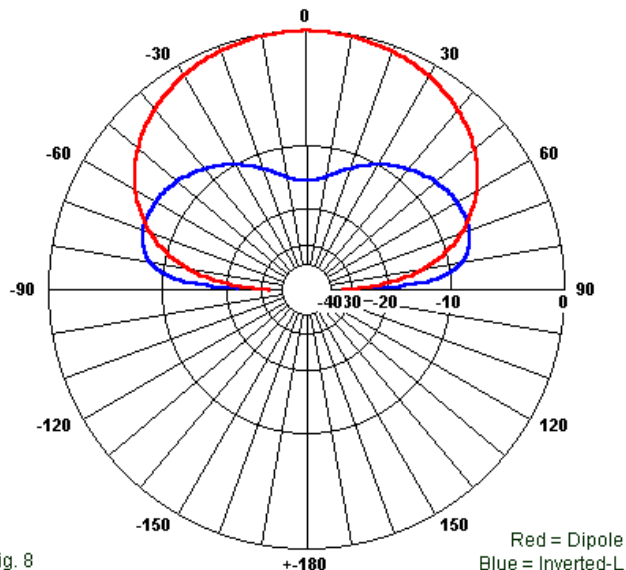


Fig. 8

Note that the horizontal wire provides the strongest radiation (and receiving sensitivity) straight up. **Fig. 8** compares the elevation pattern of the dipole with the elevation pattern for the inverted-L with 16 radials. The horizontal wire is superior for NVIS service, but inferior for long-range, low-angle service. The horizontal wire is likely to be more susceptible to lightning noise, but less

susceptible to man-made noises. The patterns for the two types of antennas cross at about the 23-degree elevation mark.

Despite the low height of the dipole when registered as a fraction of a wavelength, the azimuth pattern at almost any elevation angle is still bi-directional and broadside to the wire. **Fig. 9** shows the azimuth pattern at a lower angle (25 degrees elevation). Radiation (and reception) off the ends of the wire is about 8-dB or about 1.5 S-units weaker than broadside to the wire.

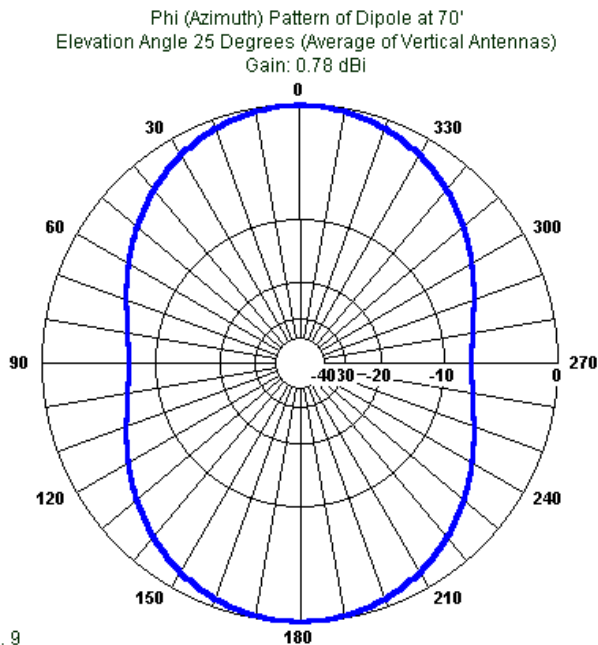
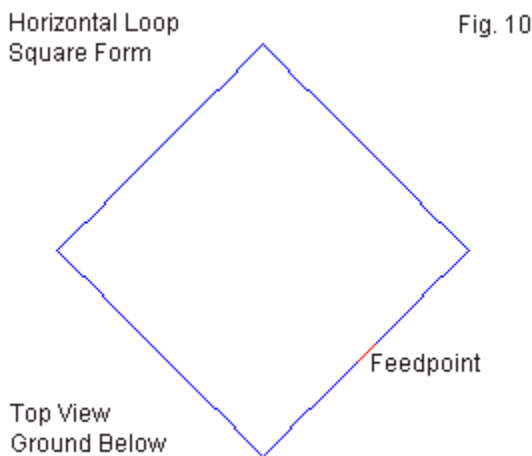


Fig. 9

Linear wires with open ends can build considerable levels of static charge unless we take measures to bleed it off as it develops. One technique is to place either a high-value resistor or an RF choke across the antenna feedpoint, ensuring that

one side is connected to the coax braid--and the coax braid is well grounded. Inserting a transmission-line transformer type of balun at the feedpoint will defeat this measure by physically isolating the feedpoints from the cable braid. However, using a W2DU-type ferrite-bead choke as the balun will allow the bleed-off component to do its work.

*The 2-Wavelength Horizontal Loop:* A closed loop antenna is more immune to static charge build-up, but has some special requirements. To understand why the heading specifies a 2-wavelength circumference for the loop horizontal antenna, we should proceed a step at a time. Let's begin with a simple square loop, like the one shown in **Fig. 10**. Our initial exercise will place the loop in free space and vary the circumference from 1.0 to 2.5 wavelengths.



The following table lists the free-space performance values for the loop. The column marked "Horizontal Gain" lists the gain in the plane of the loop. The column labeled "Vertical Gain" shows the gain broadside to the face of the loop.

## Free-Space Performance of Horizontal Loops of Various Sizes

Circumference	Horizontal	Vertical	Feedpoint Z
WL	Gain dBi	Gain dBi	R +/- jX Ohms
1.0	0.09	3.27	124 + j 17
1.5	1.49	2.97	5300 - j 4700
2.0	3.07	0.18	300 + j 240
2.5	2.06	1.09	2600 - j 2700

The 1-wavelength loop is most useful in parasitic beams called quads, where the individual loops are set up vertically to take advantage of the stronger radiation broadside to the plane of the loop. However, when we place the loop horizontally over ground, the radiation from the edge of the loop--the plane of most interest--is much weaker. As the table shows, the edge, in-plane, or "horizontal" radiation is strongest when the loop is about 2 wavelengths in circumference. For our test model, that length is about 340 m (1115'). Since the loop is not resonant, we shall need parallel transmission line and a tuner. Hence, the exact length is not at all critical. Any total circumference around 1100' will work fine.

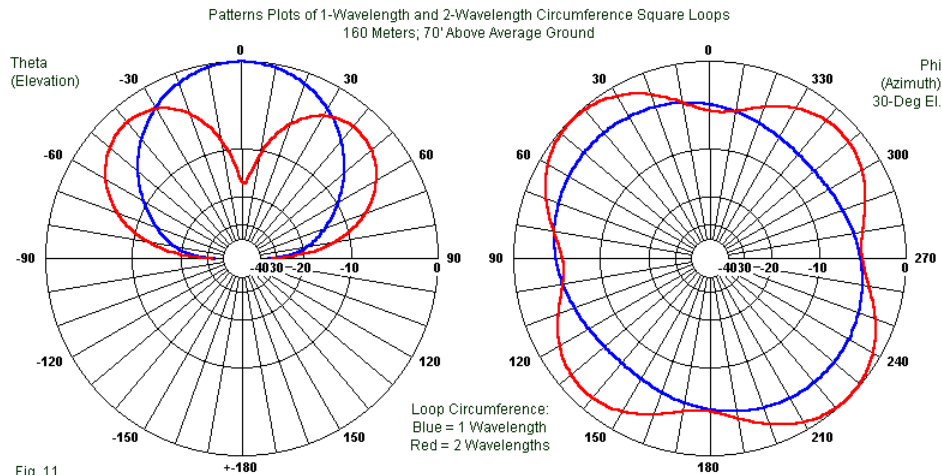


Fig. 11

**Fig. 11** compares the elevation and azimuth patterns for 1 and 2 wavelength loops 70' above average ground. Note that due to the low height, even the 2-wavelength loop has a relatively high TO angle. However, the 2-wavelength radiation strength (and reception sensitivity) at lower angles is considerably greater than the 1-wavelength loop. The advantage at lower angles appears clearly in the azimuth patterns on the right. The "tilt of the pattern follows the placement of the feedpoint, shown in **Fig. 10**. Note that the 2-wavelength loop does not produce a circular--or even an oval--pattern. Rather, it has four wide major lobes. The following table completes the equivalent data for all of the loop sizes that we tested in free-space. Note that the impedance reports change relative to the free-space values--as a function of the low height of the antennas above ground. The resistive component is lower, while the reactive component is more inductive.

Performance of Horizontal Loops of Various Sizes 70' above Average Ground

Circumference	Maximum	TO Angle	Feedpoint Z
WL	Gain dBi	degrees	R +/- jX Ohms
1.0	7.38	90	100 + j 100
1.5	6.65	90	2600 - j 5200
2.0	5.65	50	200 + j 380
2.5	6.02	53	1400 - j 3300

The pattern shapes and TO angles for a horizontal loop change as we change the shape of the loop. They also change if we move the feedpoint, say, from a corner to the middle of a side. As samples of the sort of changes that we might encounter with relatively symmetrical simple structures, I modeled triangular, square, and hexagonal loops, feeding each structure both at a corner and in the middle of a side. The following table summarizes the results. It adds a column listing the maximum gain at a "standard" 30-degree elevation angle, since the TO angle is considerably higher in most cases and varies from case to case.

