seven steps to Designing your own HAM EQUIPMENT

by L. B. CEBIK, W4RNL

7 TESTING

6 BUILDING

5 LAYOUTS

4 PARTS

3 CIRCUIT SELECTION

2 BLOCK PLANS

1 OBJECTIVES

Seven Steps to Designing Your Own Ham Equipment

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Preface

This book on ham radio equipment design is written for you, the reader. I have kept the style informal, much as I would in any of the classes that I would teach. My only regret is that we cannot talk about design face-to-face. I could learn much from your comments and your questions.

In developing this book, I have relied heavily upon my experiences in teaching amateur radio classes for licensed hams who wished to upgrade. My chief aim has been to transform pure enthusiasm into a way of thinking about electronics that will allow the enthusiasm to achieve success. Like every teacher, I have not always been as successful as I have wanted to be, and that is what keeps me trying.

The subject of this book is not electronics in the sense of presenting the latest project or the latest developments. Rather, the subject is the art of design, explored at a level that can take advantage of what is electronically well known. My reason is simple. Much has been written for the newcomer to electronics so that he or she can get started. Much has also been written for the old-timer who needs an update on the latest developments. For the person in the middle, the one who wants to put the pieces together so that a larger part of the field will make sense, there is little information. This is one effort to fill that gap. I hope others will help by making their own contributions.

I wish to thank the editors of *73* for their kind permission to use material from my article, "One Stage At A Time: Practical Ideas On

Designing Equipment Aimed At The Non-Engineer," (soon to appear in *73*). This material is used throughout Part II. To the editors of *CQ* go thanks for their kind permission to use my article, "Getting The Most Out of Schematic Diagrams" (*CQ,* Vol. 35, June and July, 1979), which appears in revised form as Chapter 3.

This book is dedicated to my father, James S. Cebik, W1BUK, whose career as an engineer has provided me with an example of and training in clear thinking and whose life has given me more values than I can thank him for or live up to. A ham since the late 1920s, W1BUK is still on the air and is still designing. I still learn from him.

L. B. CEBIK, W4RNL

Part I

Getting Ready to Design Your Own Equipment

Chapter 1

How to Use This Book

At some time or another, almost every amateur radio operator and electronics technician has a dream—to be able to design his own equipment. For many of us, the dream dies all too soon. We think that the job is just too hard. We need to know more mathematics. We need to learn about the very latest developments and circuits in electronics. For these, and for dozens of other reasons, we give up the dream.

The ability to design electronic equipment, for communications or for other purposes, does not have to be a dream. We can all acquire the ability. In fact, the ability to design equipment does not require advanced mathematics or even the latest information on developments in electronics. Granted, an engineer would not get very far without such knowledge, but the field of equipment design is open to anyone who wants to try his or her hand.

Design occurs at many levels, and the odds are that you have done some designing already. Engineers and product designers use their university training to make a living designing equipment or parts of equipment to fulfill the specifications of their companies. Often, this requires that they design from scratch, and that they develop new circuits to do new things in new ways. Mostly, however, their work is much more routine, like making standard circuits do standard jobs in just the way their company wants them to operate.

Nonengineers—technicians and amateurs—do a lot of design work, although they often do not think of what they do as designing. They modify existing equipment to better meet their needs. They add or subtract circuits, or they make changes in the physical appearance of equipment. They build combinations of circuits to perform jobs that need to be done. Each of these acts involves an act of design.

Just what is design? Design, whether in electronics or in any other field, is the process of developing materials into a configuration which enables them to meet certain predetermined needs or objectives. This abstract definition becomes more real if we think about specific examples. If we decide to paint a cabinet with certain colors so that it will be restful on the eyes, then we have designed something. If we plan the layout of parts on a chassis or circuit board so that all will fit and so that the circuit will perform as it should, then we have designed something. If we combine established circuits into a unit which will perform the functions we want it to—functions such as transmitting an ssb signal that is up to FCC standards, or receiving a cw signal without interference from other stations, or controlling a series of functions by pressing a single button, then we have designed something. If we calculate the response of a new filter configuration and discover the optimum values of the components, then we have designed something. In other words, designing means many things, some of which we already do pretty well and others which we do not yet do so well. Some of them, we may never do well. But the point is that we can all do some things better. That is what this book is all about—learning to design better. If we can learn to design better, then we will probably design more and, in the end, we will build more and better things.

Learning design does not mean learning more electronics. It is always good for radio amateurs and technicians to learn more about their field, but that alone will not make you a designer or builder of your own equipment. Learning design means learning how to do two main things. First, we learn how to extract the *most useful* information out of the materials we read and, second, we learn how to *think through* the process which runs from "deciding to design" to the final testing of the finished product. Learning these two things is useful at whatever level of electronics you may find yourself. As you increase your knowledge of electronics, you will find the same principles coming into play in advanced projects that you used in simpler ones. In fact, once you have made the principles that are outlined in the succeeding chapters a part of your way of thinking, you will find that, almost automatically, you will learn more electronics. That is because you will be approaching everything you read with the right kinds of questions.

Asking the right questions is the key to both acquiring knowledge and acquiring useful knowledge. Random questions produce random answers. Even if you have never had a course in electronics or read a book on the subject, it is a good bet that you have a large pile of electronic information. What makes you feel you do not know much about the subject is that the information is not yet organized in a useful way. Learning to ask the right questions at the right time produces organized information, and that will be useful information. You will be able to prove the usefulness of the information by actually designing and building equipment for your ham shack or shop.

WHO SHOULD USE THIS BOOK?

Suppose you are a ham who has just received his general license. Perhaps you have built a kit or two. You are familiar with components, soldering, and the adjustment of equipment. You may have even built a device or two (perhaps a keyer) by reproducing a circuit and layout that you saw in one of the amateur radio magazines. You have been looking at some of the home-brew designs and wish you could tackle something that complex.

However, suppose that all you know about amateur radio is what you have learned from your fellow hams, from the classes at your radio club, and from books published especially for hams. As a salesman, school teacher, carpenter, or whatever profession, you feel unprepared to tackle the big task of designing your own gear.

Now, suppose that you have reproduced some complex circuits. But you do not exactly like what you see in the design you are looking at. Some of it is too complex for your needs. Some of it is too simple. You have some parts on hand which none of the designs that you see in the magazines use.

Or, suppose that you have completed a technical course in electronics. You have been trained to analyze problems in existing television sets, two-way radios, stereo equipment, or computers. You can fix almost anything you run into, but you have never tried to design anything for yourself.

If any part of these descriptions fits you, even if only loosely, then this book is for you. There is a way to go about designing which will maximize your chances of successfully building a piece of equipment that will suit your specific needs and which will work. In contrast, this book is not for the engineer who spends most of his working life using designing principles. It is not for him, unless he has never thought about the processes he goes through. What follows may not inform the engineer of anything new, but it just might put into place a process he already uses. For that reason, this book might just be worth reading.

Also, this book is not for the person looking for advanced mathematics or the most recent electronic innovations. Instead, it is a book on thinking electronics design; the math and innovations can be added according to your own interests. The same principles will apply at whatever level you use them, but to reach the greatest number of readers, the ones who never thought they could design and build their own equipment, only the tried and relatively true ideas will be used here. The tried and true methods also make the best test of the ideas being put forth. In addition, specific electronics ideas, if quite conventional, will not obscure the whole idea of the book—to give you a process of thinking that will make the work of "design" successful.

One warning, however; there is no magic to the process of thinking, no one specific way which works to the exclusion of all others. While a sound method is presented here, the same points might be made in several other ways. After you have practiced working through the process of "design," you will want to modify some of the steps in the process. By all means, feel free to do so. Modify everything, including thinking, so that it works best for you. Even feel free to discover places where you think I am wrong. That is what makes progress, and thinking needs progress just as much as electronics does.

THE PLAN OF LEARNING TO THINK "DESIGN"

Learning to think "design" requires two steps.

1. Getting ready to design.
2. Designing and building equipment.

Part I of this book is devoted to the first step, and Part II, to the second step.

In order to meet the requirements of the first step, *getting ready to design,* we must learn to get the most out of the information sources that we tap. For amateurs and technicians, this usually consists of a series of magazines as well as a small number of books and handbooks. It is not necessary to radically increase the number of things we read, although reading widely is always a good thing. Instead, we must learn to squeeze more useful information out of the sources we do have.

Squeezing information is a process of "organizing the questions" we bring to the materials we read. Then, we must organize the information we get out of the material in answer to those questions. This new and organized information will, in turn, evoke new questions. If the process sounds like an expanding circle, it certainly is. We could enter in on the information side or on the question side. In the next chapter, some ideas on organizing information for design purposes shall be reviewed. This will be the beginning of an "idea book" which you will create for your own design purposes. In the following two chapters, you will be shown some ways of reading the text and schematic diagrams of articles more productively. In the case of both the word and picture parts of the articles, a systematic way of interrogating what we read will be devised so that we can get just what we want out of what we read.

One of the hardest ideas to convince people of is that reading is not like a sponge sopping up water (unless we are reading westerns or murder mysteries just for fun). It is a process of questioning everything in an organized way to make the content useful to us, the readers. We may even ask whether the author of an article is right and, if he is not, we are on the right track to grasping the correct information. People who write books and articles do not have authority over their readers; authors are servants who are read and supported as long as they serve well. (That includes me, too, as the author of this work.)

With this in mind, we shall look at ways, in Part I, to increase what we get out of our source books and articles and ways to organize it in a manner which serves our design desires.

In Part II, the seven steps to designing and building your own equipment will be presented. These will range from "setting objectives" to "testing the finished equipment." Along the way, we shall pause several times to consider special problems, mainly those of circuit interaction. The order in which I present the steps and the pauses may strike some readers as too obvious to need elaboration; others will see the ideas as a kind of revelation. At least this has been my experience while teaching these ideas over a period of time.

The reason for the particular arrangement of the steps and pauses is simple. *There is a proper place in the design process for thinking about each problem.* If we think about the problem too soon, we have no way of making the necessary decisions as to which way to go. If we think about the problem too late, we may have already frozen a problem into the design. Ordinarily, there is some latitude; we can shift the point of thinking a bit, and for home construction projects, we can always tear something up and start over. Yet, we all like success in what we do, especially when we do it for ourselves. The steps given in Part II of this book are designed to maximize our chances of success by setting up each problem in its proper place.

As in Part I, questions are the key to Part II. In getting ready to "design," our questions are directed to gathering information, and they all have the form, "What do I want to know?" In Part II, the general question is "What do I want to do?" Thus, in Part II, when we deal with the actual process of design, we will be making decisions. These decisions will then be translated into actions which include spending money to buy parts, cutting and drilling chassis and cases, and wiring circuits. By asking the right questions at the right times, each step in the process is more likely to be the right one, the one that makes the equipment work.

HOW TO USE THE PLAN

It is probably not a good idea to read this book straight through and hope that you remember it all. Like learning to solder, a certain way of thinking has to be practiced until it becomes the natural way of doing something. Design thinking is especially ripe for practice, and this volume has been divided up in such a way as to make the practice easier.

I would recommend that you read one chapter at a time. After each chapter, turn to some of the materials you usually use in your work or hobby and put the principles of the chapter to use. For example, the next chapter deals with creating your own idea book. After reading the chapter, try out some of the ideas. Like all ideas based on principles, you will have to do some adapting until you hit a style which is the most comfortable and productive for you. Even so simple a thing as deciding on the right type of pencil or pen with which to take notes and make sketches can be important to achieving the best results. Hence, practice is the key word.

You may want to read Part II quickly as a unit and, then, reread it later, chapter by chapter. In fact, it would be good to have a small project in mind to which to apply the principles. There is no substitute in learning for actually doing, and this "doing" should be something that interests you. If you can think of a project to work on while proceeding through the ideas in Part II, you may speed up the process of mastering designing.

With these things in mind, then, let us begin the process of thinking design. The first thing every designer needs is an idea book. We can buy them in the form of handbooks of projects, or we can create our own. Since the object is to be able to design and build our own equipment, making up our own idea book is essential. Otherwise, we may be forever bound to the equipment others design. In the next chapter, we will begin to free ourselves from such bondage.

Chapter 2

Creating Your Own Idea Book

Designing electronic equipment is not like creating a painting or a sculpture. The artist seems to start with nothing and, then, develops his idea as he works with his materials. Out of this almost magical process, a masterpiece emerges. Unfortunately, the designer of electronic equipment cannot work this way, especially those of us who do not design for a living.

The first step to designing is to accumulate a large collection of ideas. If the ideas are to be useful to us, we must accumulate them in one place and arrange them so that we can find what we are looking for when we are ready to go to work. This means that the work of design does not begin when we have an overwhelming urge to build something. Instead, it begins whenever we see something interesting in one of our magazines or handbooks. Out of the accumulation of ideas collected and arranged, we can begin to develop the configuration which will meet our needs or purposes. In this way, design differs from art, just as it differs from merely building a good idea that originated with someone else.

The worst possible place to collect ideas is in your head. Unless you have a photographic memory with a built-in filing system, you are subject to the three laws of lost memory:

1. If you store everything in your head, it will not be there when you need it.
2. If you store everything in the original books and magazines that they appear in, you will forget which document the crucial idea

came from, and, when you finally remember, that document will be the missing issue or volume.

3. If you rely on photoreproduction, you will forget what the article contained and where you filed it.

Gathering ideas for future use in designing projects is an active process. That means taking notes and making sketches and schematic diagrams. It also means developing a system for arranging these notes and sketches into groups that reflect your interests. The work may begin some weeks before you actually begin the design process, or it may be a continuing habit you develop. Getting into the habit of taking notes on what you read in electronics is by far the best procedure, because it makes the growth of your idea book automatic and continuous. However, not all of us are that eager to renew the habits of our school days.

Taking notes and making sketches is not a random process, nor does it demand that we take notes on everything we read. Most of what we read in magazines and handbooks is far outside the range of what we might someday build. The first task is to decide what interests us. The list may be as short as one item. (One ham I know likes to build nothing but electronic keyers.) However, the list may include dozens of items from test equipment to computers, from code oscillators to transmitters. Having decided what interests us as even a "someday" project, we have accomplished two things. First, we have determined what to take notes on. Second, we have the beginnings of our file system.

Creating an idea book for the purposes of designing equipment which meets our personal needs and desires is not at all like taking notes in school. Those dreary pages of word after word about subjects which scarcely held our attention have no place in our plan. Our object will be to take notes in such a way that they are natural to us. Our idea books will differ from each other just as we differ as human beings. We will also take notes in a way which is natural to the subject matter, which is electronics. Putting all of this together means leaving some old ideas behind.

TAKING NOTES AND MAKING SKETCHES

The easiest and most useful way to take notes for an idea book consists of four actions:

1. Making lists.

2. Making sketches.
3. Drawing schematic diagrams.
4. Asking (and answering) questions.

Straightforward note taking can be dreary unless we organize the job to put the most information into the least words. This is where lists work very well. The key to making useful lists is to decide in advance what sort of list will be useful. If you have never worked with an idea book before, start with the following roster of lists:

1. Functions and goals—What will the equipment be designed to do?
2. Internal blocks—What circuit functions go together to make up the equipment?
3. Interesting circuits—What circuits are worth copying down for future reference?
4. Special parts—What parts are notable because they are expensive or cheap, on hand or hard to get, close tolerance, etc.?
5. Layout features—What special precautions should be taken?
6. Construction order and precautions—What hints will make construction easier?
7. Testing procedures—What tests should be made, and when?

Each of the preceding items can be the heading for a list of short entries taken from the text of our source article. It is no accident that this list corresponds to the seven steps of design. These are elements that play a role in designing your own equipment by using the ideas in your book. Therefore, it makes sense to start the work of building ideas with this in mind. However, feel free to modify the note-taking headings so that they reflect your interests and are the easiest way for you to gather information. More will be said in Chapter 4 about getting the information out of the text of articles.

Most electronics articles contain photographs of the finished equipment. One of the ways of preserving its content, if an article interests us, is to sketch the equipment or those parts of it that interest us. Panel arrangement, chassis or circuit-board layout, or anything else that is part of the equipment might be sketched. The drawings only have to be good enough for you to read. Neatness counts, but artistic or draftsman's talents do not. These sketches can reveal many things about the equipment—the placement of the parts, the relative size of components, the ease of building and the technique used by the author, the ease of operating, and so on. You should

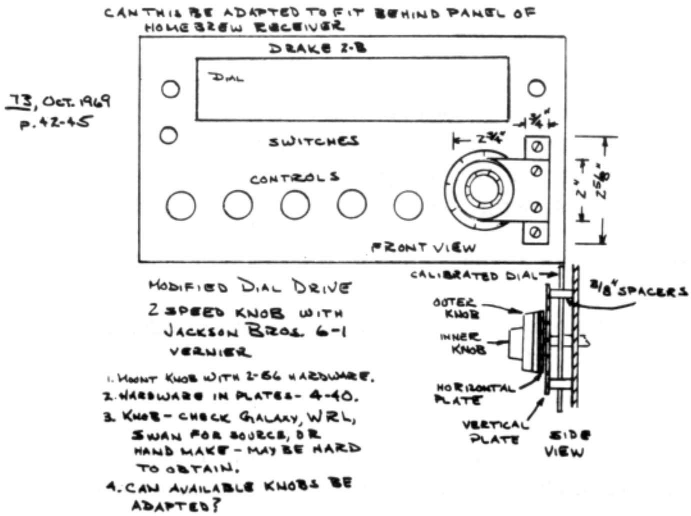


Fig. 2-1. Sample notebook page showing a panel and a dial drive.

sketch only those things which are important from your perspective. Most important, do not try to put too much into one drawing. (Figs. 2-1 and 2-2 show a couple of sample pages from the author's notebooks.)

Fig. 2-1 is a sketch of a front panel. The purpose here was to note a particular idea for mounting dial assemblies. Notice that everything else on the panel is only generally indicated so that the central idea will not get lost with time. Notice, too, that the sketch is filled with notes and a few questions. It is most useful to make notes right on your sketches; I will save further comments on the questions for a while.

The sketch in Fig. 2-2 shows a chassis with a series of holes. This sketch is based on a photo from an article, but it does not try to reproduce what is in the photo. Rather, I tried to infer, from what the photo showed, how the chassis would have to look underneath all the components mounted on it. This, in turn, showed me the metal work I might have to do. The notes around the sketch are devoted to this topic. Notice that in each sketch there is a reference to the article from which I made the sketch. This is a must for every entry in your idea book because you will find that questions will always come up later and you will require a reference to the article for answers.

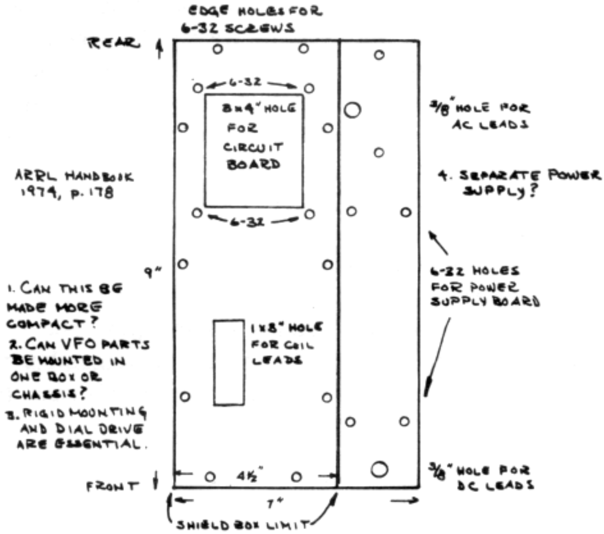


Fig. 2-2. Sample notebook page showing chassis metal work.

Schematic diagrams can be treated the same way as sketches. Draw only one of them to a sheet of paper, well centered on the page. This leaves plenty of room in the margins for notes and questions. Fig. 2-3 shows a sample page adapted from my own idea books. Notice that Fig. 2-3 does not show a complete circuit diagram for a whole piece of equipment. In this case, it was the oscillator circuit in which I was interested, and this is what I drew. I was careful to be sure I entered all the relevant parts. The notes, which come from both the text and the original schematic, label everything, as well as providing specifications not usually found on schematics.

In general, unless a piece of equipment is fairly simple, it is not a good practice to include an entire schematic diagram on one sheet. While complete schematics are often convenient for a magazine publisher, they can be confusing when you draw them, and they can obscure the parts of the circuit that made a drawing interesting to you. Copy only what you need.

Both the sketches and the schematic diagram contained questions. Since the drawings in each case left me with some questions, I wrote them down at the place where they came up. Then, I left space for some notes to answer them. In a few cases, no answers were found.

In general, writing down questions as they occur and in the place that they occur is the most useful practice. If we do not write down a question, we tend to forget it. If we do not put it next to the material that raised the question, we tend to forget the significance of it. Hence, in your idea book, feel free to write all over the parts of a drawing page that do not contain the drawing itself. As Fig. 2-3 shows, there is a wealth of information that can be put on a page.

The same holds true of material that you note from the text. If an idea leaves you with a question, it is best to write down the question as it occurs. Then, leave a space for an answer. Go back and answer the question when you find the material. Ordinarily, the text will provide at least part of the answer. If not, then a short trip through the index of a handbook will usually do the job. The sooner you look up the answer, the more likely you are to remember the point. That is because the information has a context; in this case, the equipment that interested you.

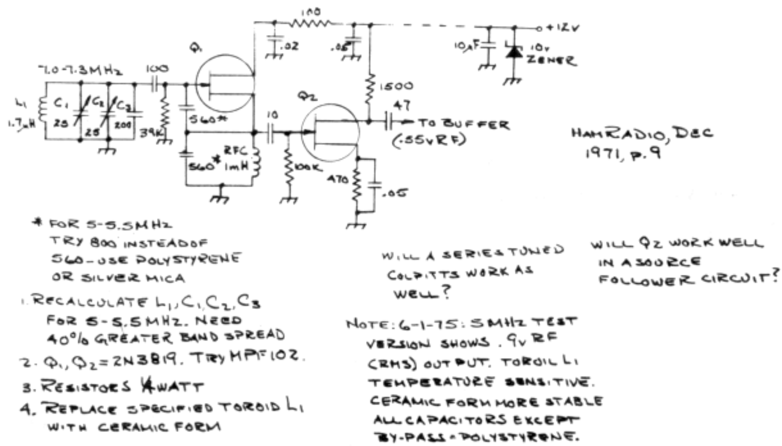


Fig. 2-3. Sample notebook page showing a vfo circuit.

By no means feel bound to make notes on every item in an article. Some articles may have one small item of interest. Others may hold dozens of good ideas. Fig. 2-3 illustrates a diagram that held much interest for me. Fig. 2-4 shows a much simpler case. Although the schematic is no simpler, my interests in it were, since like most buffer amplifiers, it is untuned and resembled many others in construction.

To keep all of this straight, I usually use various colors of felt-tipped pens. Being old-fashioned, I do notes, sketches, and diagrams in black or blue. Then, I vary the color for questions to make them stand out. The answers are in still another color. Since I sometimes add notes from other sources, these get a different color. Last, but not least, references to source articles and books take a special color so that my eyes always find them. This system is not original with me,

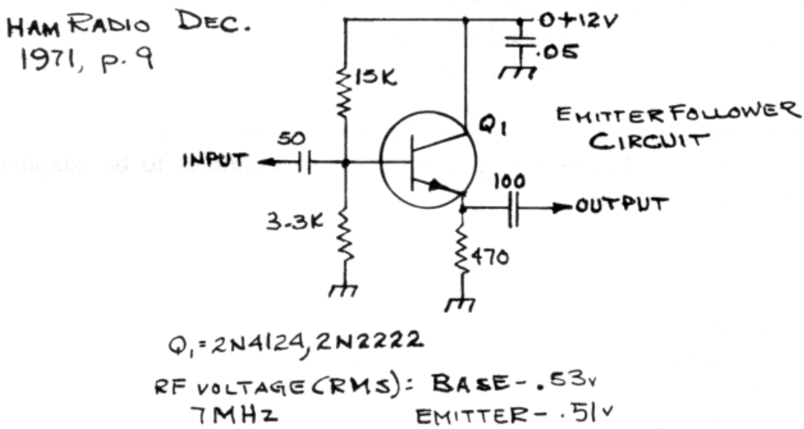


Fig. 2-4. Sample notebook page showing a buffer amplifier.

but it works. It also confuses and amazes those who look over my shoulder, and that can be fun.

ORGANIZING NOTES AND SKETCHES AROUND IDEAS

Whether you start to take notes with a project in mind or make them whenever you find something interesting, you will find that they pile up in a hurry. Good notes that are badly organized are almost as bad as no notes at all. Therefore, the next task is to develop a scheme for sorting out the notes and collecting them together under topical headings. Probably the worst system to use in this type of work is the alphabet.

The best systems of organization are those which accurately reflect your interests. Since your interests may change with time, your organizational scheme may change, too. You should take a few minutes every few months (or years, if your interests are long-term ones) to check on the method that you are using to arrange notes and sketches. Keeping the arrangement current makes your ideas more useful to you.

In developing a scheme, work at two levels. First, decide what the major categories of your interests are. Second, see if they have meaningful subdivisions. For example, if you are interested in receivers as a major category you might want to subdivide your notes according to the subsections of typical receivers. Or, the subdivisions might concern reception modes or frequencies of interest. Since the chief test of a good scheme is personal interest, there is no absolutely best scheme. The only guide is whether you are able to use your idea book effectively. If not, then perhaps some changes are in order.

Even though no absolute guide is possible, some examples of arrangements that cover a few varied interests might spur some thoughts of your own. The following lists, then, are examples to be adapted to meet your needs.

System A—Equipment

1. Receivers
   a. Amplifiers
   b. Filters
   c. Detectors
   d. Oscillators
   e. Mixers
2. Transmitters
   a. Oscillators
   b. Mixers
   c. Amplifiers, low level
   d. Amplifiers, power
   e. Ssb filters
   f. Ssb modulators

System B—Devices

1. Transistors
   a. Amplifiers
   b. Oscillators
   c. Mixers
   d. Switches
2. Integrated Circuits
   a. TTL
   b. CMOS
   c. MSI and LSI
   d. Memories

System C—Computers

1. Circuitry
   a. CPUs
   b. Memories
   c. Terminals
   d. Interfaces
2. Software
   a. Calculation
   b. Word processing
   c. Games
   d. Graphics

System D—Receivers

1. Mixing schemes
   a. Up-conversion
   b. Down-conversion, single
   c. Down-conversion, double and triple
2. Oscillators
   a. Vfo's
   b. Hfo's
   c. Bfo's
3. Filters
   a. Front end
   b. I-f, crystal and mechanical
   c. Af, active IC
   d. Peak-notch, Q multiplier and T-notch

The four systems illustrate differing interests and differing levels of detail. They should suggest how you can arrange your own interests in a topical way. In general, if you find only one or two notes per category, you are cutting things too fine (for the present, at least). If you find dozens of varied notes in each category, the time may be at hand to think about making some finer distinctions. The principal criterion is this: Can you find what you want easily and can you put ideas together conveniently? If so, then you are on the right track. If not, then perhaps you have not organized your ideas around topics that make a difference to you, topics that reflect the sort of equipment and circuits you want to work with. There is no need to adopt headings from a handbook; just think about your own interests in a natural way, the way you would think about them when discussing them with friends.

NOTEBOOKS AND FILES—GOOD WAYS TO PRESERVE IDEAS

Perhaps the only thing worse than no notes, or good notes badly organized, is good notes, well organized, which get lost or destroyed. It is one thing never to have had something and another to have had something good and lose it. This last category is what writers make love stories out of.

In developing an idea book for electronic design, our book need not be a real book. It can be any system which preserves and makes available to us the notes we have made and organized. One of the easiest ways to preserve notes is in a loose-leaf binder. Since many people find such binders difficult to write in, let us think of the loose-leaf notebook as a storage and reading device. Pads, both lined and unlined, are useful for note taking, and hole punches are inexpensive.

Or, you can buy prepunched loose-leaf paper and use a clip board. The clip board system can be helpful, since you can mark the board "For Design Use Only." The problem is how to keep relatives and friends from using up your stock of note paper for their own purposes.

If you use a loose-leaf binder, buy or make section dividers. These enable you to turn to the section of the idea book you want. They also help to protect the contents of each section from edge tattering. A few minutes devoted to clear labeling, as shown in Fig. 2-5, can make your file system a joy to use.

Notebooks are not strictly necessary, although they are convenient. Other systems that work are file folders and bound notebooks. If you use file folders, a file cabinet is convenient for storage. If one is not available, take care either to use file envelopes or to bind the edges of the folder with tape. Dropping a file folder and then having to sort the sheets a few times will verify the wisdom of this suggestion. If you use file folders, do not overlook the newer colored folders. Manila folders with labels are adequate, but sorting categories by color can make information much more accessible. If you do not have a file cabinet, there are smaller corrugated file boxes and accordion-type folders which will hold all your note files together.

Spiral-type notebooks can be used effectively, if you limit entries to one major category per book, or one major project per book. They are also interesting to read long after a project has been completed. The notebook, when devoted to one project, provides a history of the thinking of the designer as the project progressed from a desire to a finished product. The major danger with bound notebooks is that sometimes the wrong sketches or notes get into the wrong book. Then, the pages must be torn out and refiled. Soon one finds a dual system of notebooks and files. Without care, the system breaks down.

In general, then, choose a system you are comfortable using, both when developing notes and sketches and when using them to make design decisions. If you are not in the habit of making, collecting, and keeping notes, then perhaps you should start by trying one of the systems on a moderate-scale project. What you learn about information gathering and storage may make the next project go more smoothly.

KEEPING YOUR IDEA BOOK ACTIVE

Notes, sketches, and schematic diagrams are aids to our thinking. They are not matters to be passed on to future generations. If we

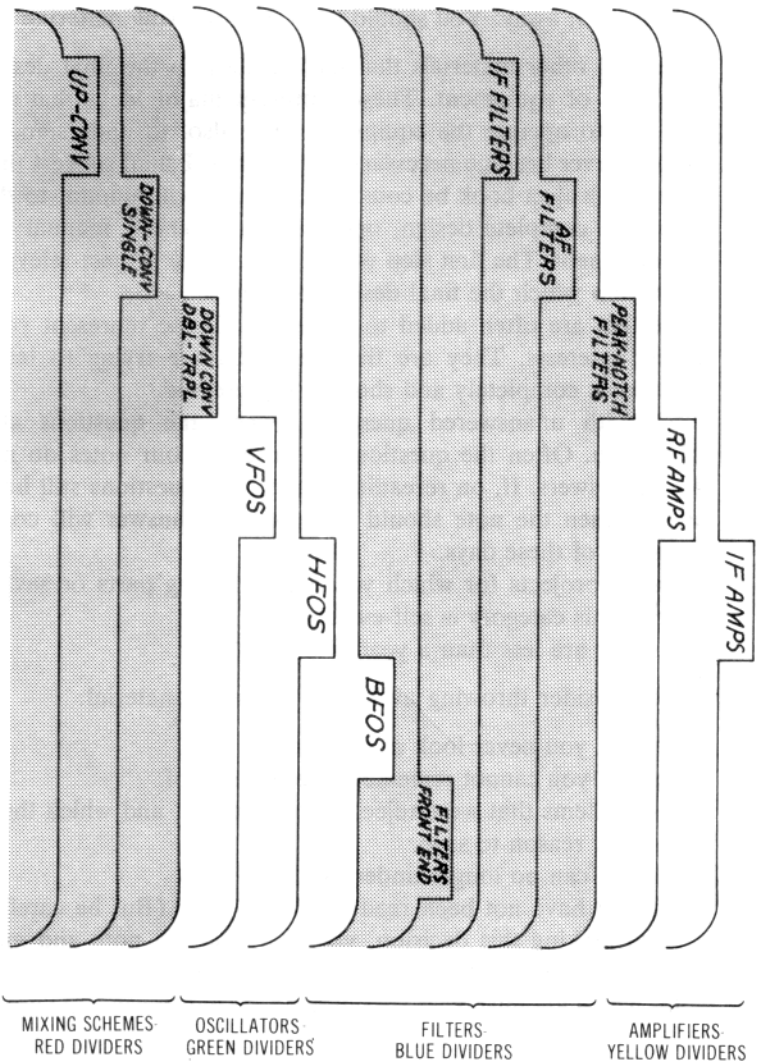


Fig. 2-5. Example of a method for labeling the dividers of an idea book.

collect too many notes which have long since passed their useful lives for our design plans, our notebooks will become less useful or downright cluttered. The trick is in knowing when to keep and when to throw away. So let us divide up this section into two parts. First, we will list some good reasons to keep material and, then, some good reasons to throw it away. You should keep the following material:

1. Notes and other materials that have gone into the final design of a piece of equipment. These represent major ideas that can help you to operate the equipment and, also, to understand it if repairs ever become necessary. (In Part II, I shall suggest that a specific project book be constructed which will amount to the same as a complete design, operating, and service manual for the equipment. The first step will be to compile project-relevant notes from which the final designs are chosen.)
2. Notes that are often added to or reread. These represent your current interests. They are the items you are trying to learn about most completely and should be preserved.
3. Notes with unanswered questions, when the questions still puzzle you. Often the questions we insert in our notes do not receive answers. If, on rereading a note, the questions still hold interest, then the note should be saved. An answer will come along one of these days.
4. Notes on projects for which you are collecting parts or saving money. This category is self-evident.
5. Notes that are less than a year old.