## Performance of 2-Wavelength Horizontal 70' above Average Ground

Loop and Feed position	Maximum Gain dBi	TO Angle degrees	Gain at 30-deg dBi	Feedpoint Z R +/- jX Ohms
Triangle-Corner	6.05	54	3.56	135 + j 315
Triangle-Side	5.99	58	3.18	225 + j 300
Square-Corner	4.92	55	1.24	75 + j 220
Square-Side	5.65	50	3.51	200 + j 380
Hexagon-Corner	5.65	53	2.75	140 + j 320
Hexagob-Side	5.57	54	2.45	145 + j 320

The wires of a 2-wavelength loop interact with each other to produce distinctive patterns for each combination of overall shape and feedpoint placement. **Fig. 12** shows the azimuth patterns for the two triangles, with plots taken at the TO angle at a standard 30-degree elevation angle. The insets show the loop outline and the feedpoint placement relative to the pattern for each version of the triangle. In all of the plots of 2-wavelength horizontal loops, the feedpoint will be at the top or 0-degree azimuth direction.

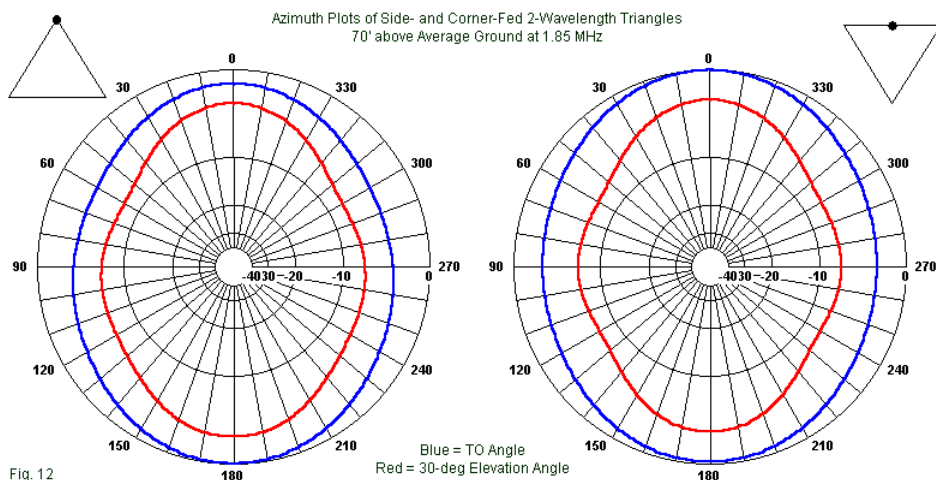
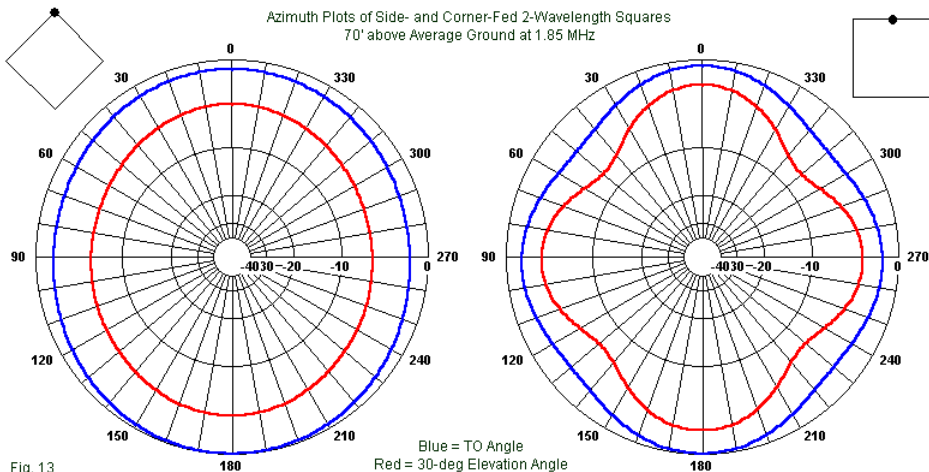


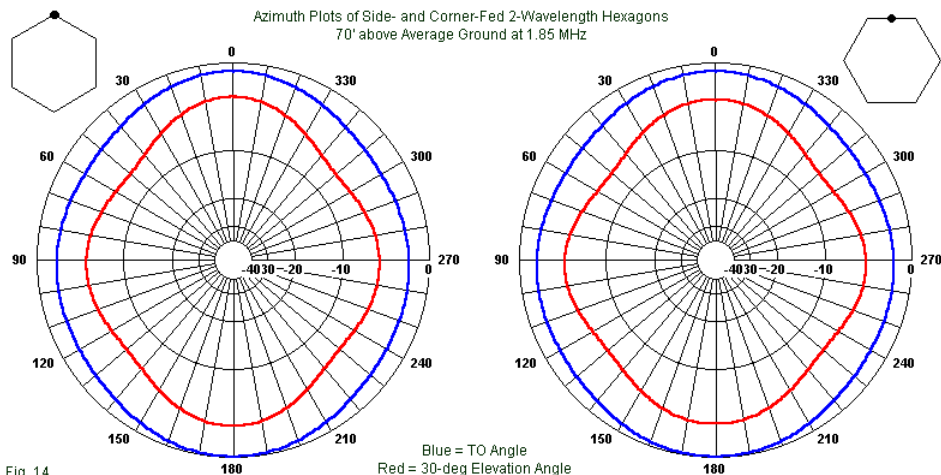
Fig. 12

The two triangle patterns are similar, although there is a small displacement of the pattern toward the long-wire side and away from the triangle point. More significant is the fact that in both cases, the pattern is significantly stronger (by about 3 dB) along a line from the feedpoint through the center than from side to side. Otherwise, there is not much to choose between the two versions of the triangle.



The patterns in **Fig. 13** confirm what the data in the table suggest: the feedpoint position makes a much more important difference to performance with a square loop than with any other form. With a corner feed, we obtain nearly circular patterns, but at lower strength. With a side-feed, we obtain more gain, but the patterns take on the 4-lobe shape. The lower the elevation angle, the more distinct that the lobes become. Whether the pattern shape and gain provide an advantage may depend on the possibilities for laying out the antenna relative to desired communication targets.





As we make the loop more circular, the exact shape and feedpoint make less difference to performance. The hexagon patterns appear in **Fig. 14**. Neither the pattern shape nor the gain change very much as we re-orient the loop and the feedpoint. As well, the corner-fed and side-fed versions of the loop exhibit feedpoint impedance values that are much closer together than for either the triangle or the square.

The most desirable version of a 2-wavelength horizontal loop would be a circle. However, the realities of antenna construction will not only require simpler forms, but as well, they may dictate somewhat irregular shapes. Nonetheless, virtually any horizontal loop will provide very reasonable performance. In addition, unlike a dipole, they will provide a null overhead, much like the nulls of vertical antennas. Therefore, if NVIS operation is the goal, you must either create a 1-wavelength loop or a dipole. For operation in the 20-30-degree elevation range, the 2-wavelength loop will usually provide as much or more gain than a wire vertical. **Fig. 15** compares the elevation patterns of the corner-fed hex loop and the inverted-L with 16 radials. The maximum gain limits of the loop are similar to

those of the dipole at the same 70' height, but the pattern is nearly circular rather than being bi-directional.

Theta (Elevation) Pattern Comparison  
2-Wavelength Hex Loop at 70' vs. Inverted-L with 16 Radials

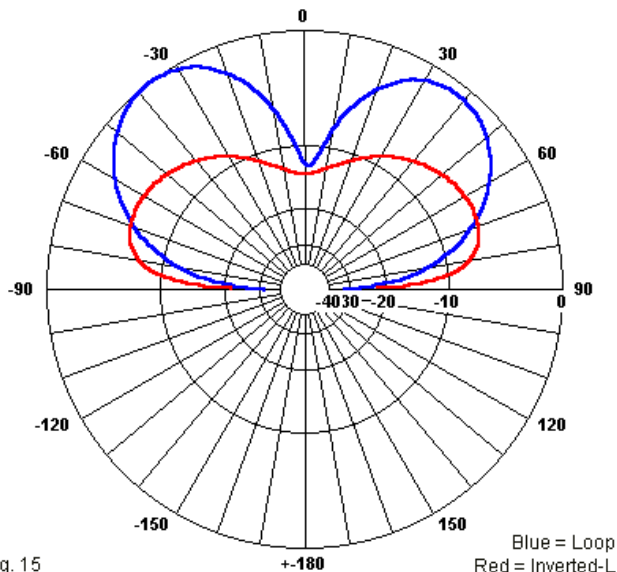


Fig. 15

Both the 160-meter dipole and the 2-wavelength loop are useful as multi-band antennas if we feed them with parallel transmission line and employ an antenna tuner to achieve a match with the transceiver. A number of other items at this site address the kinds of patterns that we can expect from a 250+' doublet and from horizontal loops (HOHPLs) of various shapes across the HF region.