You should consider throwing away the following material:

1. Notes that you never look at any more.
2. Notes that you cannot remember the purpose of.
3. Notes on items that were rejected for a project and which there is no other reason to save.
4. Notes you can no longer understand.
5. Notes that have not been read in over a year. (But be careful, since in making this decision, you will read the note and may again become interested in a certain project.)
6. Notes which are mistakes, are outdated, or have been supplanted by better ideas.

There is much that these criteria do not cover. If in doubt, save the material unless you just have to make room. Never decide to clean your idea book when you are in a bad mood or depressed—you will surely throw away too much!

The idea underlying this entire chapter has been to provide you with some ideas which will help you generate your own idea book. Here is the place to gather ideas that will someday play an important role in designing your own equipment. Here is also a place where you will find your improved knowledge of electronics. What we take the trouble to write, sketch, and reread, we usually remember better. So even if an advanced home-brew computer does not emerge, the work of compiling an idea book will have had very large intangible benefits.

With the process of getting things into an idea book fairly well settled, we can turn to the question of getting things out of source articles and books so that we will have something worthwhile to put in the book. This is the subject of the next two chapters.

Chapter 3

Getting the Most Out of Schematic Diagrams

Schematic diagrams contain a wealth of information. Engineers, technicians, and teachers who use schematics nearly every day read them with ease and understanding. However, the person who turns to electronics as a hobby and whose professional life may be unrelated to the electronics field often stumbles over schematics. At first they appear to be little more than vague pictures of what is "inside the box." Slowly, we begin to understand that the pictorial representation shows how a piece of electronic gear is wired, but often we do not fully appreciate all the information the schematic can give us. This also applies to many people who work in electronics.

There is a systematic way to dig the wealth out of schematic diagrams. Where the wealth is in the form of information, the way to dig is by asking the right kinds of questions. The right questions can turn every construction article into a profitable adventure. Given the tremendous variety of equipment and components, it would be impossible to codify precise questions for every variation of schematic diagram. However, there are some fundamental types of questions, and these will lead you, with a little experience, to formulating your own more precise questions. If you have come a little way into thinking design, this review of principles may be of help.

WHY DO WE USE SCHEMATIC DIAGRAMS?

Schematic diagrams are not what they used to be. But what is? Long ago in the history of radio, schematic diagrams were a special form of pictorial diagram that showed not only the interconnection of the components, but also the physical arrangement of the parts. Fig. 3-1 shows a design from about 1930. Notice the neat symmetry in this drawing of a push-pull amplifier. The builder of this transmitter followed the same symmetries in placing his parts on a wood frame. His wires, whether for rf or dc, were neatly routed, well separated, and bent into crisp 90° turns where necessary.

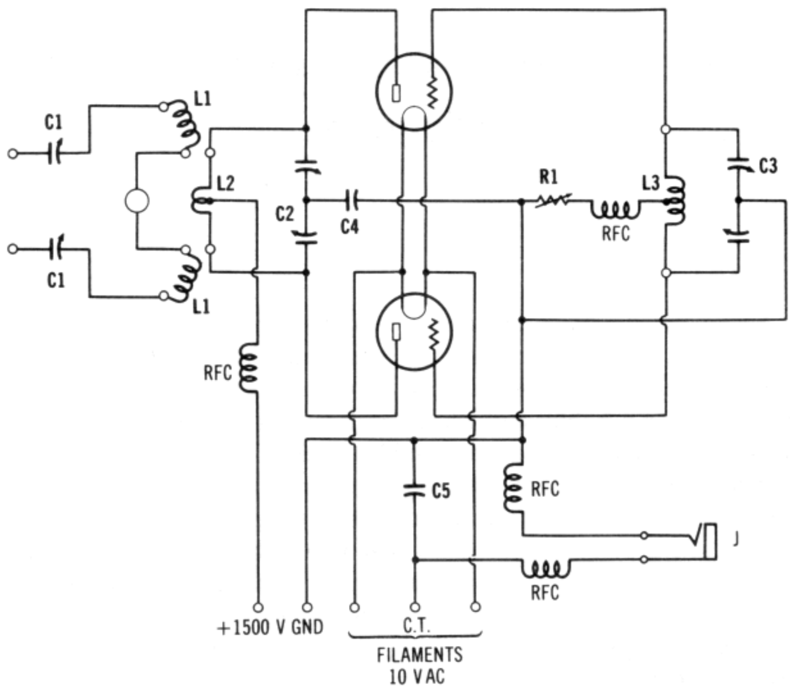


Fig. 3-1. Diagram of a 1930 push-pull amplifier.

Of course, we have learned some things since then. The dc leads may be long, but the rf leads should be as short and as direct as possible. Parallel dc and rf wires make good capacitors and will couple rf into the power supply. Therefore, shielding is now needed. A variety of available components gives a great many options as to component placement. In short, the schematic diagram and the actual piece of equipment have become more and more physically dissimilar, although the schematic has retained its function of showing how the parts are electrically interconnected.

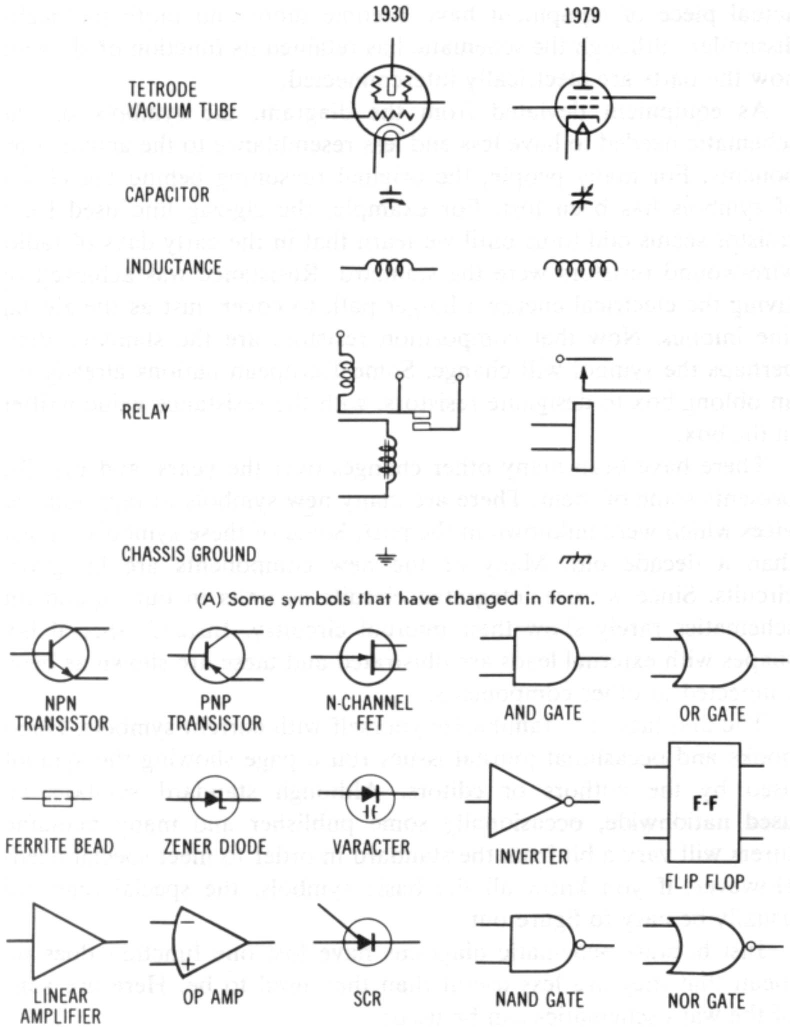
As equipment deviated from the diagram, the symbols on the schematic needed to have less and less resemblance to the actual components. For many people, the original reasoning behind the choice of symbols has been lost. For example, the zig-zag line used for a resistor seems odd to us until we learn that in the early days of radio, wire-wound resistors were the standard. Resistance was achieved by giving the electrical energy a longer path to cover, just as the zig-zag line implies. Now that composition resistors are the standard item, perhaps the symbol will change. Some European nations already use an oblong box to designate resistors, with the resistance value written in the box.

There have been many other changes over the years, and Fig. 3-2 presents some of them. There are many new symbols to represent devices which were unknown in the past. Some of these symbols are less than a decade old. Many of the new components are integrated circuits. Since we use integrated circuits as units in our equipment, schematics rarely show their internal circuitry. Instead, special box shapes with external leads are illustrated and these are shown as being connected to other components.

The first task is to familiarize yourself with current symbols. Handbooks and occasional journal issues run a page showing the symbols used by the authors or editors. Although standard symbols are used nationwide, occasionally some publisher and many manufacturers will vary a bit from the standard in order to meet special needs. However, if you know all the basic symbols, the special ones will usually be easy to figure out.

Just because schematic diagrams have lost one function does not mean that they are less useful than they used to be. Here are some of the ways schematics can be used:

1. *To wire*—Schematic diagrams still show the interconnection of components in a piece of electronic equipment and, thus, they guide the wiring we must do when building something. Whether we etch a circuit board or use one form or another of point-to-point wiring, the schematic shows the way. Understanding the nature of components, the physical necessities of parts placement, the function of a lead (e.g., signal or dc path), and the type of interconnection needed are necessary functions. They are



(A) Some symbols that have changed in form.

(B) Symbols for devices that were not even dreamed of in 1930.

Fig. 3-2. Examples of schematic diagram symbols.

all required to do the job correctly, but the schematic is basic to the process.

2. *To service*—Maintaining a piece of equipment also requires attention to the schematic. Replacing bad parts obviously comes to mind as a time when a schematic is needed to show the value, rating, and function of the component needing replacing.

However, service includes more than parts replacement. It also involves adjusting circuits to certain levels of operation. The schematic often gives signal voltages and other operational information useful in this process.

3. *To adapt or revise*—We often modify equipment in order to tailor it to our specific needs. To alter the circuitry of a piece of equipment requires that we know what the circuit was, as well as how the modification must fit in with the rest of the circuitry in the equipment. Here, the schematic is the basic point of reference.
4. *To design*—We may also design equipment for ourselves. While engineers may be able to develop circuits out of basic formulas, most of us design by adopting or adapting to our own needs circuits from many sources. Our home-built equipment is a concatenation of tried and true circuits put together in a custom fashion. The design process is partly a matter of reading, selecting, copying, and originating schematic diagrams which embody our design objectives.
5. *To learn*—Reading a schematic diagram can be a pleasant end in itself. To attack a construction article and master every aspect of the equipment, as shown in the schematic, can teach us a great deal about more than just the prize project of the author. A schematic is a review and application of basic electronic principles, a survey of ordinary and special circuits, an introduction to new or special components, a lesson in equipment design, a help in evaluating commercially built gear, and much more.

These are not all the possible functions of schematic diagrams, but they are certainly enough to show the profit in learning to read schematic diagrams thoroughly and intelligently.

ASKING THE RIGHT QUESTIONS

Back in the days when tubes reigned supreme, we used to read schematics by asking the questions: "What tubes did the author use? What pins of the socket connect to what elements? What circuit values did the author use to make them function? How did he couple the circuits? What supply voltages did he use?" Today, with the many varieties of active devices available to the builder, the questions appropriate to tubes do not tell us all that must be known. A circuit function can be performed not only with active devices having different numbers, but the job can be done with different kinds of devices, such as tubes, discrete transistors, integrated circuits, etc. What we need is a new set of questions.

The questions that should be asked of schematics can be divided into just four initial groups:

1. Questions about equipment functions.
2. Questions about individual circuits.
3. Questions about components.
4. Questions about supplementary information.

Each of these four groups leads to specific questions which help us gather information from the diagram. If you have a special reason for consulting a schematic, such as a search for a usable amplifier or a vfo circuit, then you need not take the categories in order. However, if you are looking at the schematic out of general interest, or to learn, or to file information for future reference, then the order of the groups will give you a system for keeping the information you acquire in usable form.

Questions About Equipment Functions

Look at Fig. 3-3. This code practice oscillator is so simple that this first type of question almost loses significance. In fact, we are likely to memorize the diagram with just a couple of looks. It obviously has the function of producing a tone when the key is depressed, and all it consists of is an audio oscillator with enough output to be heard. Unless we happen to be interested in the internal circuitry

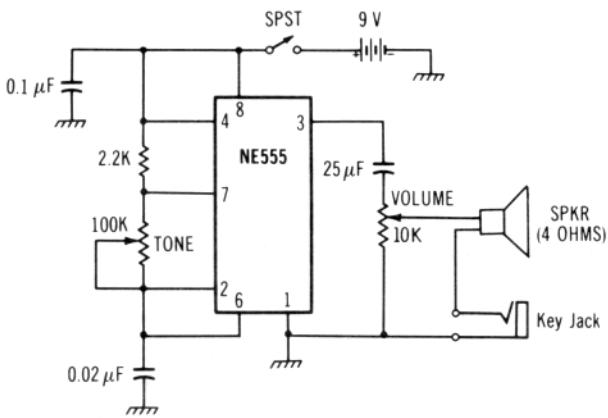


Fig. 3-3. A simple circuit that needs little analysis.

of the integrated circuit, a functional breakdown of the circuit would be out of place.

Fig. 3-4, on the other hand, shows a multistage solid-state cw transmitter. It is drawn as it might appear in a construction article. The author, who is interested in describing how to build and adjust the transmitter, simply links all components in the most compact way, consistent with enabling the reader to find the interconnections. He may not label stages with anything more than component numbers. To understand the schematic, we must break it down into functional sections according to what we can gather from the text and the drawing itself.

Fig. 3-5 shows the schematic of Fig. 3-4 with some explanatory notes added to the diagram. The dashed lines divide the functions. Some blocks contain only one transistor; other blocks contain several, since the group together may perform a specific function. Functions are noted for each circuit group. (Many authors do try to show this type of information in their schematics. If they do not, feel free to add information by making marks and notes right on the drawing.)

Functional information on a schematic diagram helps us to answer many kinds of questions. The following are a few samples. Does this unit have all the functions I would want out of it? (For example, is the power output high enough for my needs? Do I need a vfo?) Are the functions performed in the way I need or want them to be? (For example, do I want separate transmitters for each band or would bandswitching be desirable?) Could the transmitter be modified easily to add other functions, e.g., a crystal-controlled oscillator? Are the functional units going to be too complex and difficult to adjust and maintain? Many of these questions have answers that are unique to each of us, depending upon our individual interests and desires. Some of the questions concern wiring, servicing, modification, or design. They all, however, help us learn a bit more about the equipment in question.

Questions About Individual Circuits

After breaking a diagram down into functional blocks, you are ready to tackle the individual circuits. A circuit is nothing more than a complete path for electrical energy. Therefore, the idea of an individual circuit can be a bit misleading. We tend to think of active devices as the focal point of individual circuits. Each device, however, will contain at least four circuits. Fig. 3-6 breaks down one of the amplifier stages from Figs. 3-4 and 3-5. In Fig. 3-6A, the entire circuit

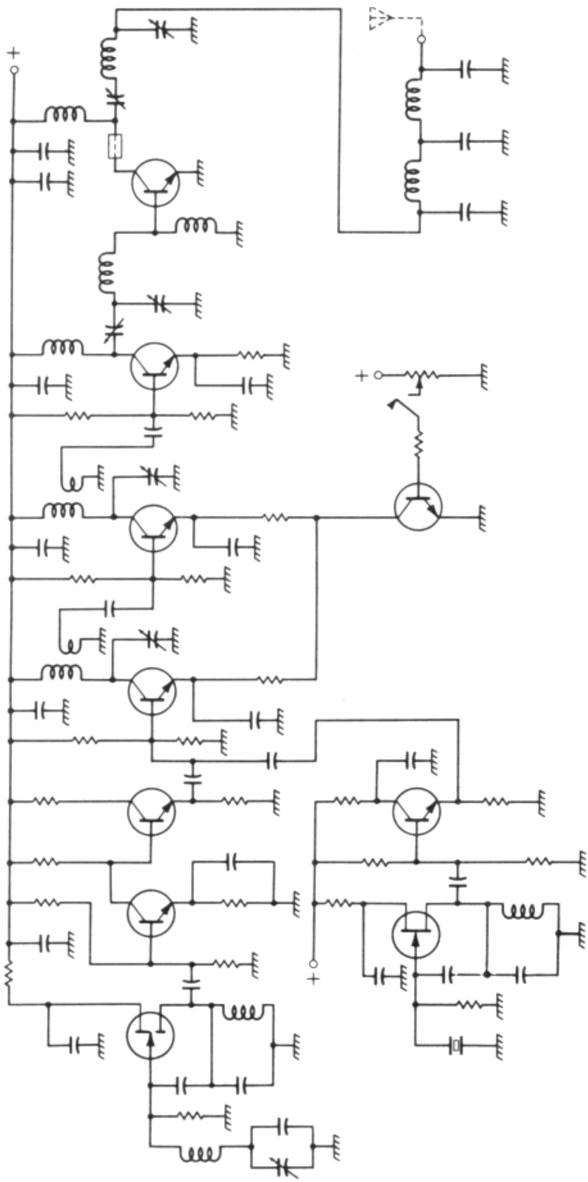


Fig. 3-4. Schematic of a solid-state cw transmitter. (Parts values are omitted.)

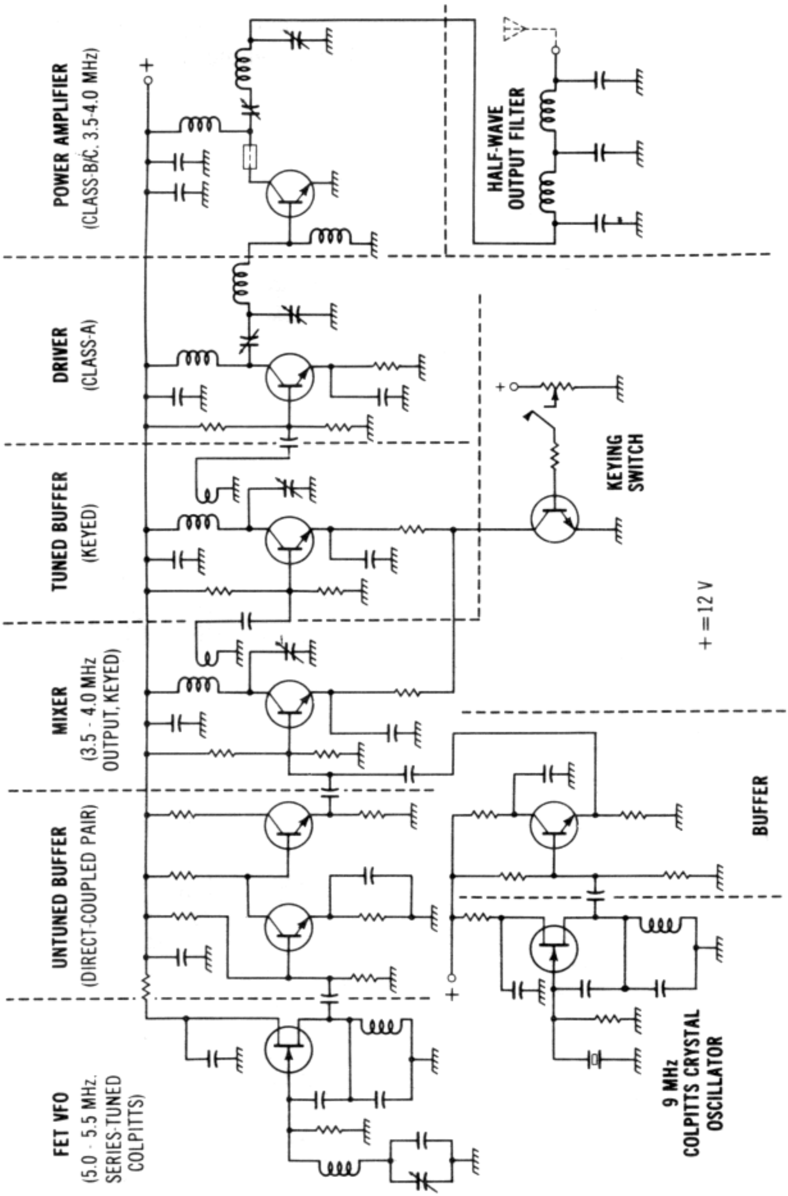
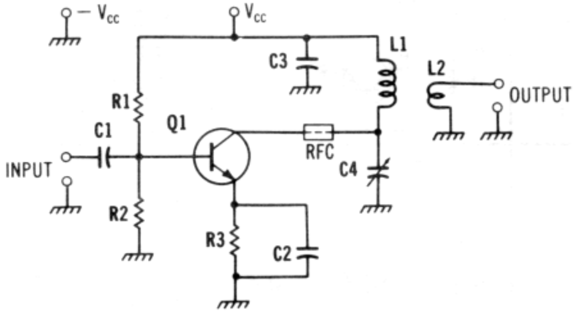
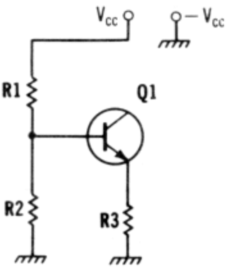


Fig. 3-5. The same diagram as in Fig. 3-4 with functional information added.

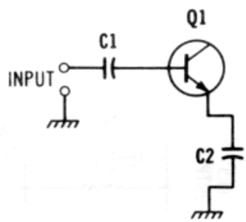
is shown as a unit, while Figs. 3-6B through 3-6E trace the four circuits. Fig. 3-6B is the base-emitter bias circuit, Fig. 3-6C is the signal input circuit, Fig. 3-6D is the collector-emitter bias circuit, and Fig. 3-6E is the signal output circuit. We can analyze each of these circuits, as well as the amplifier circuit as a whole.



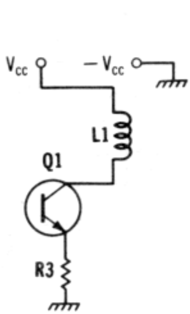
(A) Typical transistor low-level rf amplifier.



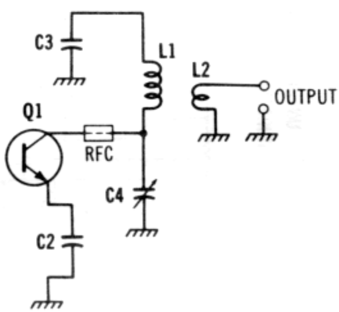
(B) The base-emitter bias circuit.



(C) The signal input circuit.



(D) The collector-emitter bias circuit.

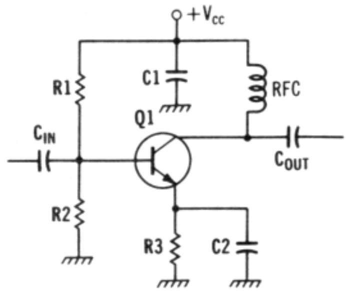


(E) The signal output circuit.

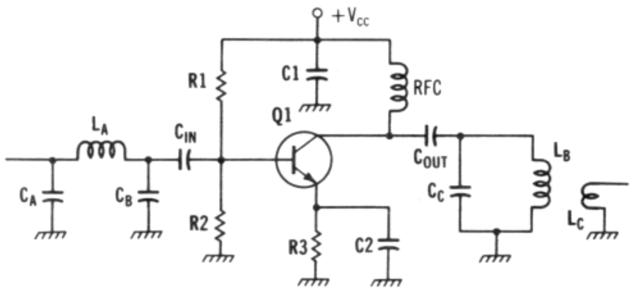
Fig. 3-6. Breakdown of a typical circuit into its component circuits.

When we draw individual circuits, we often overlook parts that are held in common between two circuits. Fig. 3-7A shows what appears to be an untuned amplifier. Fig. 3-7B, however, expands the drawing a bit and shows that the amplifier indeed has frequency-determining circuits; they just happen to be on the other side of the coupling capacitors. Do they belong to the adjacent circuits or to this one? The answer is to both. If you are thinking about the process of building, then, the coupling capacitor may be a good dividing line, especially if different circuits are being constructed on different boards. If, however, you are thinking in terms of feedback, stability, selectivity, impedance matching, and the like, then, the tuned circuit is indeed part of this circuit. If you copy the circuit into an idea book for future reference, be sure to include all the elements that affect its immediate operation.

Although I have not expressed the points in this section as questions, it is easy to see that they imply questions which a schematic can answer. What are the energy paths in this circuit? What control elements work in conjunction with this circuit? What adjacent ele-



(A) An apparently untuned rf amplifier . . .



(B) . . . becomes a tuned stage when we add the circuits on the other side of the coupling capacitors.

Fig. 3-7. When is an untuned amplifier really tuned?

ments affect or operate effectively as part of this circuit? Questions like these will help you to completely analyze a circuit in a way that eventually will permit you to evaluate, compare, and select circuits for a project of your own. They will also aid you in analyzing what may be wrong with a piece of equipment that you are servicing. They will also call attention to good construction practices with respect to the components which may interact.

Questions About Components

The progression of thought about schematic diagrams has slowly grown more and more specific. When we reach the level of individual components, we have just about reached bottom (except for integrated circuits, which include complex circuitry inside their tiny plastic or metal bodies). But the questions we ask at this level can be just as important as those asked at any other level. The list of questions that can be asked about components is nearly endless, but the following is a starter list upon which you can build.

Active devices—What kind of device is used? What supply voltages and currents does it require? What is its power level? How does it perform its function in this circuit, e.g., amplifying, mixing, detecting, etc.?

Bias resistors—What values did the builder choose? Why were those values chosen? What size (power level) did he need? Which resistors control the voltage or current levels, and which are for decoupling? (See Fig. 3-8 for an example of the uses of resistors.)

Other resistors—What is the function of resistors that do not form

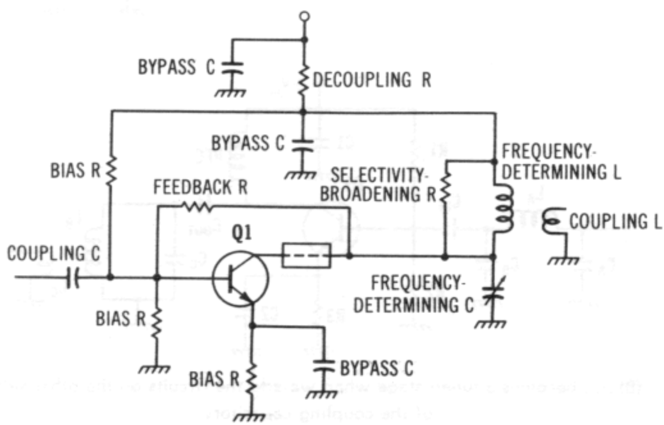


Fig. 3-8. Some uses of resistors and capacitors in a circuit.

part of the bias circuit? Are they used to broaden selectivity, to provide feedback, etc.?

Capacitors—Which capacitors control the frequency? Which ones are bypass capacitors? Which capacitors control feedback? Why were certain values chosen? Why were certain types of capacitors specified, e.g., disc ceramic, silver mica, polystyrene, etc.? (See Fig. 3-9, which is a simplified schematic of a vfo, for an illustration of some of these points.) Polystyrene capacitors are used where maximum frequency stability is desired. Silver mica capacitors are the second best type for stability. They are readily available in many values and, also, with close tolerances. N-500 indicates a negative temperature coefficient which counters heat drift in the other capacitors; the number varies with the degree of the negative coefficient. Ceramic disc capacitors are used mainly for bypassing purposes, where close tolerances and stability are not major factors. A diagram notation for disc capacitors is rarely made.

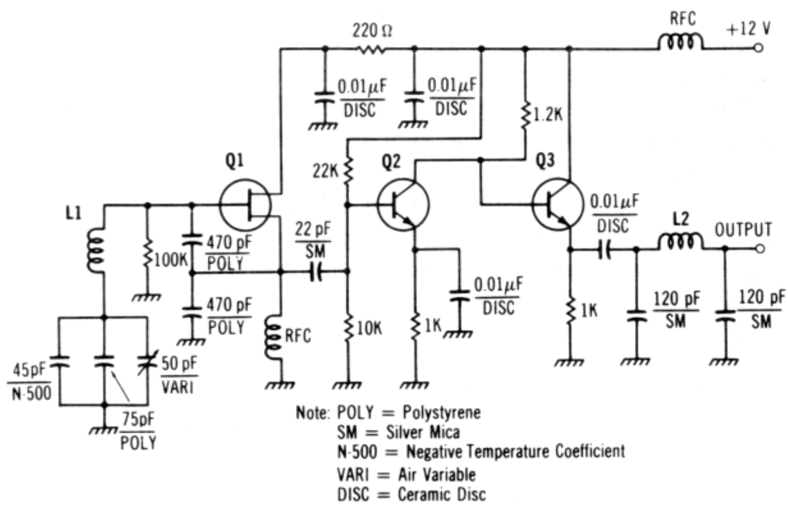


Fig. 3-9. A schematic diagram of a vfo with the types of capacitors specified.

Inductors—What is the value of the inductors in tuned circuits? What construction is specified (for example, slug tuned with brass or iron, toroids, ceramic or phenolic forms, air wound, etc.)? Why is that type of construction specified?

Chokes—What types and values of chokes are used in the circuit?

Other components—What are the functions and values of the diodes and transformers (including baluns)? Are there any special connectors, switches, or jacks? How is metering, if any, handled?

The answers to these and to other questions that you can pose about individual components may not be readily apparent from the schematic diagram alone. Many of the answers may occur in the text of the article. The author may specify that he used polystyrene capacitors for temperature stability, or that he used a ceramic coil form for higher Q and mechanical rigidity. On many points, however, the author may be following common practice, as, for example, in using disc ceramics for bypassing. The explanation has been given long ago and in many handbooks, so the author feels no need to mention that within tolerances of ±50% or more, bypassing is not critical, thus making ceramic disc capacitors perfectly satisfactory. If this is not the case, as with bypassing at vhf frequencies, he will usually bring up the matter.

This situation—the one we call "following common practice"—is the most difficult for the new schematic reader to master. What is common practice for old timers may be totally new for you, since it may be the first time you have encountered it. Here is where your reading might go well beyond a given article into handbooks and texts. This is not so awesome as it seems. Handbooks and texts are most bewildering when we try to read them from cover to cover without looking for something specific. In this case, however, we will have definite questions. The index will help us locate sections of interest and we need read only those. And, because we have specific questions, we will more than likely remember what we read (or, at least, where we read it).

Questions About Supplementary Information

Besides all the information noted above, schematic diagrams often contain supplementary information concerning various aspects of circuit operation. The most important parts of this information are voltage readings taken at various points in the circuit. Examine Fig. 3-10 closely. Notice that there are numbers in boxes and in circles as well as crosses and asterisks next to some of the numbers. Coding of the boxes is given in the note, since there is no single standard for giving this information in schematic diagrams. In making up this example, I have filled the diagram with more information than most authors include. However, some of this data may be given in the text of an article. Hence, you should have in mind certain questions to ask about

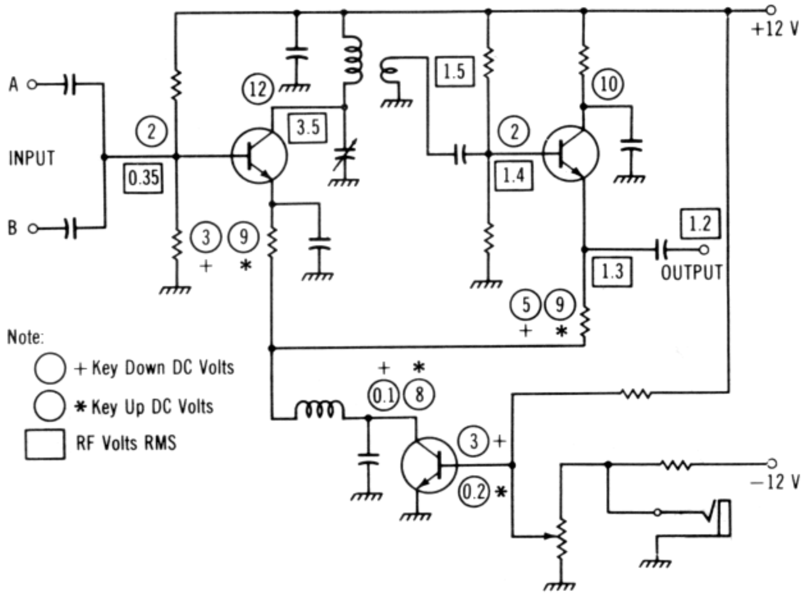


Fig. 3-10. Mixer, buffer, and keyer circuits showing the operating and signal voltages.

the diagram and article. If answers are available, filling them in on the diagram helps to organize information in a very useful place.