## Conclusion

We have surveyed some of the simplest antennas used on 160 meters. They are simple in principle, but require a lot of wire, whether used in the element or in radials. Insulation on the wire makes virtually no difference to performance. As noted early on, element wire should be strong, and copperweld is desirable. However, radials may use virtually any wire available. If a sale on wire allows you to add more radials to a vertical system, then it is worth the price. However, exposed elements require good strength or additional supports. As well, use good non-conductive insulators wherever an elevated wire terminates or changes direction. Do not lay a wire directly over a tree limb or wood support. High voltage has been known to gradually sever limbs or to set dry limbs ablaze. Suspend an insulator below the support and run the wire through the insulator. Likewise, use a strain relief fixture for any connection between the element and parallel transmission line.

We have not examined a number of excellent antenna systems, such as phased or parasitic verticals. 160-meter wire Yagis and LPDAs are also possible. These are advanced projects, and our mission was to set out and compare some basic antennas. However, eventually, you will wish to purchase a copy of ON4UN's book on *Low-Band DXing*. It is possibly the best collection of 160-meter (and 80- and 40-meter) antenna ideas available.

## Chapter 26: A Great Backup Antenna for 80-20

**E**veryone needs a back-up antenna in case one or more of the main arrays at the antenna farm becomes inoperative. The requirements for the back-up antenna are very straightforward:

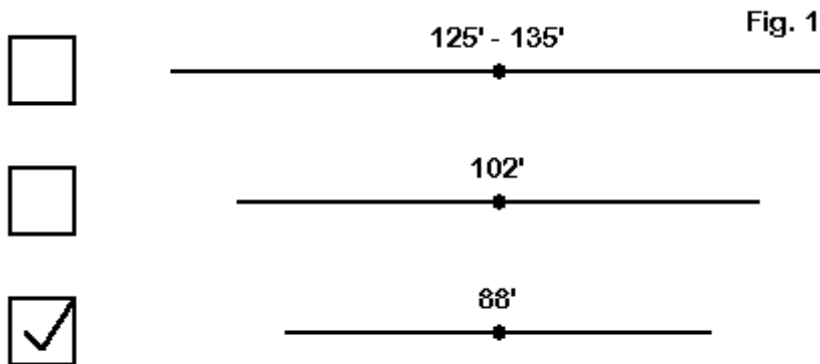
1. It should be a simple, multi-band design--in order to replace any one or more of the main systems. We shall accept the need for an antenna tuner (ATU).
2. It should also be mechanically simple--to make maintenance a relatively easy matter.
3. It should cover all bands of main interest--here defined arbitrarily as 80 through 20 meters.

For this exercise, I shall confine myself to horizontal antennas, with the proviso that they be as high as possible. 70' is not very high on 80 meters for a horizontal antenna, and I shall use that as my minimum height. However, if the back-up is to replace wounded high-altitude horizontal beams, 100' is not unrealistic. If you live in the right kind of forest, these heights can be attained using trees instead of towers as the end support points.

These notes do not imply that a vertical does not make a good back-up for the main antenna systems. In fact, I use a multi-band vertical myself for just such purposes. However, it is too difficult to cover both vertical and horizontal possibilities in one small article, so I shall confine the discussion to horizontal antennas.

### The "Best" Single Wire

If we begin with a single horizontal wire, placed as high as we can achieve, only one question remains: how long? **Figure 1** suggests the answer I would give.



### The "Best" Length for an 80 - 20 Meter Back-Up Antenna

Notice that I have by-passed the standard multi-band doublet lengths of 135' and 102' (or thereabouts). The reason is simple. As we increase frequency, the azimuth patterns for these antennas break into many lobes, with much reduced radiation broadside to the wire. I shall take the following condition to be desirable for a back-up antenna: we know where the main lobes of the pattern go. The best way to guarantee consistency for all the bands we wish to cover with the back-up antenna is to ensure that the lobes on every band are broadside to the wire.

88'--plus or minus a non-critical bit--is the longest wire we can use to ensure broadside lobes on 20 meters. The antenna length is about 1.25 wavelengths on 20, which makes it an extended double Zepp. At the same time, the chosen length is between one- third and three-eighths wavelength on the low end of 80 meters. With care, that length is usable at a lower level of performance than for the other bands.

Free-Space Azimuth Patterns  
88' Doublet: #12 Copper 120  
80 - 20 Meters

Outer Ring = 5.03 dBi

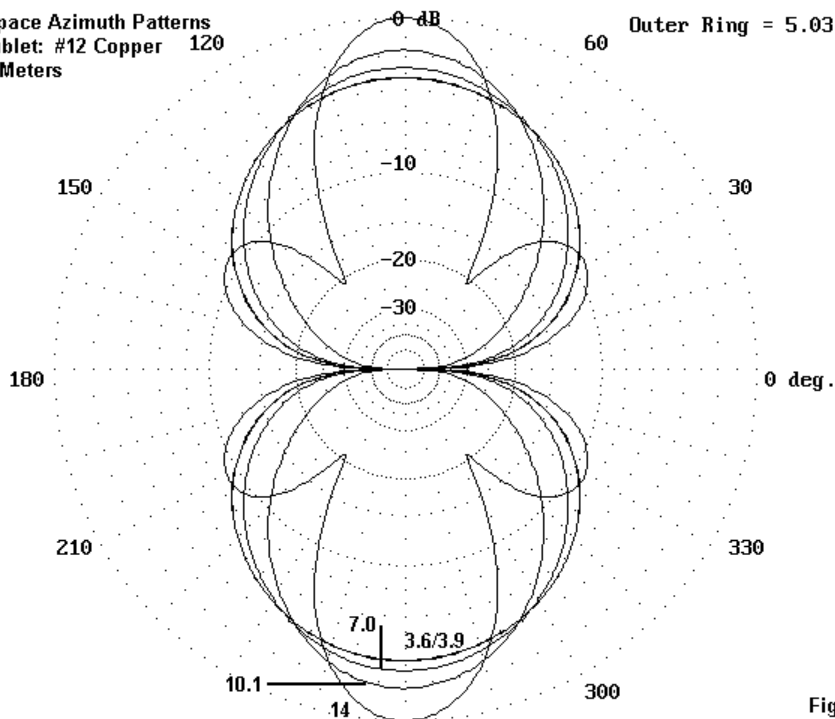


Fig. 2

**Figure 2** shows the free-space azimuth patterns for the back-up antenna for 80 through 20 meters. You may correlate the patterns with the data in **Table 1**.

Table 1. Free-Space Performance of an 88' #12 Copper Wire Doublet

Freq. MHz	F-S Gain dBi	Horizontal B/W (deg.)	Feedpoint Z R +/- jX Ohms
3.6	1.77	85	25 - j 615
3.9	1.82	84	30 - j 500
5.37	2.05	79	71 - j 20
7.0	2.38	71	185 + j 510
10.1	3.36	53	3360 + j2245
14.0	5.03	32	155 - j 805

Of course, these NEC-4 modeling numbers are more precise than would be operationally significant. However, they do clearly show the trends in performance. An often overlooked figure of merit is the beamwidth, which gives us a measure of relative coverage for an antenna. Note that the 60-meter values place the antenna at close to resonant-dipole length on this band.

No one has ever decreed that we cannot make an 88' doublet out of aluminum tubing. Before we dream of rotating such an antenna, let's examine the free-space performance figures for a version with an average effective diameter of 1".

**Table 2** tells the story.

Table 2. Free-Space Performance of an 88' 1" Aluminum Tubing Doublet

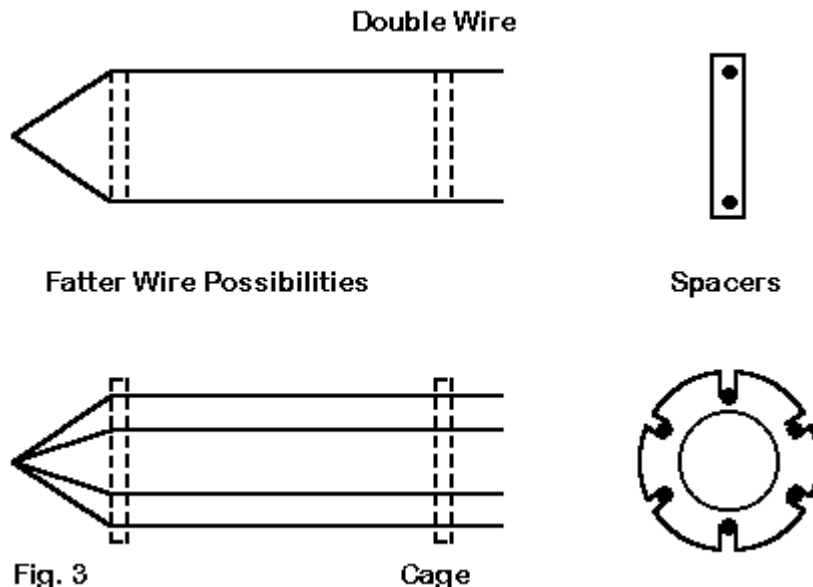
Freq. MHz	F-S Gain dBi	Horizontal B/W (deg.)	Feedpoint Z R +/- jX Ohms
3.6	1.90	85	24 - j 425
3.9	1.93	84	29 - j 340
5.37	2.13	78	72 - j 2
7.0	2.44	71	197 + j 385
10.1	3.43	53	2560 + j 220
14.0	5.02	31	125 - j 495

There are some interesting differences between the numbers in the two tables. First, the trend with the fatter element is higher (but not significantly higher) gain--except for 20 meters. Here, the gain actually decreases (although insignificantly), because the fatter wire more closely approaches an electrical length where the EDZ ears come to dominate the azimuth pattern. At an electrical length of 1.5 wavelengths, the antenna would show 6 nearly equal lobes.