The key questions to ask are these:

1. What are the dc levels at various points in the circuit? What are their "key up" and "key down" values? Notice that in this mixer stage of a cw transmitter, there is a difference between the two values, since the key removes the negative dc voltage from the base of the keying transistor. The stages it keys also undergo changes in voltages depending upon whether the emitter-collector circuits are conducting (key down) or are not conducting (key up).
2. What are the signal-voltage levels at various points in the circuit? Again, returning to Fig. 3-10, notice that rf voltages can be read at many points in the circuit. Voltages tend to drop after passing through passive components such as capacitors. In general, amplifiers tend to raise the voltage levels. However, look at the buffer following the mixer. Its function is to isolate the mixer stage from the succeeding stages and to transform the impedance to a lower level; therefore, the voltage actually drops a bit. This is proper operation for a circuit of this sort.

The utility of specifying dc and signal voltages is to provide you with a general guide to proper circuit operation. Whether you are building or servicing a piece of equipment, you can be confident that of the dc voltages are within 10% to 20% of the specified values, all is probably in good order. Keep in mind, however, that there are other ways for things to go wrong.

There is no universal standard for listing voltages on a circuit diagram. Usually, the method used by an author will be given in a key on one side or the other of the diagram. In the same general area will be other notes. Some may specify that resistance values with M (e.g., 1.5M) are in megohms, while those with K (e.g., 4.7K) are in kilohms. Other notes may specify that values of capacitance up to 1000 are in picofarads and decimal values (e.g., 0.01) are in microfarads. Variations from this scheme will supply the unit as well as the value (e.g., 10 μF). Such notes may also give the meanings of abbreviations used with components, for example, poly = polystyrene capacitor, sm = silver mica, etc.

In diagrams of digital IC circuits, do not expect to find many, if any, major notes on voltage levels. The reason for this is that digital IC circuits usually provide one supply voltage for all units, and the "high" and "low" states will be approximately the same from unit to unit. These values will be consistent for each series of ICs. For example, TTL ICs in the 7400 series have a regulated 5 volts fed to the supply pins (see Fig. 3-11). "High" levels are generally above 2.4 volts and "low" levels are below 0.8 volt. Any variations from these values which do not mean some type of trouble, either in the device or in the circuit, are rare. It is necessary to know the general parameters for the series of digital devices that the author used in his article, since he will rarely cover this either in the text or in his diagrams.

Learning how to use voltage information, whether dc or signal voltages, is important, whether you are building, servicing, modifying, or adapting a circuit. Given a piece of equipment, these values present useful clues as to whether the circuit is operating properly. From a design or building perspective, the voltage values can let you know what to expect from a circuit and whether it will do the job you want it to do. An amplifier that does not amplify enough calls for either another stage or some circuit changes. A unit that amplifies too much can create just as many problems by overdriving the next stage, perhaps generating distortion or harmonics. In the early years of radio, the by-word was to get as much as possible from every circuit and,

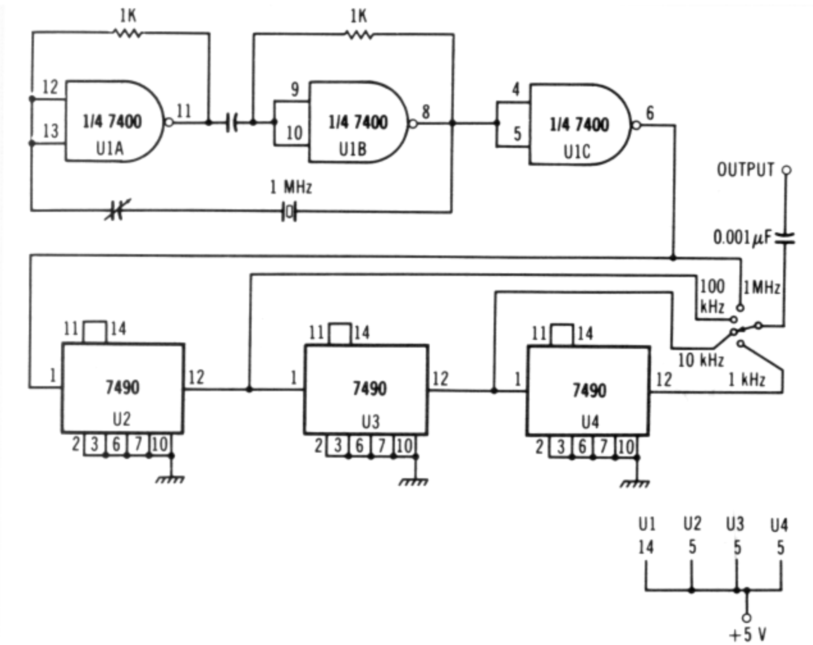


Fig. 3-11. An example of digital circuitry—a crystal calibrator.

usually, even that was barely enough. However, the high gain, efficient, and inexpensive devices of today have changed our thinking. We can now design circuits for neither too much nor too little output, and this has given our circuits a flexibility as never before.

SOME SPECIAL CONSIDERATIONS

In addition to the basic questions which help us squeeze information out of a schematic diagram, there are dozens of other considerations which do not lend themselves to a completely systematic account. Therefore, here is a potpourri of items to think about.

First is the matter of special circuits that affect many other circuits. Figs. 3-12 and 3-13 illustrate ways in which such circuits might be shown on a schematic. Fig. 3-12 shows an avc circuit along with parts of the rf and i-f amplifiers. Notice that there is no line drawn from the avc amplifier to the two stages it affects. The voltage output of the avc amplifier (more negative as signals grow stronger) will be shown only at the avc circuit itself. Yet, when reading a schematic of the receiver as a whole, you must understand the way in which this circuit

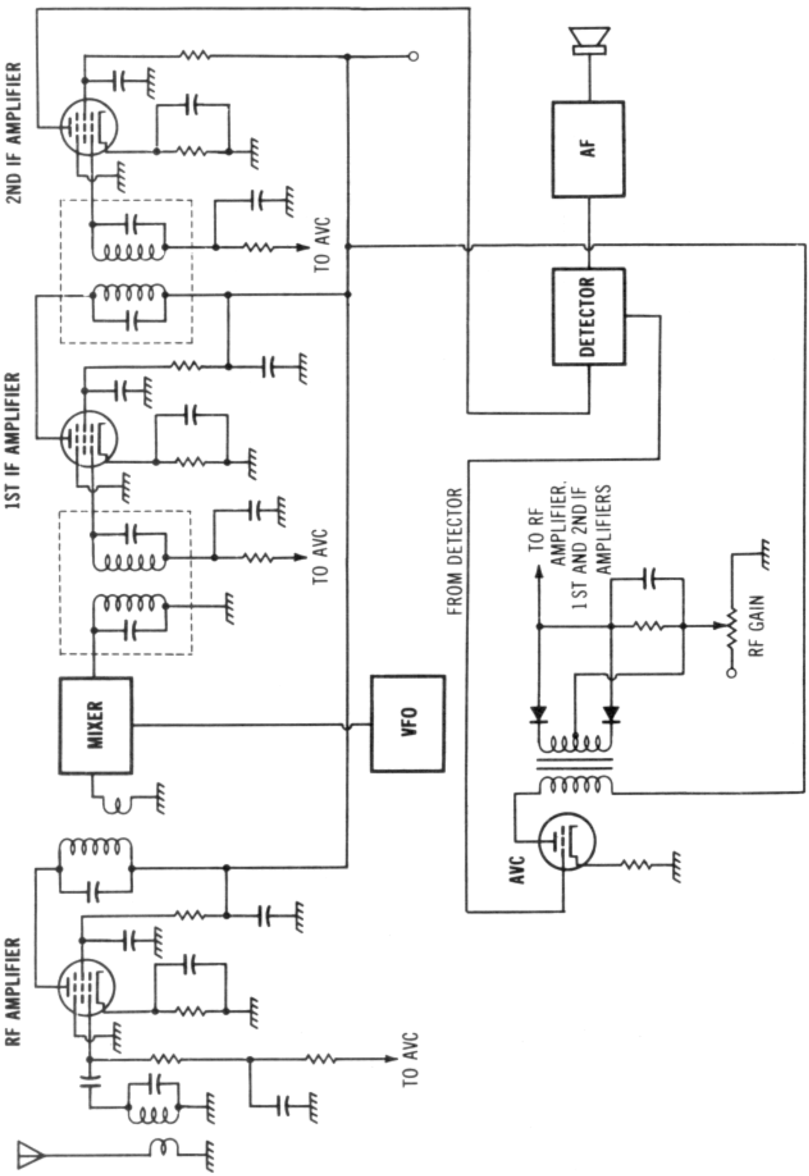


Fig. 3-12. A partial receiver schematic showing discontinuous avc connections.

affects the other circuits. The voltage on the grids of the rf and i f tubes will vary with the output of the avc amplifier. In short, you must make the connection in your head since it is not shown on the drawing.

Fig. 3-13 shows the power supply and blocked-grid keying connections for two transmitter stages. Here the lines are completely drawn, but certain important components which affect the circuit operation are drawn at a considerable distance from the circuits themselves. Resistor R1 affects the key-down current of the keying circuit and is part of a voltage-divider circuit (with R2) that determines the precise negative voltage on each grid. However, notice R3, the voltage-dropping resistor in the high-voltage line. It is easy to overlook since it is drawn close to the power-supply terminal, rather than to the stages. Diagrams of commercially built gear may separate components even further. Thus, the key question is always this—where does that line go, what does it do, and why?

A second set of major considerations are switching circuits. Switches represent single mechanical devices which may perform functions in widely separated parts of an overall circuit. It is not uncommon to find six or seven wafer switches changing circuit values in many parts of a modern transmitter or receiver. Fig. 3-14 is a simple illustration that shows a switch that is used to change the tuned circuits in the oscillator and in the transmitter output, even though several stages of the transmitter intervene between the two sections. Note that the transmitter stages are shown only in a block diagram style.

The central question to be asked is what things must work together to alter the operation of a piece of equipment. Band switching is just one obvious example. Changing a transmitter from the standby to tune-up mode and then to the operate mode may require the shifting of several voltages, including the plate, screen grid, and control grid supplies. Once it has been determined what things must be switched together, you are in a better position to analyze what changes were made in each stage.

Integrated circuits provide a gigantic third consideration. Some of their peculiarities in schematic diagrams have been mentioned, and some of the symbols were shown in Fig. 3-2. Let us take a brief but more orderly look at what we can expect to find in schematic diagrams.

Most writers divide ICs into two groups—digital and linear. The ICs in the first group tend to be operated to obtain only two states—

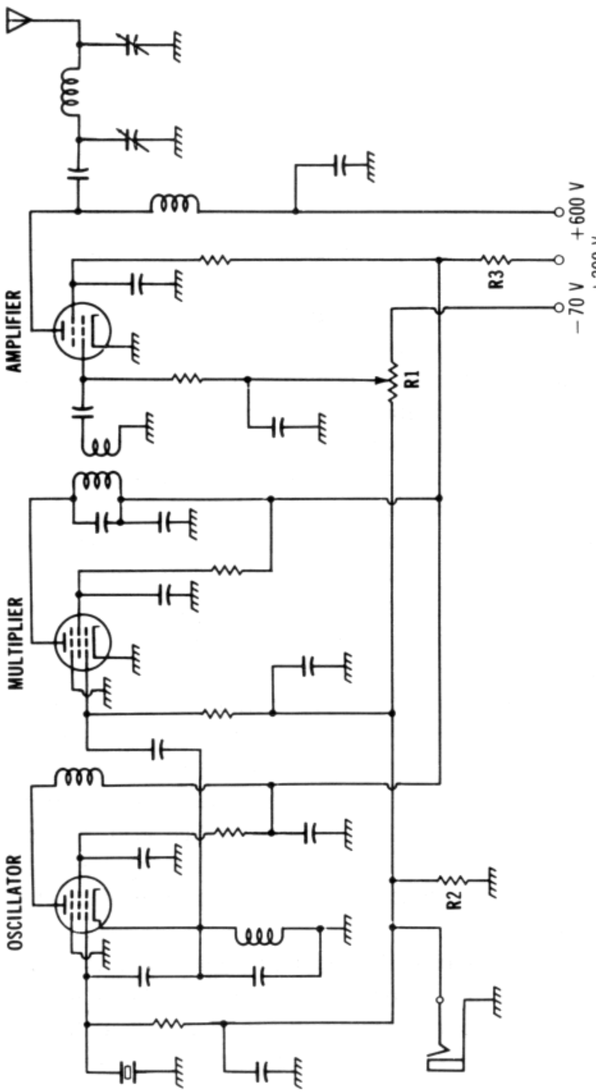


Fig. 3-13. A simplified schematic of a transmitter with some components drawn apart from circuit they affect.

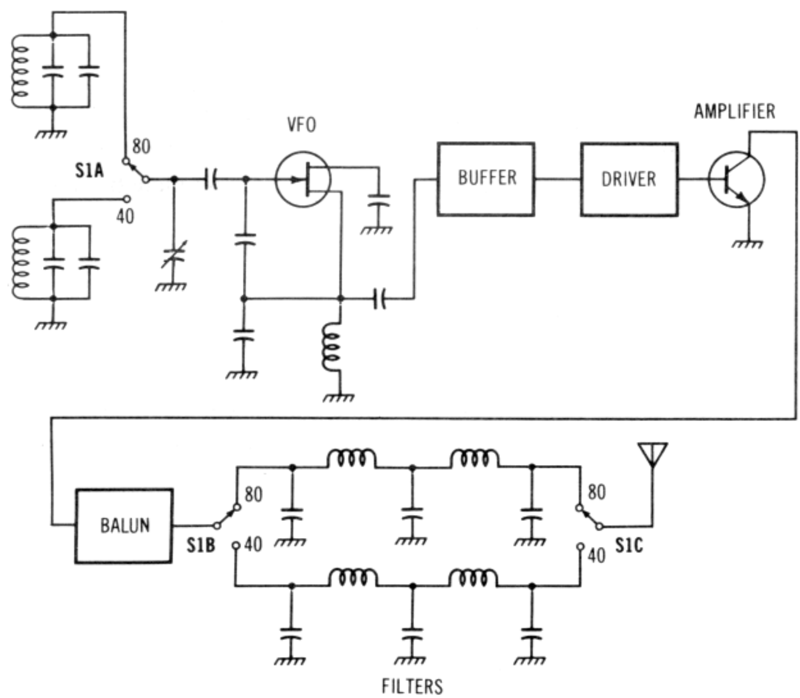


Fig. 3-14. Partial schematic of a transmitter showing "separated" switch sections.

high or low. They are widely used in such devices as computers, frequency counters, keyers, and control circuits. The second group, the linear ICs, perform amplifying functions much like discrete transistors, with the exception that their complex internal structures often permit doing something better than it can be done using individual components.

There are four major subgroups of linear ICs.

1. *Transistor arrays*—These are simply matched transistors, some in special configurations inside one case. Often, each transistor can be used separately. An example is the CA3018-A integrated circuit.
2. *Regulators*—These devices are designed to be used in power supplies to control the voltage and/or current.
3. *Operational amplifiers*—These versatile multistage amplifiers provide high gain, positive and negative inputs, and relatively easy control with just a few external components. The 741 is

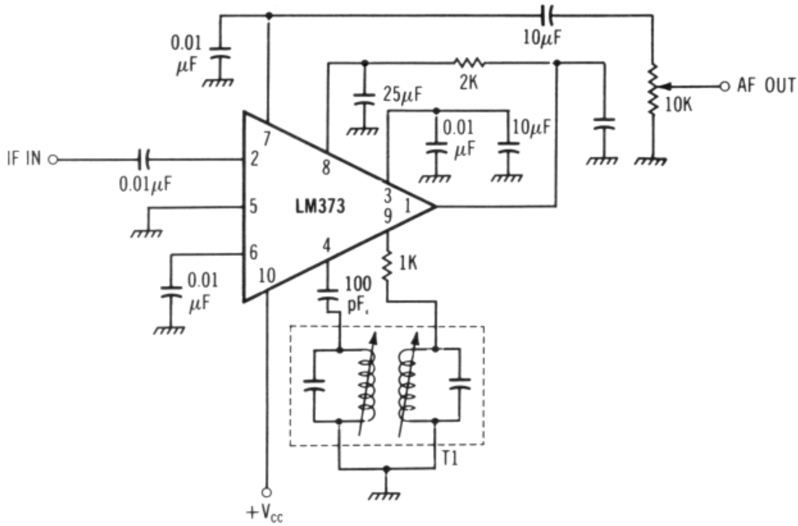
perhaps the basic op amp for the home experimenter, and the "active audio filter" that is controlled only by external resistors and capacitors is a primary example of a good use for op amps.

4. *Special-purpose ICs*—The special-purpose IC may range from a complete audio amplifier on a chip to a complete i-f system. A chip by one manufacturer even contains a complete broadcast-band receiver.

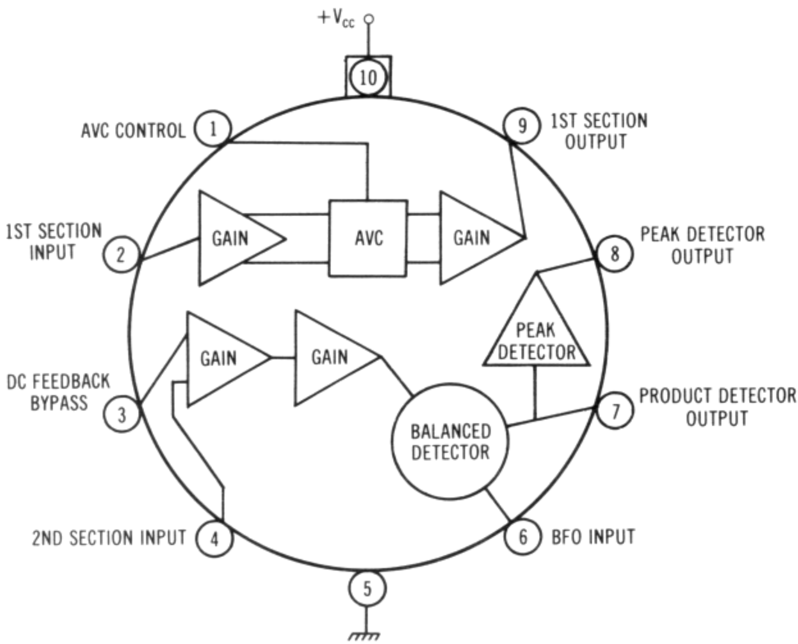
Schematic diagrams containing any of these elements usually provide us with less information than those containing discrete components. For the most part, we are shown only a shape (such as any of those given in Fig. 3-2) along with the components attached to the various leads. Sometimes, the connections will have less to do with the order in which a signal is processed than with the need to squeeze many components into a limited diagram space. Thus, IC schematics should rarely be read without supplementing the diagram with information from other sources. A functional guide to the interior of the specific IC is a necessity. Fig. 3-15 shows a typical circuit using an IC, together with an expanded view of the functional blocks inside the circuit. Circuit elements that are without meaning suddenly become clear. For example, the tuned circuit between pins 9 and 4 in Fig. 3-15A are now shown to couple two separate amplifiers that are in the same package. Unfortunately, not all authors include interior views of their ICs. For digital ICs and op amps, this is usually not needed since we tend to think of these types of ICs as functional units. To obtain information on other types of ICs, you have to search through manufacturers' handbooks or through one of the IC guides.

Refer to Fig. 3-11. This is another example of a schematic that furnishes wiring information but gives little other information. Perhaps the crystal symbol gives away the fact that U1A and U1B, together, form an oscillator. Unless we already know the functions of the other chips, it would be difficult to fully understand this circuit. The switch and its notations suggest that the 7490 ICs divide the frequency by ten, but there is no hint that they do this by dividing in a sequence of by two and by five. Without some knowledge of how NAND gates operate, we might well miss that gates U1A, U1B, and U1C are set up as inverters. If we wish to fully understand the circuits that we build, we will end up reading much supplementary material.

All of which brings us to this conclusion. A schematic diagram contains a wealth of information, but it is not an end in itself. Whether



(A) I f circuit diagram.



(B) Internal functional arrangement of the IC.

Fig. 3-15. An LM373 IC i f circuit diagram and internal functional arrangement.

we are interested in building, servicing, modifying, or designing equipment, or just wanting to learn about electronic circuits, the schematic leads us to other helpful material. And, this material will lead us to other schematics. The schematic diagram is most useful as a focal point for our thinking. Back in 1930, one author said, "When you can draw and talk about circuits in terms of the various conventional symbols, you are on what is familiar ground to every amateur and experimenter. Then you can meet the dyed-in-the-wool expert and understand what he talks about" (A.R.R.L. Handbook, 1930, p. 52). Modern electronics may not be quite that simple any more, but mastering the art of reading schematic diagrams can still teach a lot. It is all a matter of learning to ask the right questions.

Throughout this chapter on schematic diagrams, we looked to the text of an article to supplement what the drawing told us. In the process, we came nowhere near to using all of the available information. In fact, we cannot design a piece of equipment just from schematic diagrams, even though some experienced builders may appear to do so. They just hide lots of information in their heads. In the next chapter, we shall learn how to convert what the text says into useful entries for our idea book.

Chapter 4

Getting What You Want Out of Articles and Handbooks

Engineers and others for whom electronics is a career and a livelihood have an advantage over amateurs and hobbyists. Because they have committed their lives to a profession, they are willing to go to whatever lengths may be necessary to learn what they must know about their field. Whether they read fast or slow, whether they learn easily or with pain, whether they absorb information easily or with difficulty, engineers have disciplined themselves to staying with the material they study until it sinks in and is theirs.

By contrast, we are at a distinct disadvantage. Our jobs take up most of our time and energy, and the other parts of living take up most of the rest. After we have mowed the lawn, taken out the garbage, repaired the car, cooked a dinner, and played with the children, there is little free time left to devote to hard study of what others would call "just a pastime." Unless we can develop ways to get more out of our reading the first time around, the chances of improving our understanding of electronics to the point where we can design our own equipment to serve our personal needs and desires seems remote.

The answer is not speed reading. Speed reading techniques increase the quantity of what we can read, but they do not contain means of sorting out the important from the unimportant. Thus, we can fill our heads with all sorts of information and still have almost nothing useful to us. The answer is selection. We do some of this when we decide to read one article and pass over another. The one we read is the one which attracts our attention, either because of something in the article or because we have an interest in its subject. The trick of making our reading more productive, rather than just more voluminous, is to extend this selection process down to the contents of the articles. If we can select from the text just those pieces of information we need or think we need, the amount of close scrutiny we give any piece of writing will be reduced. In the process, we will discover that we actually read and retain more in less time.

However, make no mistake. I am not suggesting that you give up reading articles in magazines and handbooks out of idle curiosity. That is the one important way we increase the spread of our interests and, ultimately, our knowledge. But idle reading from casual interest and reading in preparation for design are two quite different things. To generate useful entries in your idea book without letting the process become a burden is easy once you develop a few techniques for selective reading. Your selective reading will be closely followed by selective note taking.

Part of the process you have already encountered in the last chapter. Extracting information from schematic diagrams involved looking into the text of the article for relevant information. However, not everything we want to know about the design of a piece of equipment can be caught in the schematic alone. In Chapter 2, I mentioned the utility of other diagrams and pictures which may be used as a basis for sketches in the idea book. Still, much of the information we may find useful will be in the text itself. This chapter will give you some ideas for extracting that information painlessly. Or, nearly painlessly.

READING BY ASKING QUESTIONS

Our usual process in reading electronics magazines and handbooks is to scan through them, picking out a few interesting articles, and reading those articles word by word. Our interests lead us to spot certain articles and to reject others. Although we do not usually ask it aloud, the selection process was based on the question, "Is this article about something in which I have enough interest to spend the time it takes to read through it?"

Reading the text of the article should make use of the same type of question. The reason it usually does not is that we do not take the time to refine our interests to the level of sorting out the content of articles. Almost automatically we sort out the types of equipment or electronic devices which interest us. We can carry the process a few steps further so that we select out of the article those points which interest us and pass lightly over the others. The general question is this: "What about the article, or the equipment described in it, interests me?" This, in turn, breaks down into any number of questions.

Note that we are beginning to read by asking questions of the material. In order to do this, we should begin by scanning the article with a quick reading. The light reading tells us if there is information worth noting. Perhaps the article contains nothing more than what we have already stored in our idea book. In that case, the light reading may be enough. Perhaps the circuit, the construction, or some other combination of features tells us that this design will not contribute to our aim of designing equipment. Again, we may not want to reread the piece in detail. On the other hand, some articles will seem to have an interesting point in every paragraph, every diagram, and every photo. Here is a gold mine. The next object is to refine our stock of questions so that we can extract the wealth in a systematic fashion.

Technical and construction articles are often organized to make this task easier. After a brief introduction, they usually follow the following organization (or a variation of it):

1. General remarks about the equipment.
2. An analysis of the circuit(s).
3. Construction details or notes.
4. Test and/or operational notes.

Part of the work of sorting out the material has already been done. If you recognize that the circuit(s) or the construction hold the most interest, your attention is already focused on what you need, and you will read the proper section most thoroughly. In fact, these two sections of an average construction article may be all that many readers will read through. These readers usually do not have enough of the right questions to ask.

In Chapter 2, some types of questions were listed that you can keep in mind to ask of any article. These questions concern the seven steps to design. In the last chapter, we discovered that schematic diagrams and the supplemental information we could find in the text covered the analysis of circuits quite thoroughly. What did not go into the diagram itself usually found its way into the margins of our page. Therefore, let us concentrate on other parts of the question list and develop some ways to get more out of the text itself.

REORGANIZING THE TEXT—FUNCTIONS AND BLOCKS

As important as circuits are to designing equipment, there is a more basic element—the functions which the equipment is designed to perform. Somewhere in your notes, if you deal with the piece of equipment as a complete operating unit, you should list the functions that the author had in mind when he designed the device. Function lists do two things for us:

1. They give us an idea of the kinds of functions that we can design into a piece of equipment. This leads us to the next question of how they can be designed into it.
2. They provide, once we have a few such lists, a range of possibilities that we can evaluate in terms of our own interests and desires.

Someday, when we are developing a design for ourselves, we will have to answer the question of what we want the equipment to do. The first step in making an intelligent decision is to have a range of ideas (taken from articles on equipment or from the brochures of commercially available gear).

What we enter into a list of functions will as always depend on what makes us interested in the equipment. We may initially be satisfied with a list with only a few basic entries—a transmitter produces upper and lower sideband signals of a hundred watts, or a keyer produces Morse code at speeds from 5 to 50 words per minute with automatic spacing and self-completing dots and dashes. Later, our lists might become more detailed as we become more familiar with the basic and special use of equipment. A few examples from which you can develop your own style of listing functions are given in Chart 4-1.

Notice that the entries in Chart 4-1 are short and compact. In textual notes, there is no need for complete sentences. The object of taking notes in lists is to get the most information in the shortest time and smallest space. If you can make sense of the entry, it is a good one. But, beware—what makes sense today may be cryptic tomorrow. With a little practice, you will sense how much you have to write to make a good note. Also, note that some questions are attached to the entries in Chart 4-1. Just as in the margins of schematic diagrams, textual notes make good places to ask and to answer questions that come to mind.

Chart 4-1. Different Types of Function Lists (With Typical Questions)

Functions by panel controls (For ssb transmitter)

1. USB/LSB at 100 watts output.
2. Variable pa tuning/loading.
3. Frequency: 80–10 meters.
4. Driver tuning.
5. Af and carrier gain.
6. Spotting capability.
7. Transceive with receiver.
8. Meter: pa current and output.
9. Key, mike, mute, relay control, and vfo output jacks.

Questions:

a. Do I need cw capability?
b. Should VOX gain and delay be controlled from front panel?

Functions by device capabilities (For Morse code typewriter)

1. Speed: 5 to 70 wpm
2. Negative line keying only.
3. Dual output: ASCII for video and Morse code for transmitter.
4. Af monitor: tone/volume controls.
5. Buffers for flexible keyboard speed.
6. Keys: alphabet, numbers, and ham prosigns.
7. 256-word memory.

Questions:

a. Can memory be subdivided?
b. Do I need ASCII output?
c. Can I design an adapter for positive line keying?

Functions by author's equipment design requirements (For small cw transmitter)

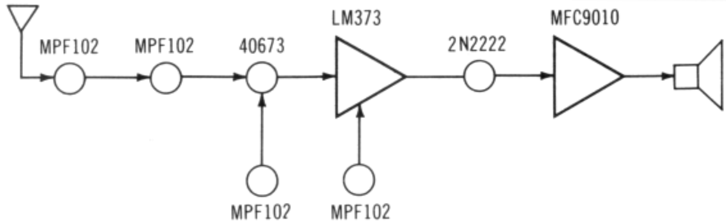
1. Station standby rig.
2. QRP operation.
3. 10 watts output.
4. Frequency: 80–15 meters.
5. Crystal oscillator with external vfo.
6. Tubes and junkbox parts.
7. Basic reliable circuits.
8. Also used as teaching aid in ham classes.

Questions:

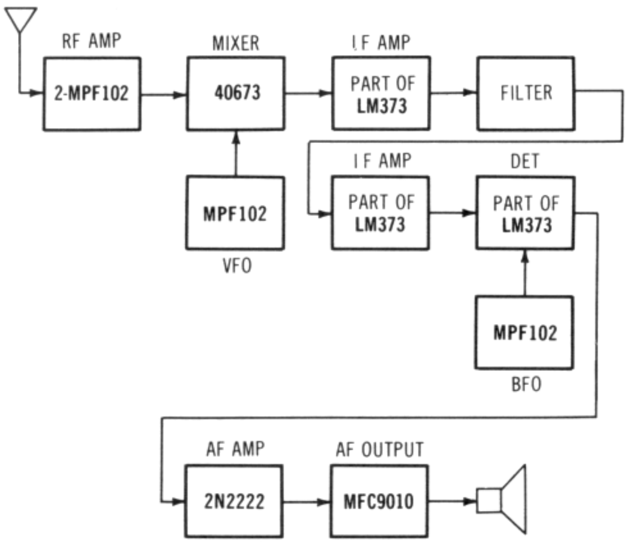
a. Do I want this level of power?
b. How large an amplifier will this transmitter drive?
c. Are author's junkbox parts readily available?
d. Can I add internal vfo?

Many of the questions which come to mind raise a general question which always follows the listing of the functions of a piece of equipment: "How did the author accomplish the functions listed?" For some readers, this leads to the schematic diagram. There is, however, an important intermediate step which is halfway between functions and circuits—the *block diagram.* Block diagrams give a picture of the circuit groups which are devoted to the internal functions of the equipment. These internal functions go together to produce the overall functions of the unit. Thinking about a piece of equipment in terms of circuit blocks is an essential step in understanding a piece of equipment fully.

In transmitters and receivers, circuit blocks are customarily called stages. Because improvements in receiver and transmitter performance have, in a large measure, come about through the improvement of the individual internal functions, it is natural to name each of the



(A) A diagram showing active devices.



(B) A diagram showing functional blocks.

Fig. 4-1. Comparison of diagram layouts.

stages distinctively. For example, we think of rf amplifiers, first mixers, second mixers, i-f amplifiers, filters, detectors, and audio amplifiers when working with communications receivers.

For each of these stages, there is more than one type of circuit that will perform the function indicated. Some of these circuits involve more than one active device. In some cases, one active device may perform more than one function. Therefore, just a schematic diagram plus a list of equipment functions may not tell us accurately what is going on in a receiver. Take, for example, Fig. 4-1. The top half of the diagram (Fig. 4-1A) shows a line-up of the active devices. Even if we were familiar with all of them, the line-up does not tell us what functions each is performing. Now compare this with Fig.