Second, the fatter wire tends to reduce the feedpoint impedance, especially the reactive components. This effect can be very useful in easing the burden on the ATU. On 80 and 75, there is a disproportionately high ratio of reactance to resistance in the feedpoint impedance. Hence, even with very high efficiency parallel lines, expect line losses to add to the reduced performance from the already short antenna length (about 1/3 wavelength). That is an important reason why I call this antenna a back-up rather than a prime station antenna.

One of the limiting factors for every ATU is the range of reactance it is able to compensate for at any given frequency. Of course, if we choose the "wrong" line length, we may encounter such cases due to the impedance transformation properties of every transmission line. One easy solution is to change the line length until we reach the best compromise setting. This technique--plus tuning up using very low power--can be critical on the lowest band (80/75 meters).





For those who would like the benefits of tubing but the low cost and lighter weight of wire, **Figure 3** offers a couple of the many alternatives. We can simulate the diameter of any size tubing with a pair of wires spaced by a certain distance. The spacing would have the value that allows the antenna to be naturally resonant on the same frequency at which the tubular antenna is resonant. This is an easy modeling task that takes the work out of field adjustment.

An alternative to the paired wire arrangement (shorted at both the outer end and at the feedpoint) is the old-fashioned cage. Since everything old becomes new again, cage antennas for low-band dipole use have gained a certain popularity, especially as the newer polycarbonate plastics have become generally available. As these figures suggest, the cage may also have some utility for multi-band doublets.

Even more significant are the figures for the doublet's performance over ground. **Table 3** and **Table 4** list the figures for heights of 70' and 100'. Added to the table is the TO angle (the take-off angle or elevation angle of maximum radiation) and the vertical beamwidth. Together, these figures give us a view of the range of incoming and outgoing skip angles over which we may effect communications. Like the horizontal beamwidth, the vertical beamwidth is a much overlooked valuable piece of data.

**Table 3. 70' Performance of an 88' #12 Copper Wire Doublet**

Freq. MHz	F-S Gain dBi	TO Angle (deg.)	Vertical B/W (deg.)	Horizontal B/W (deg.)	Feedpoint Z R +/- jX Ohms
3.6	5.90	59	130	180	30 - j 610
3.9	5.86	53	134	180	35 - j 495
5.37	6.41	37	51	97	80 - j 30
7.0	7.84	28	33	79	165 + j 485
10.1	8.66	19	21	55	3810 + j2160
14.0	10.81	14	15	33	155 - j 820

**Table 4. 100' Performance of an 88' #12 Copper Wire Doublet**

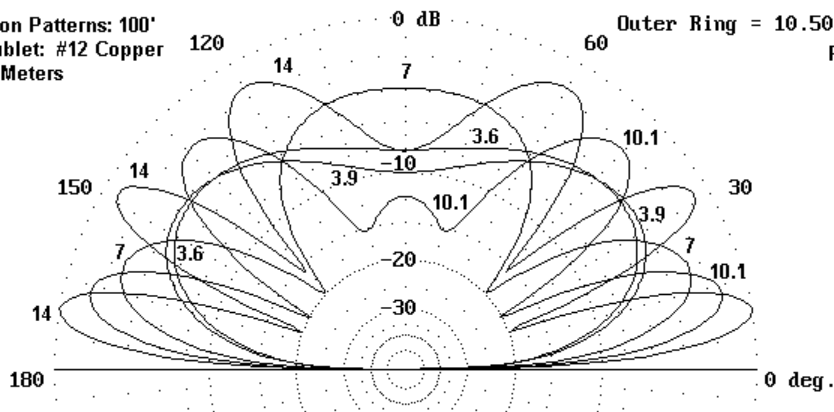
Freq. MHz	F-S Gain dBi	TO Angle (deg.)	Vertical B/W (deg.)	Horizontal B/W (deg.)	Feedpoint Z R +/- jX Ohms
3.6	6.12	38	57	107	30 - j 620
3.9	6.40	36	47	102	35 - j 505
5.37	7.93	25	29	85	60 - j 25
7.0	7.83	20	21	74	185 + j 530
10.1	9.16	14	14	54	3115 + j2450
14.0	10.50	10	10	32	165 - j 810

The feedpoint impedances at the two levels fall well within the margins of rough equality. The most important differences show up in the gain and TO angle columns. Although usable, the 70' model shows very high TO angles and lower gain on 80 meters. The 180-degree beamwidths on 80 meters indicate nearly circular patterns. In contrast, the TO angles and vertical beamwidths for 80 meters in the 100' model promise significantly better DX performance, with much more oval patterns. On 40 through 20 meters, the gain differentials disappear, but the higher model shows the expected lower TO angles.

Elevation Patterns: 100'  
88' Doublet: #12 Copper  
80 - 20 Meters

Outer Ring = 10.50 dBi

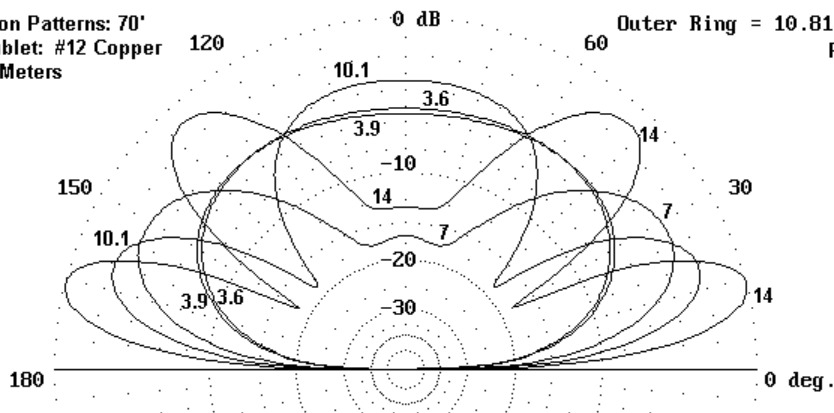
Fig. 4



Elevation Patterns: 70'  
88' Doublet: #12 Copper  
80 - 20 Meters

Outer Ring = 10.81 dBi

Fig. 5



In order to get a better perspective on the significance of these figures, examine **Figure 4** and **Figure 5**. They show the elevation patterns of the antenna at the two heights: 100' and 70', respectively. Besides illustrating the notes just given,

they also reveal the growth of secondary lobes at the upper frequencies as we raise the antenna by 30' or so. 20 meters has grown a third elevation lobe. The high dome pattern gravitates from 10.1 MHz down to 7 MHz in the move from 70' to 100'. The shape difference at the two heights in the 80/75 meter patterns is self-evident.

I have not added the azimuth patterns, since they resemble too closely the patterns in **Figure 2**. The key difference is that as we reduce the frequency of use, the side rejection decreases. The decrease is more radical at the lower height, where it disappears almost completely at 80 meters. In addition, the high X:R ratio at 80 meters tends to yield higher line losses that do not appear in the basic antenna patterns. The gain of the antenna along remains unchanged, although a high-loss line situation means that less power will reach the antenna.

### A Pair of Semi-Eternal Triangles

Although it is not likely to be true, let me assume that I have convinced you that an 88' doublet is the best single-wire back-up antenna for 80 through 20 meters. Once we have gone this far for the sake of the argument, we can pose the question of how to derive the best world-wide coverage with such a wire antenna. The answer is as simple as the triangle.

Actually, I want to explore two versions of the triangle: a Y-array and a true triangle. For no particular reason, I shall begin with the Y-array, shown in **Figure 6**.