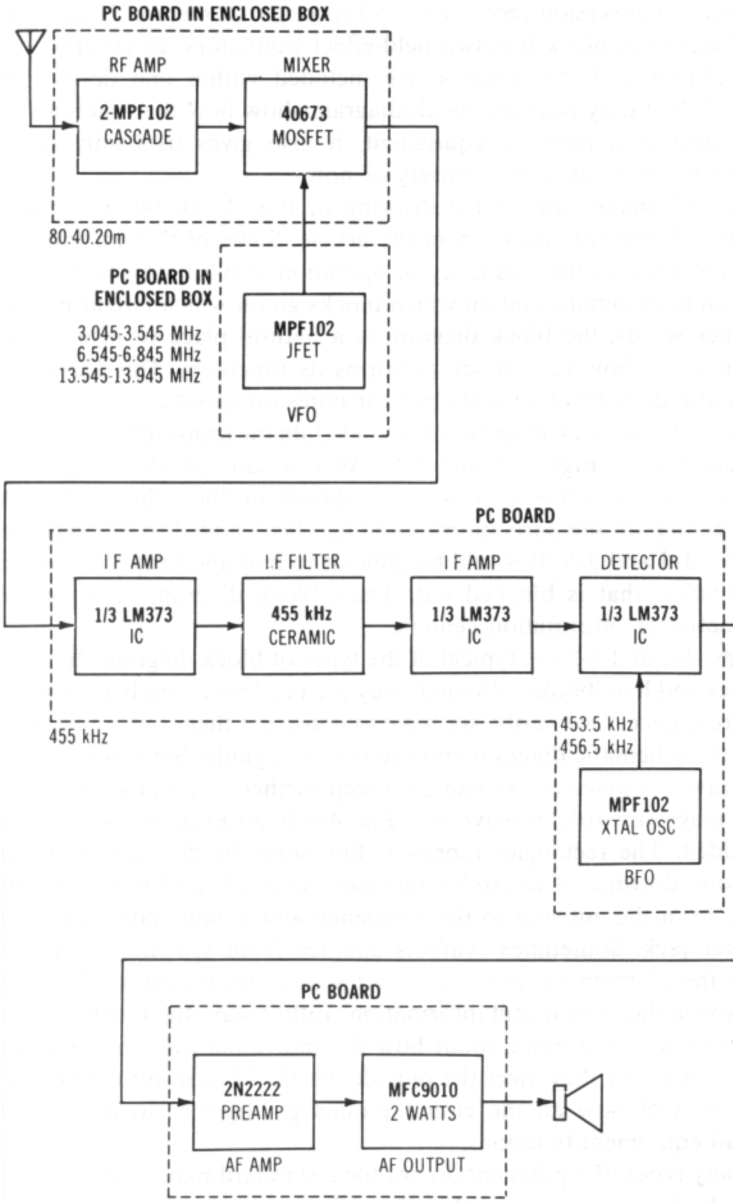


Fig. 4-2. The drawing of Fig. 4-1B with more information added.

4-1B (the bottom half of the drawing). Here we have a block diagram of a single conversion receiver for 80 through 20 meters. Notice that the rf amplifier block lists two field-effect transistors. In contrast, the if amplifiers and the detector are included within one device, the LM373. Not only does the block diagram show how the functions interconnect in a piece of equipment, it also gives us handy points around which to arrange a variety of notes.

Fig. 4-2 makes use of the drawing in Fig. 4-1B, but it includes further information drawn from the article. Some of that information includes notes on the frequency of operation of oscillators and amplifiers, on filter details, and on which blocks go on which circuit boards. In other words, the block diagram is a natural place to insert notes pertaining to how each block performs its functions. This leaves the schematic diagrams free and clear for notes on specific circuit values.

Fig. 4-3 is a block diagram of a solid-state cw transmitter. Compare this diagram to Figs. 3-4 and 3-5. As you can see, this diagram is simply a block version of what is shown in the schematic. Now imagine that all the parts information had been added to the diagrams in Figs. 3-4 and 3-5. It would be difficult to find and keep track of the information that is blocked out. Thus, block diagrams complement schematics as information centers.

Figs. 4-2 and 4-3 are typical of the types of block diagrams found in articles and handbooks, although they are not found nearly enough for my preference. Ordinarily, we have to construct them ourselves, using both the schematic diagram and the text as a guide. Since we must do the drawing ourselves, we can go a step further and add some blocks most magazine articles leave out. Fig. 4-4 is an example of what can be added. The rectangles represent functional blocks, similar to the previous drawing. The circles represent controls and terminals that range from the antenna to the frequency and volume controls to the speaker jack. Sometimes symbols adapted from schematic diagrams make the diagram easier to read, but sometimes we must add words to provide the most useful information. Either way, the block diagram now tells us much more about how the individual functions are controlled and how they meet the outside world. This, in turn, gives us a good idea of how all the circuit groups go together to achieve the overall equipment functions.

Many types of equipment do not have standard names for all of the individual circuit groups within them. In some cases, types of equipment are too new to have standard names applied to subunits. In other cases, there are many ways to accomplish the same goals so that

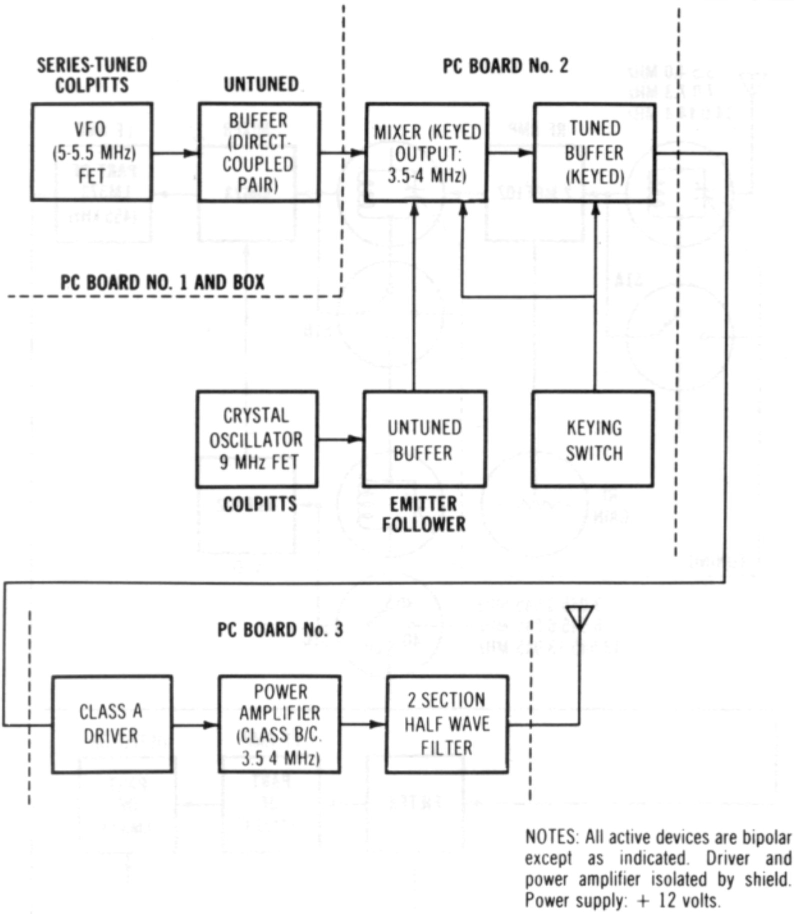


Fig. 4-3. Block diagram of the transmitter circuit shown in Figs. 3-4 and 3-5.

standard names do not have a chance to become established. In such cases, you should develop a block diagram trying to provide short descriptive names for each of the groupings. The text will aid your drawing by describing the functions performed by the groups. Fig. 4-5, taken from a home computer keyboard, gives one of many possible examples. Since digital integrated circuits, especially those called large-scale integration (LSI), contain many functions, we often simplify the line connections within them and among them and note how many lines actually go from function to function.

Although block diagrams are useful in themselves, they also serve a special purpose for us. They allow us to group our notes in a way which makes them instantly useful. If we have not gone to school in a

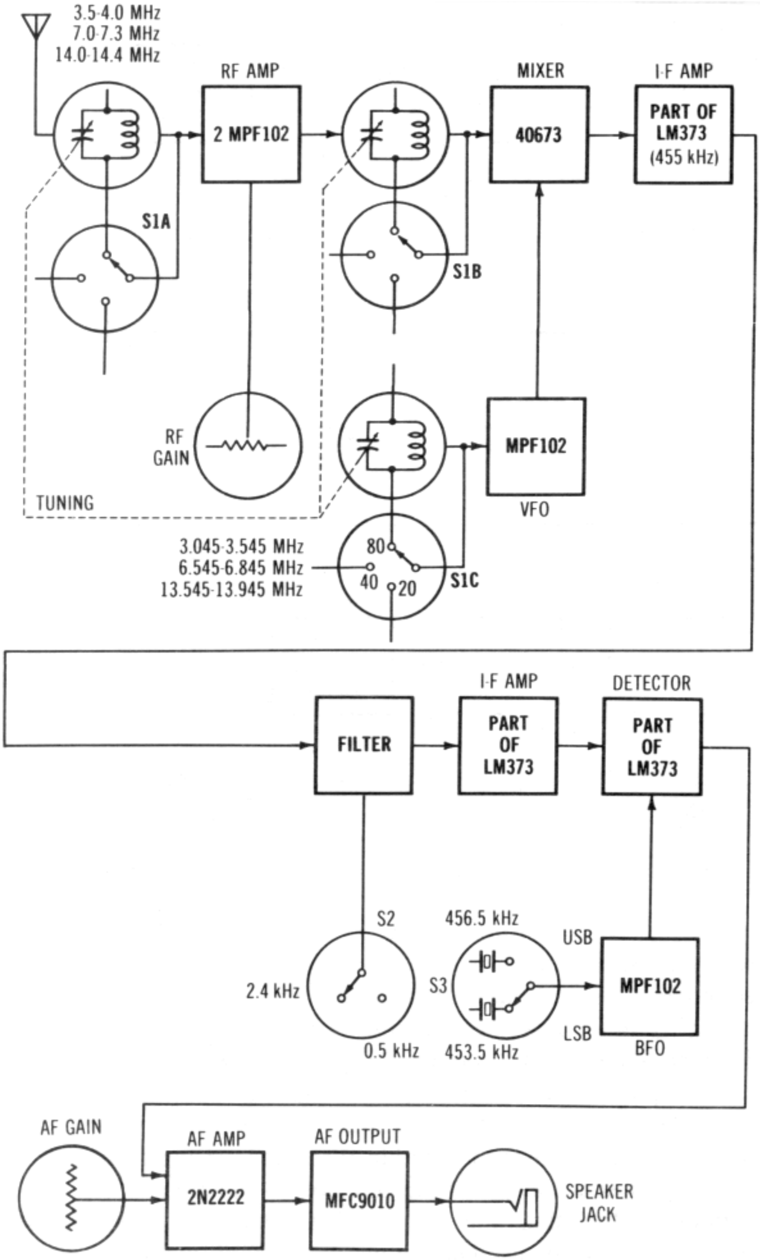


Fig. 4-4. Expansion of Fig. 4-1B to show controls and terminals.

long time, it is unlikely that lines of words on a page will interest us for very long after we have written them down. But if they surround a sketch, whether that sketch is a schematic, block diagram, or construction drawing, the notes remain meaningful and permit us to review them again and again as we proceed from gathering information to the process of design.

CONSTRUCTION AND TEST INFORMATION

Since schematic diagrams were thoroughly covered in Chapter 3, we may pass over them and explore ways to gather construction and test information. Construction information includes parts layout, notes on acquiring any special parts, and ideas for the construction of the equipment. Just as schematics and block diagrams aid in the process of putting information into an easy-to-use, organized form, so too will sketches help the process of noting construction information in our idea book.

Construction ideas abound, and we can fill many notebooks with

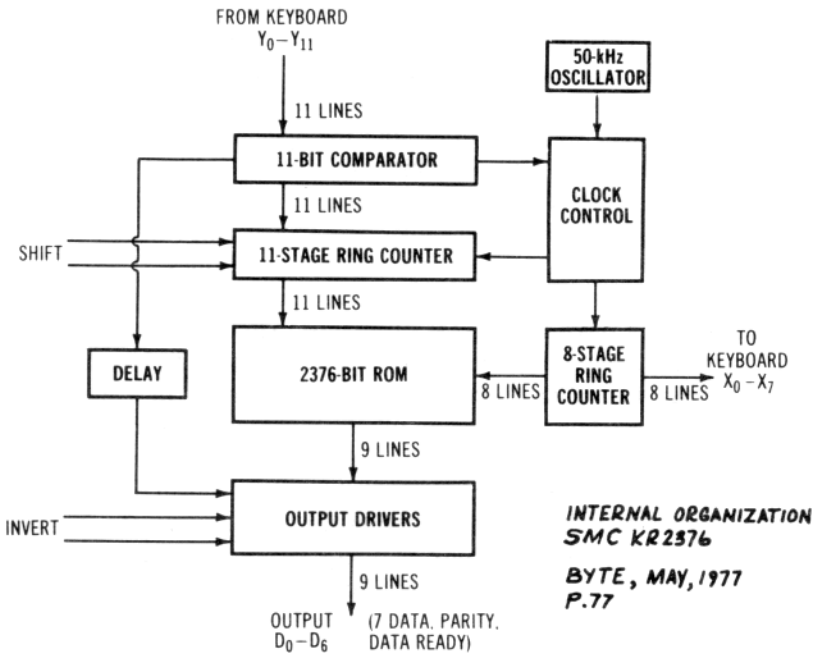


Fig. 4-5. A typical integrated-circuit block diagram, showing the internal organization of a keyboard chip.

the ideas that appear in articles and handbooks. To keep our idea books compact, we should make some decisions in advance. If we can get a rough idea of what sort of information we will be interested in, our notes will always be relevant to the kinds of equipment we might design and build. A first step in this direction is to decide in advance what sorts of construction we do not wish to use. We can always change our minds later and add a new technique. In a few months of magazines, we will usually find many articles that have ideas to help us master the new technique. So, for the present, we might want to rule out making our own circuit boards, or difficult levels of forming metal to make our own cabinets, or assembly techniques like wire wrapping. None of these techniques are bad. Rather, we rule them out only because we have decided that for the present they are not the things we want to do.

For everything we rule out, there must be a replacement. We must be ready to use perf board or chassis tie points or premade circuit boards, or we must be willing to rearrange parts to fit ready made cabinets, or we must be willing to solder. If these are the techniques we rule out as undesired or beyond our capabilities, then we must keep the first set of techniques. For now, these decisions only tell us what we will take notes on and what we will omit. After we have accumulated some notes, we will discover that construction techniques repeat themselves. Then, we need only note the special features of equipment that interest us. This simplifies the task of general note-taking by a good bit. However, we should keep our eyes open for any novel technique, especially if it is simple. Some magazines have tips and hints columns which are gold mines of such techniques.

In developing notes on any particular piece of equipment, you should focus on three main areas of interest. The first area is the way that parts are laid out by the author. Here a sketch, such as the one given in Fig. 4-6, makes a convenient starting point. In some cases, you may want to show all parts; in others, you may want to show only the major parts. For larger parts, list the dimensions. These can often be inferred from photos or from similar parts shown in catalogs. Then, if you later think about altering the layout, you can be sure everything will fit. If you think in these terms, be sure to consult the block diagram and the schematic to be sure that the parts which belong together go together.

The layout sketch makes a good place to enter notes on special parts, the second area you must think about. Some authors use parts that are on hand or surplus parts. Make a note of this, since reproducing a circuit may become difficult if certain key parts are not available. Other authors may use parts which are so specialized that they are too expensive for you to buy. Unless you can assure yourself that readily available substitutes will work adequately, you may have another circuit which is not applicable to any of your projects. If a supplier's part number is available, list it with the part. Even common parts are easier to find if you have parts numbers. Some of this information is shown in Fig. 4-6.

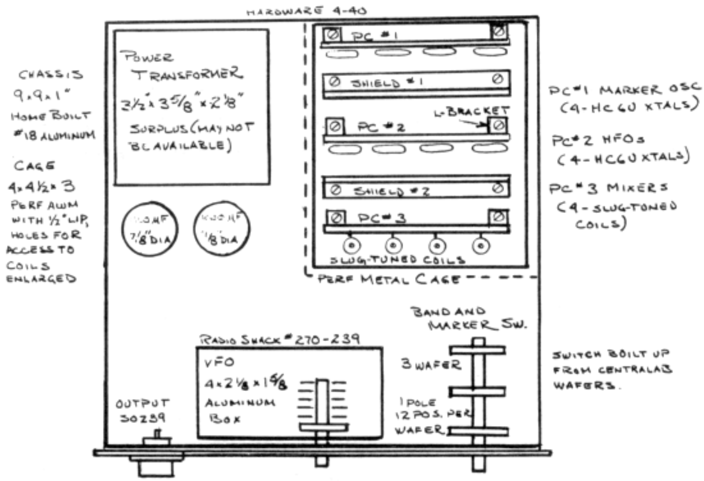


Fig. 4-6. Sample chassis layout of a ham band signal and marker generator.

Construction notes form the last area we need to consider. For general layouts of metal work and panels, sketches are very useful. In other cases, notes might be introduced into the block diagram, schematic, or the layout plan. Warnings that certain components are fragile should be noted. (One author saved me much work by telling that a coil slug might drop out if turned too far. Another author failed to warn me about a similar problem, and I ended up having to buy a new coil, because the slug would not go back in without damage to the form.) If construction of an assembly or subassembly requires that certain jobs be performed in a set order, by all means note them, if the assembly is significant to you. Installing dial assemblies is typical of this kind of note. Other notes may concern the placing of parts too close together (for example, tube heat can melt wire insulation) or too far apart (rf leads should be short, for example). Still others may include hints on static charge damage, shielding, modifying components, and other small but essential tips and tasks. The key is that if the type of construction intrigues you or if it is necessary to make an interesting circuit work, then it goes into the notes.