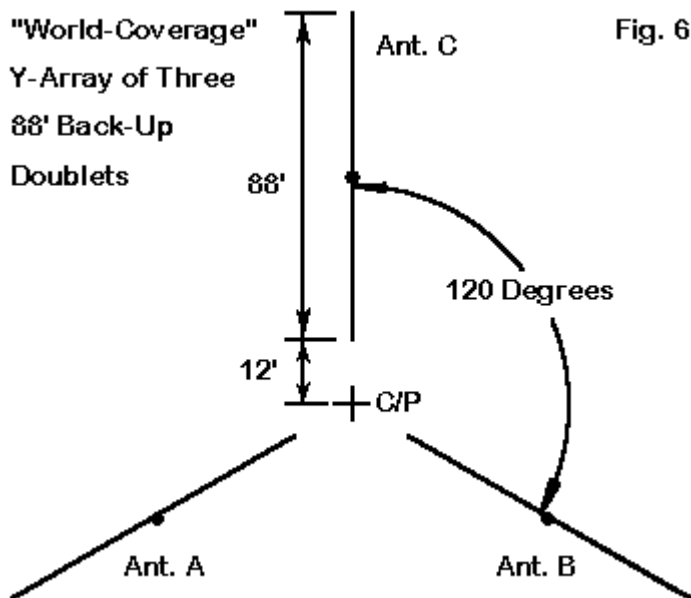


Fig. 6

As the figure shows, the ends of the wires are set 12' from a center-point for the array. The array would require a rectangle about 100' by 175' for implementation. A 4- post construction method seems most obvious (1 at the center and three on the perimeter). However, those with special skills in high-strength wire trussing might manage with only the perimeter posts. A slight dip in antenna height toward the center point would create no significant performance problems

There is no special magic to my choice of element separation from the center point. The goal was to minimize interaction between the active element and the inactive ones. 18' between adjacent ends is sufficient to achieve this goal, as evidenced by the modeled data in **Table 5**. The data are for a 100' array height.

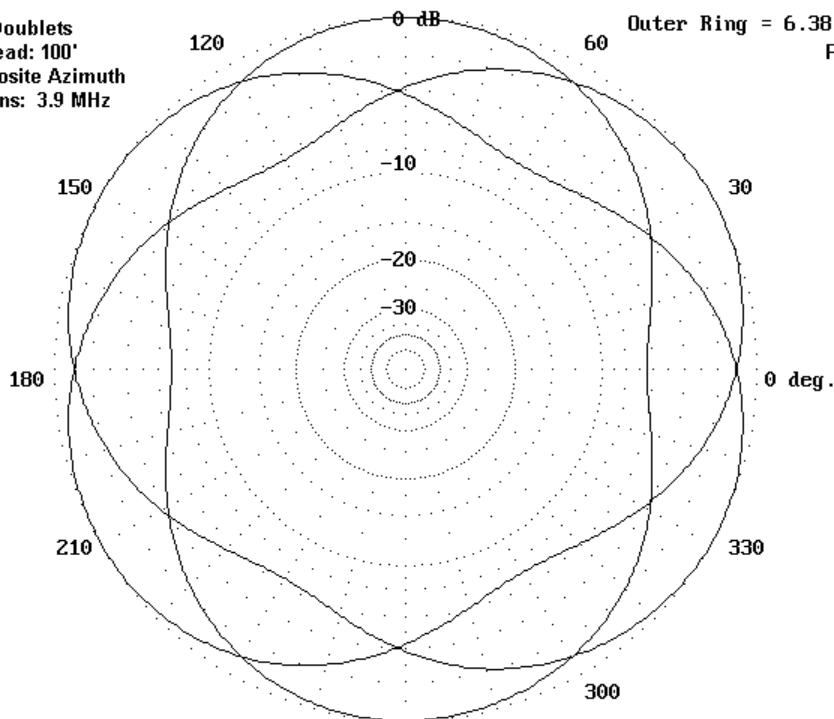
Table 5. 100' Performance of a Y-Array of 88' #12 Copper Wire Doublets

Freq. MHz	F-S Gain dBi	TO Angle (deg.)	Vertical B/W (deg.)	Horizontal B/W (deg.)	Feedpoint Z R +/- jX Ohms
3.6	6.11	38	58	108	31 - j 620
3.9	6.38	36	47	104	35 - j 505
5.37	9.18	26	29	135	130 - j 30
7.0	7.87	19	21	73	185 + j 535
10.1	9.14	13	14	55	3110 + j2470
14.0	10.39	10	10	33	165 - j 810

The data are insignificantly different from those of **Table 4**, which gives modeled values for an independent 88' doublet. 60 meters is the exception. On that band, the near-resonance of the elements yields a beam pattern with an 11-dB front-to-back ratio. The main lobe is away from the inactive elements, which form a composite parasitic reflector. The significantly different feedpoint impedance relative to the value for a single 88' wire at the same height is another indicator of the odd behavior on this band. Whether that odd behavior is an advantage or a disadvantage depends upon operating needs.

3 88' Doublets  
Y-Spread: 100'  
Composite Azimuth  
Patterns: 3.9 MHz

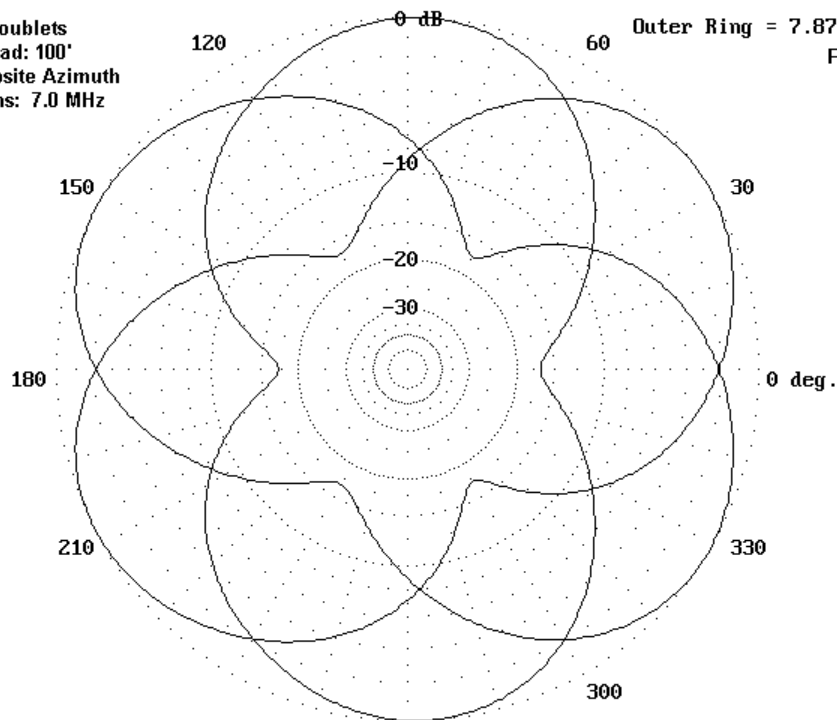
Outer Ring = 6.38 dBi  
Fig. 7



To effect world wide-communications, we should understand how the patterns for the triangle overlap. As well we should examine the nulls in the pattern. As **Figure 7** attests, on 80 meters, there is no significant null ( $<1$  dB). On 40 meters (**Figure 8**), the nulls are only about 2 dB, which is likely small enough not to occasion any repositioning of wires.

3 88' Doublets  
Y-Spread: 100'  
Composite Azimuth  
Patterns: 7.0 MHz

Outer Ring = 7.87 dBi  
Fig. 8

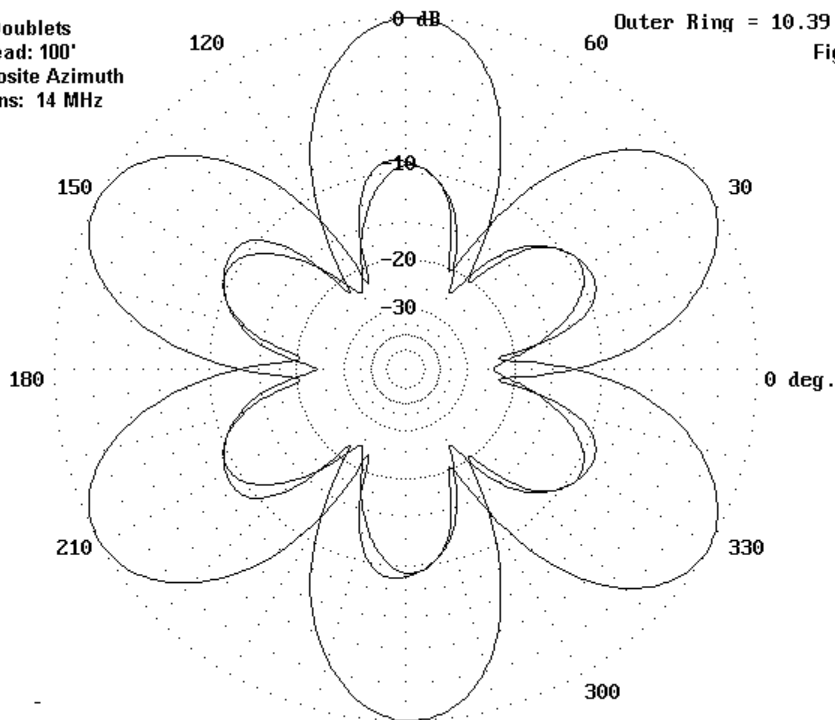






3 88' Doublets  
Y-Spread: 100'  
Composite Azimuth  
Patterns: 14 MHz

Outer Ring = 10.39 dBi  
Fig. 10



In modeling exercises, no negative effects resulted from warping the Y array from its perfect 120-degree separation. Changes up to 20 degrees appear not to create any noticeable consequences for the radiation patterns from the individual antenna wires. Consequently, the array designer can position the three wires in an approximate Y, with each wire broadside to the most favored contact directions, whether those are domestic or DX.

It would be incorrect to say that the wires do not interact at all. **Figure 10** shows the very slight interaction by the manner in which the secondary lobes of the

three patterns overlap in slightly irregular ways. In fact, the main lobes depart from the true broadside by about 1 degree in the direction of the other wires. These facts, however, do no more than complete the record. Their operational significance is negligible, and the three wires may be considered as aiming in a true broadside direction for all practical purposes. As well, the wires more severely interact on 60 meters so that the result is a directional pattern with an 11-dB front-to-back ratio. The interaction level is a function of the near-resonant length of the wires in the triangle.

The Y-array presumes that all of the parallel feedlines will be brought to a central switching point, from which a single parallel feedline will proceed to the shack. Switching would be by a remote system (unless the shack is located approximately under the center-point of the array. **Figure 11** provides the basic elements of such a remote switching system.

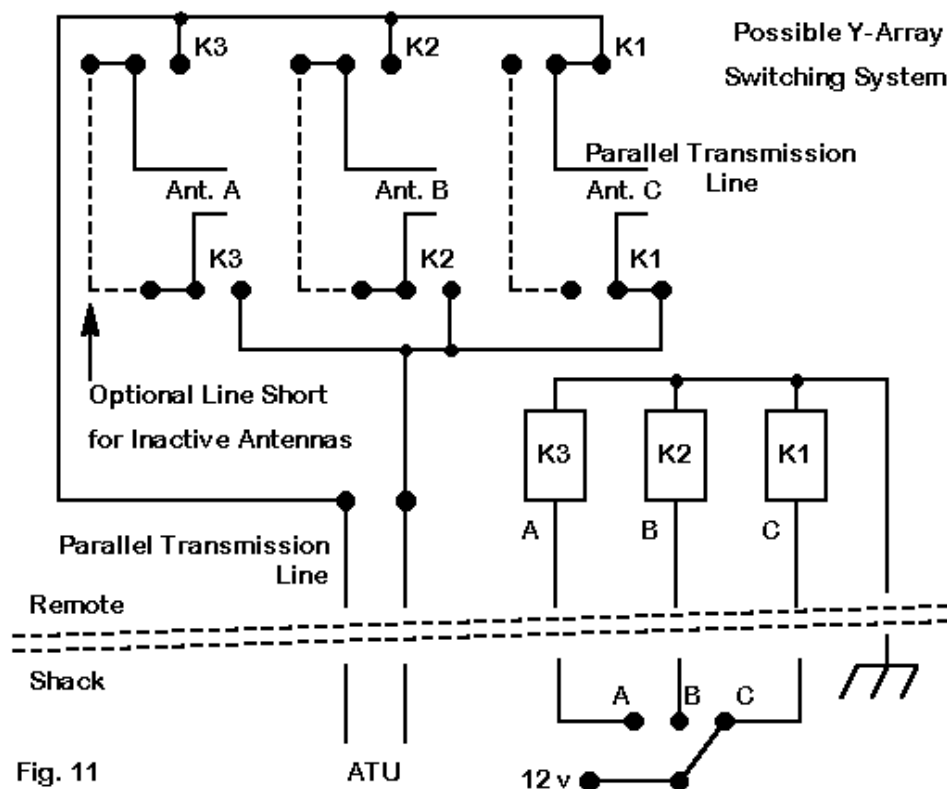


Fig. 11

The system shown can be considered a "bare-bones" version that can be embellished in innumerable ways. Since the array shows no significant differences between open and closed centers for the inactive antennas, shorting the transmission lines of the unused antennas can serve useful functions. For example, you might want to add RF chokes to the shorted contacts with a

subsequent lead to ground. The result will be to bleed off any static charges on these wires.

In fact, you may wish to add a fourth "Off" position to the switching system, for use when the array is wholly inactive. This option would simply remove all power from the relays and bleed all three wires of static charges that may build up from winds and other weather forces. (I shall assume that there will be provisions nearer to the shack for a total disconnect and grounding of both the relay power lines and the parallel transmission line coming from the switching unit. Add other safety features as the spirit moves you.)

In addition to safety features, it also pays to decouple the relay power lines from RF right at the switching unit. You may add rf chokes and by-pass capacitors to each power line inside the weatherproof relay box. Alternatively, you can place ferrite cores over each power line. Be sure to include the common in this treatment. Although shown with a ground connection at the shack, this line at the remote switching unit is ripe for RF pick-up and distribution. Additional decoupling at the shack end of the line is also a wise precaution.

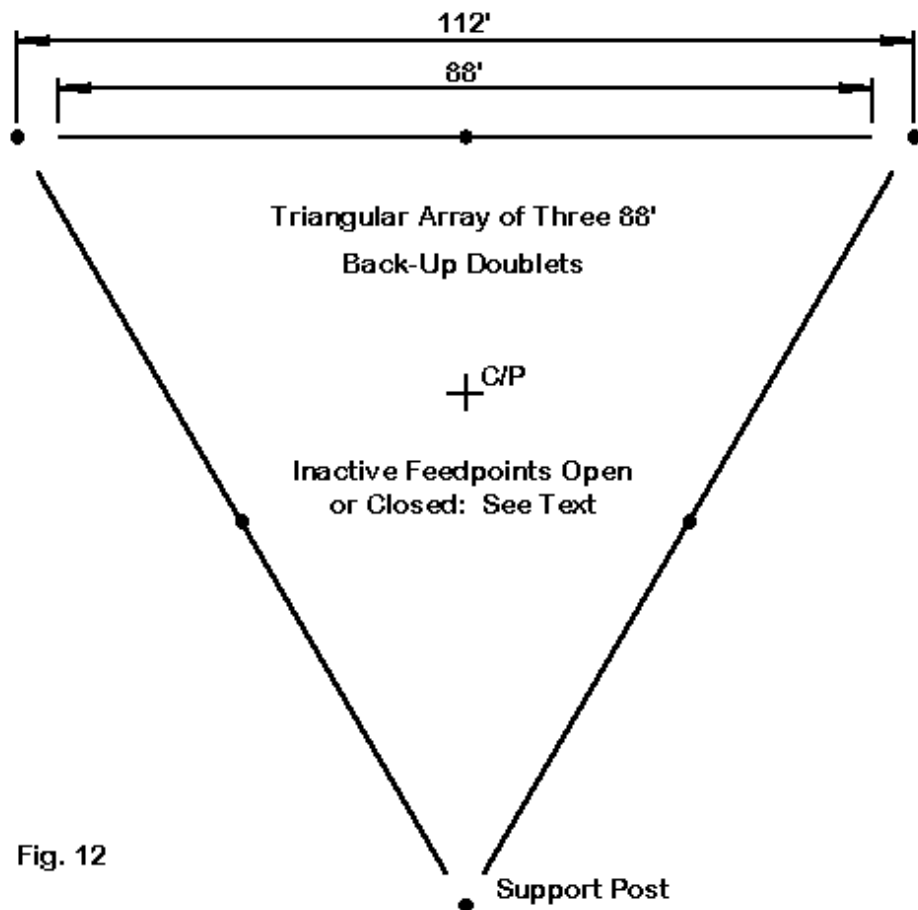


Fig. 12

The same switching unit can be used with the second configuration of the array: the true triangle shown in **Figure 12**. This arrangement requires only 3 posts, about 112' apart. The outer dimensions allows for a 12' spacing of the wire from

the post, which results in 12' of separation between adjacent wire ends. The true triangle requires less space than the Y-array. A rectangle about 112' by 97' will contain all of the wires. Like the Y- array, I shall assume that the feedlines are brought to a central point for switching among the antennas.

The true triangular array in theory shows more tendency toward interaction between the active antenna and the inactive wires. Hence, there is likely to be a more significant difference in performance based on whether the center points of the inactive wires are open or shorted.

The interaction does not greatly affect the overall performance of the antenna, as shown in **Table 6** and **Table 7**. With the unused centers closed or shorted, there is a very slight front-to-back ratio. It is never greater than 0.3 dB and the "stronger" lobe is in the direction of the unused wires. With the unused wire centers open, the front-to-back effect drops to less than 0.1 dB on all but 30 meters.

**Table 6.** 100' Performance of a Triangle-Array of 88' #12 Copper Wire Doublets

Freq. MHz	F-S Gain dBi	TO Angle (deg.)	(Unused Centers Closed)		Feedpoint Z R +/- jX Ohms
			Vertical B/W (deg.)	Horizontal B/W (deg.)	
3.6	6.25	38	55	109	28 - j 615
3.9	6.57	35	46	103	32 - j 500
7.0	7.61	20	21	71	185 + j 525
10.1	9.31	13	14	56	3320 + j2655
14.0	10.22	10	10	32	165 - j 820

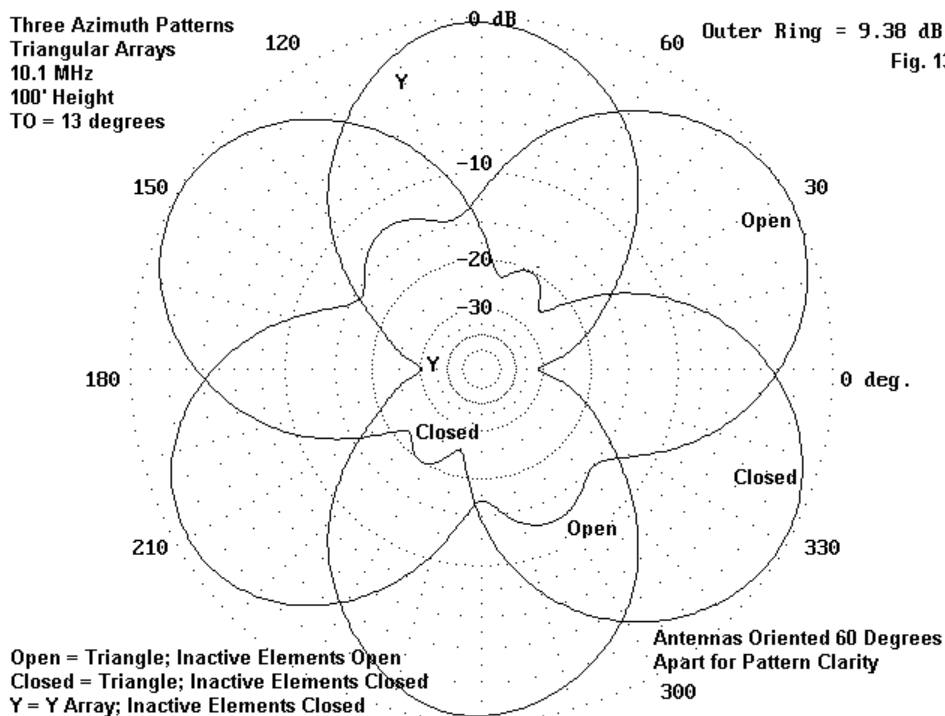
**Table 7.** 100' Performance of a Triangle-Array of 88' #12 Copper Wire Doublets

Freq. MHz	F-S Gain dBi	TO Angle (deg.)	(Unused Centers Open)		Feedpoint Z R +/- jX Ohms
			Vertical B/W (deg.)	Horizontal B/W (deg.)	
3.6	6.14	38	57	108	29 - j 620
3.9	6.42	35	47	101	34 - j 505
7.0	7.88	19	21	76	185 + j 535
10.1	9.38	13	14	62	3050 + j2490
14.0	10.16	10	10	32	170 - j 820

Three Azimuth Patterns  
Triangular Arrays  
10.1 MHz  
100' Height  
TO = 13 degrees

Outer Ring = 9.38 dBi

Fig. 13



In reality, a noticeable difference in pattern shape occurs only on 30 meters.

**Figure 13** compares the 30-meter patterns for a. the Y-array (which is virtually identical to the pattern of the independent doublet), b. the triangle with the unused centers closed, and c. the triangle with the unused centers open. I chose a different orientation for each antenna, since the key pattern alteration occurs near pattern center. The side "bulges" in the 30-meter patterns for the true triangle do not materially affect the gain of the main lobes. However, the open condition does yield a front-to-back ratio of 0.6 dB, which can be noticed on patterns, but not in operation.



In the end, then, you may take your choice of open or closed unused elements. Since the choice is so close in performance, my own preference would be to opt for the safest choice: lines closed at the remote switching center. Whether that choice results in electrically closed or open feedpoints for the unused elements depends on the exact length of the line used between the elements and the switching box. Quarter-wavelength lines will result in open centers, while half-wavelength lines will yield shorted centers. Shorted lines that are longer than  $1/4$  wavelength will add capacitive reactance to the wires and possibly increase the directive effect in the direction of the unused wires. Shorted lines shorter than  $1/4$  wavelength or longer than  $1/2$  wavelength will likely add inductive reactance to the unused wires, converting them into reflectors of sorts. The effect, of course, will vary from band-to-band, since the line length to the switching box will change its electrical length with changes of frequency.

For many applications, minor directive and reflective effects may be no hindrance, and the smaller footprint of the true triangle will be the overriding consideration. For some applications, maximum isolation of each antenna will be the dominant concern: in such cases, the Y-array should be the configuration of choice. Before making this decision, it would likely be wise to model the system--with the proposed feedline as part of the model--to gain a better view of actual effects.

## The "Expanded" Lazy-H

Before leaving the field of back-up wire antennas that are about 88' long and that cover 80 through 20 meters, we should take note of the expanded lazy-H, which likely first appeared in print in CQ in an article by W2EEY. **Figure 14** shows the essential elements of the array: wires vertically spaced 44' apart. Although there are monoband schemes for bottom feeding the array, multi-band use tends to require balanced in phase feeding of the system, as shown in the sketch.

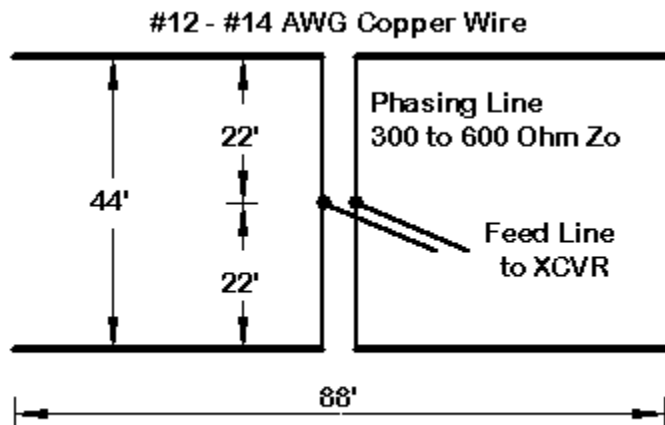


Fig. 14 W2EEY "Expanded Lazy-H Antenna

As we did with the independent doublet and the triangular arrays, let's place this antenna at a top height of 100', with the lower wires at 56'. For the data in **Table 8**, I used a 450-Ohm phasing line and took that feedpoint impedance readings from the junction of the two 22' lines.

Table 8. 100' Performance of an Expanded Lazy-H of 88' #12 Copper Wire Doublets

Freq. MHz	F-S Gain dBi	TO Angle (deg.)	Vertical B/W (deg.)	Horizontal B/W (deg.)	Feedpoint Z R +/- jX Ohms
3.6	5.95	46	138	131	10 - j 95
3.9	6.05	43	141	118	15 - j 60
5.37	8.81	30	37	137	150 - j 115
7.0	9.02	23	27	76	455 - j 445
10.1	11.69	16	18	56	20 - j 45
14.0	14.87	11	12	32	50 + j 385

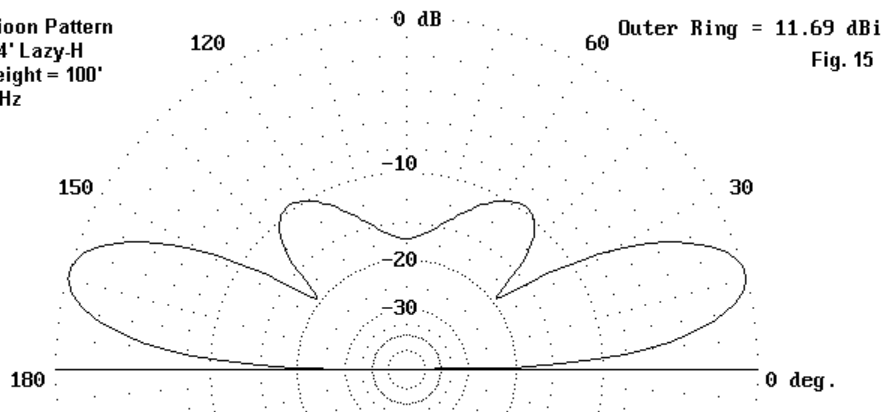
We should divide our discussion of the performance between the lower bands and the upper bands for this antenna. The lower bands show lesser gain and higher TO angles than the independent doublet. This phenomenon results from

the fact that the elevation angle at any frequency is a composite angle of the upper and lower wires. The lower wire at 56' significantly increases the 80/75-meter TO angle. The vertical beamwidth is very wide, which may compensate to a degree by offering low angle performance not far down from maximum. However, on the lowest band, the high angle reception is likely to increase the overall noise in relationship to signal strength. Hence, for 80 and 75 meters, finding a way to disable the lower wire and using only the upper wire would make good operating sense. On 40 meters, the added gain compared to a single doublet may more fully compensate for the slightly higher TO angle.

The performance on 60 meters is similar to the performance of a single wire triangle. The front-to-back ratio is 13 dB and the main forward lobe is in a direction away from the "inactive" reflector wires.

Upper band performance of the Lazy-H is marked by very significant increases in gain over a single doublet without decreases in the horizontal beamwidth. Where the gain comes from appears in **Figure 15**, an elevation plot for 30 meters.

Elevation Pattern  
88' x 44' Lazy-H  
Top Height = 100'  
10.1 MHz



Compare this plot to the 30-meter trace in **Figure 4**. That plot shows a very strong second elevation lobe at about a 45-degree elevation angle, along with the "dome" that indicates the development of third lobes. The expanded Lazy-H (which is a little under 1 wavelength long on 30 meters) shows strong first elevation lobes with second lobes about 10 dB lower in strength. The 20-meter elevation pattern would show a similar plot, with more ripples but no added strength above the first lobe. The added gain in the lowest lobes comes from the reduction in high angle gain--a very nice trade indeed.

The impedances of the triangle of lazy-H arrays suggest the use of a lower-impedance parallel line. Due to the variation in values from band to band, you can expect some tuning difficulties with common tuner designs. You may use inserts of added line length to arrive at the best set of impedance values for each band. On any band where the tuning is very sharp at the recommended low-power initial tune-up point, raise the power level slowly, checking for any necessary retuning as you go. 20 and 80 meters may present the most difficulties due to the relatively high ratio of reactance to resistance.

I have not modeled a Y-array of three expanded lazy-Hs, but I would suspect that the end-to-end isolation of the antennas would be similar to that of the doublets. If we have three (or 4) tall poles, towers, or trees for the support of a doublet array, we might wish to think about the expanded lazy-H as an alternative--at least for all of the bands except 80/75 meters.

### **Updating the Expanded Lazy-H for 80-20 Meters**

Some of the impedance values for the feedpoint junction of the phasing lines to the elements show similarities to those of the basic 88' doublet, although with a somewhat smaller X:R ratio. The most troublesome feedpoint impedance values occur when the resistive component is very low and the line impedance is quite high. The result is an exceptionally high SWR that even the low-loss reputation of parallel lines cannot overcome. That is, the line losses will be very considerable and in some cases prohibitive.

There are several strategies to lower the line losses. One route is to lower the impedance of the feedline to the lowest practical level while maintaining an open-wire construction to preserve the very low level of matched-line loss. 300-Ohm lines will go a long way toward reducing line losses to a more (but not completely) acceptable level when the feedpoint resistance is very low and the reactance is significant. Vinyl-coated lines are most common in this category, although we must use two precautions with them. First, the loss level of a vinyl coated line is higher than for open wires. Second, we must use line that is rated for transmitting duty and not the inexpensive low-power TV reception line.

We may also use other techniques to modify the arrangement of the antenna (including phase lines). One relatively easy technique is to raise the impedance of the phase line to the highest practical level, perhaps 600 Ohms. **Table 9** compares the 88' lazy-H at a top height of 100' for 450-Ohm and 600-Ohm phasing lines with respect to the feedpoint impedance.

**Table 9. Feedpoint Impedance of an Expanded Lazy-H of 88' #12 Copper Wire Doublets at 100'**

Freq. MHz	450-Ohm Line	600-Ohm Line
	Feedpoint Z	Feedpoint Z
	R +/- jX Ohms	R +/- jX Ohms
3.6	10 - j 95	15 - j 95
3.9	15 - j 60	20 - j 50
5.37	150 - j 115	90 + j 215
7.0	455 - j 445	990 - j 260
10.1	20 - j 45	40 - j 100
14.0	50 + j 385	60 + j 450

In most cases, the ratio between the resistance and reactance changes very little, but the 80- and 75-meter resistance values do rise slightly.

An alternative is to use a slightly longer element length. Chuck Gerarden, W0DLE, has constructed a lazy-H of the present type on a tall tower using 92' elements. Chuck's elements use an interesting techniques of employing aluminum tubing for the inner sections and thin-wall fiberglass tubing with aluminum wire inside for the outer sections. **Fig. 16** shows the antenna. At present, only the upper element rotates, although he will add a rotator for the lower element. He also has the ability to switch between upper-only, lower-only, and both elements in phase. For the present, he has the array aligned for bi-directional coverage of both coasts, but can rotate the upper element on the lower bands where the single element gain exceeds that of the combination of upper and lower elements. When he activates only the upper element, he can use the tower as a top-hat loaded vertical for 160 meters.



If we combine the higher-Z phase-line with the longer element, we obtain the probable feedpoint impedances shown in **Table 10**. Note that the table does not account for the fatter elements used in Chuck's antenna.

**Table 10. Feedpoint Impedance of an Expanded Lazy-H of 92' #12 Copper Wire Doublets at 100'**

Freq. MHz	600-Ohm Line Feedpoint Z	
	R +/-	jX Ohms
3.6	15 - j	75
3.9	25 - j	30
5.37	125 + j	265
7.0	865 - j	595
10.1	40 - j	75
14.0	130 + j	670

We can extend both techniques--raising the phase-line impedance and extending the element length--and effect some further small improvements. We might try for 100' elements and check phase-lines of 600 Ohms and 800 Ohms for this type of lazy-H. **Table 11** provides the results of this experiment.

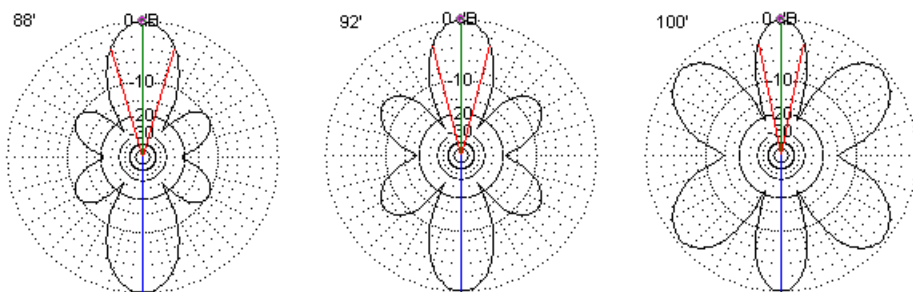
**Table 11. Feedpoint Impedance of an Expanded Lazy-H of 100'**

Freq. MHz	600-Ohm Line Feedpoint Z		800-Ohm Line Feedpoint Z	
	R +/-	jX Ohms	R +/-	jX Ohms
3.6	25 - j	20	30 + j	26
3.9	35 + j	35	40 + j	92
5.37	320 + j	435	295 + j	585
7.0	240 - j	450	555 - j	745
10.1	30 + j	30	55 + j	45
14.0	320 - j	810	225 - j	895



The effects are small, but may make the difference between whether a tuner can handle the resulting impedance at the shack end of the line. Of course, for tower-mounted elements, the user can mount a remote weatherproofed tuner at the feedpoint and eliminate all line losses except a. the small losses in the phase lines and b. the matched-line losses of coax running from the feedpoint to the equipment in the shack.

Extending the length of the element has a drawback on 20 meters. Remember that the premise of the 88' back-up antenna was to have the main lobes of the bi-directional pattern broadside to the element. **Fig. 17** shows that about 100' is the absolute limit of an element length that will cover the 20-meter band in this fashion. Even so, the sidelobes that we see at the 88' length grow until they are about equal in strength to the broadside lobes. As well, the broadside lobes suffer further reduction in their beamwidth.



Evolution of the 20-Meter Azimuth Pattern with Increased Element Length  
Extended Lazy-H at 100' and 56' at 14.0 MHz

Fig. 17

These alternatives to the 88' lazy-H for 80-10 meters with a standard 450-Ohm line prove the old saying that there may be no such thing as a perfect antenna--or at least a perfect simple antenna. As we squeeze out a slightly more convenient feedpoint impedance at 80 meters, we begin to see a decay of the desired 20-meter performance.

## **Conclusion**

The horizontal wire back-up antennas and arrays I have described depend on height for good performance on all bands. If you have the structures in place--or if you are thinking about how to place towers for a major antenna farm for the lower bands, you might seriously consider setting them up so as to support one or more of the suggested antennas as the system back-up. They offer to take up the slack in operations when the main systems are down.

However, if you only have the trees or poles with no present antennas, you may wish to give one of these arrays another kind of serious consideration. Although I have called the 88' doublet (and its variations) a good back-up antenna relative to larger systems, there is no reason that it cannot form the basis of a very good main system on its own, at least from 60 meters on up through 20. It is at least worthy of thoughtful investigation during the planning stages of a low-band antenna farm.

The key to the system is the property of the 88' doublet to have true bi-directional patterns on all of the bands from 80 through 20 meters. (We can do--and I have elsewhere done--a similar exercise with a 44' doublet to cover 40 through 10 meters.) Pattern control is a key element in serious operation, and the 88' doublet offers flexibility and reliability if we are willing to dust off that old link-coupled tuner and invest in some high quality parallel transmission line. Whether you keep it simple with an independent doublet, get bold with a Y-array or triangle, or go totally wild with the expanded lazy-H--alone or in an array--the performance is likely to be surprisingly good. However, do not develop high expectations from 80 and 75 from the short wire element and possible line losses. However, as a back-up antenna or array, the 88' length may prove serviceable as a single compromise length with determinate pattern directions.

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