When you turn to test notes, the game plan changes somewhat. Tests can be divided into four general categories:

1. Initial testing procedures.
2. Measurement values.
3. Adjustment procedures.
4. Malfunction test procedures.

These four categories overlap, but to the extent that you can identify the main thrust of a test item, it is best to put all notes relating to it in one place. For example, part of the tune-up procedure for a receiver may include adjustment of a coil slug until a certain value of voltage is read from the speaker terminals or from some other test point. If the procedure is part of the initial tests to assure that the unit is working, then put data relating to the coil under initial testing procedures. If it is related to general alignment procedures, then the best entry might be under adjustment procedures. In some cases, your interest in the item will determine the category of entry.

Initially, we may have little or no interest in the test information that articles and books supply. After all, that information is only important to the person who actually constructs the device in the article. *This idea could not be farther from the truth.* Test data and procedures give us important information on many aspects of the equipment design. Here is a short list of possibilities:

1. Sensitive or tricky stages (as indicated by detailed alignment instructions, often with warnings).
2. Weak links in the design (sometimes indicated by the need to try several active devices until one works).
3. Lack of equipment fail-safe measures (indicated by warnings to be sure a stage is operating correctly before applying power to other stages, or warnings not to let a voltage or current reading exceed a certain level).
4. Shortcuts (indicated by external components arranged to help an active device approximate perfect performance, when additional devices might directly perform the function).

The preceding list contains negative facts that the test information might reveal. Test data also give us positive information. Here are a few possibilities:

1. General parameters for circuits of a certain type (for example, frequency ranges for multivibrators or typical output voltages from a transistor).
2. Procedures applicable to similar equipment (such as pulse tracing in digital equipment or receiver alignment).
3. Special techniques as a substitute for expensive test equipment (for example, determining harmonic content without an oscilloscope).
4. General information on measuring electrical values (often found in specifications of the conditions under which an author took his readings).

These possibilities only sample the information that test methods may teach us about working with various sorts of circuits. It is one thing to picture a circuit design and quite another to feel comfortable working with it. The picture is static. Electronic equipment, when it is doing what we want it to (and when it is not), is dynamic. The more we focus on the operating characteristics of circuits, the more confident we become that not only can we build the circuits, we can also refine their operation to fulfill our goals. Test data help us gain this confidence by providing information on the dynamic aspects of a design. In gathering material for our idea book, we need to organize the data to be most useful.

Measurement values can be catalogued in two convenient ways. Both dc and rf voltages, as well as some current readings, which indicate normal operation can be entered onto the schematic diagram of the equipment. Some typical forms of entry appeared in Chapter 3. Another convenient form, which also applies to resistance readings, is a chart which indicates the reading or test point, the measured value, and the test conditions. Table 4-1 provides an example of such a chart.

Initial test, adjustment, and malfunction test procedures, if they are significant to your information gathering, can be entered as numbered lists, much like a set of assembly instructions. Good examples of malfunction test lists are those found toward the back of the assembly books issued by electronic kit manufacturers. Following their examples, even if your notes are briefer, is good practice.

KEEPING CHARTS, GRAPHS, TABLES, AND FORMULAS

Early in Chapter 2, it was suggested that photoreproduction is generally not a good method of taking notes. All that a photorepro-

Table 4-1. Typical Voltage Reading Chart

Tube No.	Voltage Readings on Tube Pins						
	1	2	3	4	5	6	7
V1	−1.1	1.7	0	6.3*	140	128	0
V2	0	0	0	6.3*	135	75	2.4
V3	−10.3	2.8	12.6*	0	135	128	0
V4	−1.3	0	0	12.6*	130	80	3
V5	−1.1	0	12.6*	0	105	65	0
V6	−1.3	1.5	0	6.3*	140	128	0
V7	4.5	0	12.6*	6.3*	0	125	135
V8	−0.5	0	0	6.3*	140	105	2.8
V9	−1.1	0	12.6*	0	135	105	0

1. * indicates an ac voltage.
2. Conditions of measurement: Gain controls are fully clockwise; band = 80; antenna is disconnected; antenna control peaked on noise; function switch set to cw. Measurements made with an 11-megohm vtvm from tube pin to chassis.

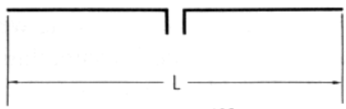
duction supplies is a copy of the original. The arrangement of information remains the author's, not yours. In this chapter, the rule still applies—with the exception of the material specified in this section.

Magazines and handbooks often contain charts, graphs, and tables which contain information very useful for design. Often these materials are relevant to some subdivision or another of your idea book. There are, for example, graphs of values for designing pi-network power amplifiers. Logically, these might be inserted into the power-amplifier section of your book. Charts and tables for filter design apply to ideas about receiver or transmitter filters of various types. If more than one section of the idea book holds promise of calling your attention to such information, perhaps two copies might be helpful.

In addition to the need for more than one copy, charts, tables, and graphs require accurate copying if they are later to provide you with accurate information. Thus, photoreproduction is often the best way to obtain copies for your idea book. Practice in drawing graphs and copying charts can familiarize you with some of the content but, in this case, the need for accuracy may be the overriding consideration. Thus, unless you have drawing or drafting skills, a trip to the reproduction machine is in order.

Formulas, on the other hand, you should always copy by hand. In fact, you should also include with each of them one or two examples of typical problems which the formulas solve. This will aid you in remembering typical values and the range of utility of the formula. Often, you can construct a useful table from a formula. For example, when I encountered the formula for half-wave wire-dipole antennas, I made the drawing and chart shown in Fig. 4-7. Notice that the sketch contains a table of values for the cw portion of each of the amateur radio bands; the table has served me well on several occasions. Acquaintances have asked for antenna lengths for the phone portion of the amateur radio bands. I have turned to the formula, applied my pocket calculator, and then compared the result with the cw value to be sure I had not made a gross error when pushing the buttons.

$\frac{1}{2}\ \lambda$ DIPOLE



$$L\ (\text{FEET}) = \frac{468}{F\ (\text{MHz})}$$

L = LENGTH (WIRE ANTENNA)
F = FREQUENCY

L FOR CW PORTION OF HAM BANDS		
80	F = 3.600	L = 130 Ft.
40	7.100	65.9 Ft. = 65 Ft. 11 In.
20	14.100	33.2 Ft. = 33 Ft. 2 In.
15	21.100	22.2 Ft. = 22 Ft. 2 In.
10	28.100	16.7 Ft. = 16 Ft. 8 In.

Fig. 4-7. Sample formula and applications table.

In general, it is best to keep charts, graphs, tables, and formulas in the section of your idea book to which the material relates. Sometimes a piece of information in graphic form will strike you as interesting, even though you have no best place to put it. In that case, a miscellaneous information section can be added to the idea book. However, try not to keep the material there too long, or it becomes dead weight. Enough entries may begin to show a pattern which might suggest a new interest and subdivision of the book. If the graphic material remains unused for over a year, then you probably were only attracted by the artwork. Whether or not you can throw the page away may depend on your ability to discard something which gives aesthetic pleasure.

USING YOUR IDEA BOOK AND KEEPING A SPECIAL PROJECT NOTEBOOK

All of Part I of this book has been devoted to supplying very practical ideas on the gathering of information in a systematic way as a prelude to designing your own equipment. Some ideas were reviewed on developing an idea book, not a general notebook. The purpose in Chapters 3 and 4 was to provide as many ideas as possible for getting the most information out of articles and handbooks, and suggesting ways of putting the information into a form which will be readily accessible and well organized. Accessibility and organization are key factors when reviewing information for use in designing and building electronic projects. Without these two features, we will soon discover that the idea book will lay on a shelf accumulating notes which we will never use when a project idea comes to mind.

Learning to use an idea book effectively requires a bit of practice and periodic review. Leafing through the book and selectively reading some entries in various sections is about all the practice we will need. In a short while, we will naturally turn to the book to rediscover what we have on file whenever a building urge hits us. Reviewing our system of arrangement also helps. Periodically looking to see if the collections of ideas make sense and still reflect our interests will keep the idea book current.

When the urge to design and build a piece of equipment becomes strong, we need to shift gears once more. As a background to the design process, we need to review whatever we have on file that is relevant to the project. That means going through the idea book to take stock of its contents. We will use the idea book again and again in the course of Part II (the actual process of design), but we can begin the process at this point with one important preparation.

As the idea for a project grows in your mind, transfer the information from the idea book to a special project notebook. At this stage, you are only deciding what looks interesting with respect to the project. This is where a loose-leaf binder or a set of file folders is handy, since the transfer is very easy. Not everything from every relevant section will make the transfer. Some of the information you move will move back to the idea book in the course of design, and some further material may be transferred to the project notebook. That will happen because the decisions you make along the path of design will change the relevance of some of the material. All of this is natural to the design process.

Starting a project notebook at this point has a special advantage. Many good project ideas pass through our heads only to become lost again because nothing tangible resulted from our thinking. Starting a special project notebook with entries from the idea book is a tangible start. Although the project has not yet even been defined, the first definite step has been taken. Every other step will be easier to take.

In the end, the special project notebook will become your personal design, construction, operating, testing, and repair manual. It will grow as naturally as the design process described in Part II so that writing the manual will never be a burden. Information which does not enter into the final design will be returned to the idea book to be used on another day. The special project notebook will then be the manual for the equipment you have designed and constructed yourself.

Before we can reach the point of calling a design notebook an operating manual, we must go through seven steps and some pauses. If we have mastered the art of gathering information in preparation for design, these steps and pauses will be easy to take—if we take them one at a time. That is what Part II is all about.

Part II

Designing and Building Your Own Equipment

Chapter 5

Steps 1 and 2—Objectives and Block Plans

In the most general terms, design is a rational decision-making process. We must make decisions on at least two levels. First, we must decide what will be the goals of the project. Then, we must further decide the best way to achieve these goals. This part of the book will present a systematic process by which we can decide upon goals and the strategies for reaching them, including verification that we have, in fact, reached the goals. In other words, we still think through a step-by-step process of design and building until we have tested the final product.

In the process, there are only seven steps and some pauses. Here are the steps:

1. Step 1: Setting down design *objectives.*
2. Step 2: *Blocking out* circuitry by stages.
3. Step 3: *Circuit* research and *selection.*
4. First pause: Circuit interaction I—Drive, Matching, Switching.
5. Step 4: *Parts* acquisition.
6. Step 5: *Layout* planning.
7. Second pause: Circuit interaction II—Shielding, Isolation.
8. Step 6: *Building.* } One stage at a time, cumulatively.
9. Step 7: *Testing.* }
10. Third pause: Circuit interaction III—Spurious Oscillations, Emissions.

This is the complete list. Key words stand out so that you may use them as a check list in your projects.

The preceding list is not arbitrary. It represents a straightforward progression of thinking and doing that can maximize your chances of successfully designing your own electronic equipment. To the greatest extent possible, most of the problems you might encounter in the design process have been considered and a specific time and place for thinking out and solving the problem has been given. At this point in time or place the solutions will stick in your mind. At each step in the process, you will be reminded of the materials and information that need to be brought to the decisions you will make. Consequently, if you follow the process, your projects will likely work the way your first vision of them says they should.

It is recommended that as you work your way through this part of the book, you have a project which you wish to build. Not only will it aid you in remembering the points mentioned by giving you a concrete case to practice on, it will also aid you in adapting the material to your unique and individual style. Everyone of us differs a little from everyone else. All general rules, even those given in these chapters, require adaptation if they are to be helpful. You should be ready to modify the ideas that are presented so that they will fit you well.

The set of design steps previously listed should give you clues to the rationale behind Part I of this book. The material that was noted from articles and books (either in words or in diagrams) begins to fall into place as fitting into the steps of design. The idea book generated in Part I becomes the source of information we need to make design decisions. In most cases, the question, "What shall I do?" will not be a cry in the wilderness. Instead, it will indicate that we need to select one of the ideas out of the collection we have made. Some of the steps of the process will refine this general question even further so that we will not make a blind decision. For example, if we decide to go solid state with a piece of equipment, we then no longer have to consider any of the good tube ideas. Also, if we learn that certain conditions have to be met to make the circuits follow one another properly, the range of possibilities may be further reduced. Other considerations will further reduce the options and, in some cases, only one circuit will be left. At most, there will be only a few items from which we must select. In each case, we will be able to enumerate the advantages and disadvantages of each option and, on this basis, we can make good decisions.

Good decisions made at the right time—this is the heart of successful design. Timely decisions allow us to develop our materials into a configuration which meets our present needs and objectives, and that is the very definition of design. The first step, however, is to set our objectives.

SETTING DOWN OBJECTIVES

Once we have set our objectives, every other step in the process of design will fall naturally into place. Some of the decisions will be difficult, but a list of objectives will supply us with the basic criteria for judging whether these decisions are good or bad ones. However, we must also decide what our objectives will be. At first glance, it seems that this set of decisions (choosing objectives) has nothing to guide it. In fact, the initial step in setting out objectives can and should be guided by three questions:

1. What can equipment of this type do and what is it that is impossible for it to do?
2. Why do I want to design and build a piece of equipment like this?
3. What features or characteristics do I want the equipment to have?

These three questions provide important information about yourself and what the urge to design and build really means to you.

The first question—what certain types of equipment can and cannot do—provides a very important review of the basic purposes of electronic gear. It is not enough to think that a receiver receives rf energy and converts it to audio or some other form of energy. We must think in more precise terms. "A high-frequency receiver for ssb and cw" is a more exact description which sets limits to what we can put into and get out of this type of equipment. It tells us that we are limited to the amateur bands between 3.5 and 30 MHz, and that we should not expect good a-m reception from the unit. Every type of equipment we can contemplate building will have some limitations, and we should be aware of them.

We should by now have a wealth of material to help us be aware of what equipment can and cannot do. The idea book, with its notes on equipment of the same general type as the project in mind, supplies us with our basic information. The functions we have listed for each item spread a number of possibilities before us. At least initially, we can select from these functions with good assurance that the objectives selected are possible to build into the equipment. Objectives that you plan, that are not a part of the functions of the equipment listed in your notes, will require further thought. Is it possible to squeeze them into the equipment without disturbing other functions or must they be reserved for a different kind of project? The answer to this question should not be hasty. You may choose to design creatively, as you add functions which fit your needs and which no one has yet thought to put in this type of equipment. Or, you can be conservative and restrict your objectives to those that others have achieved, with the confidence that your project will be successful.

Besides your idea book, you have your own desires and, therein, a second wealth of information. Tapping this information requires that you answer the latter two questions of the preceding list. The thoughts which prompted you to want to design and build such a project are good materials for setting objectives. Perhaps something in existing equipment has dissatisfied you. From the recognition of this, you can move to discovering what feature will correct the situation and satisfy you. This feature becomes one of your objectives. Or, perhaps a specific desire is part of your urge. This can be anything from the desire to use printed-circuit boards to being able to play games on a computer-controlled video screen. Any of these desires or ideas should go on the objectives list.

Motivations for designing and building are not the only kind of answers to the question of why you want to design and build a certain type of equipment. Goals also make good answers to "why" questions. If your goal is to be able to receive amateur satellite signals, then you can refine an objectives list into specific entries. For OSCAR reception, availability of all the ham bands is not necessary. Placing converters ahead of a 28-MHz receiver might fulfill your needs. Besides converting rf signals to audio, the receiver has to provide good selectivity, since the small bandwidth for OSCAR reception is crowded on each pass. And, because OSCAR signals tend to be weak when the satellite is near the horizon, the receiver has to be sensitive. The next step in this process of making your goals concrete is to specify these objectives in numerical terms. How selective is selective enough? Perhaps 2 kHz for ssb and 0.5 kHz for cw. How sensitive? Perhaps 0.5 microvolt for a readable signal. These are objectives to which we can design.

The final question requests a list of desired features and characteristics, instead of those made absolutely necessary by our motivations and goals. The question covers many kinds of concerns. First, it can refer to our eventual operation of the equipment. Do we seek operating ease or complexity—many adjustments or only a few? Second, it can refer to the building of the unit. Do we wish to use circuit boards or perf boards, use standard cabinets or do metal work, try reliable circuits or tricky ones? Third, the question can cover the basic nature of the equipment. Is it to be an experimental unit that is constantly revised or a reliable piece of operating gear; is it to be a finished item or a breadboarded unit?

Even if you see a piece of equipment that appears to have all the features you want in an article or book, it will pay to make a list of its advantages and disadvantages in terms of why *you* want to build it. The purpose in this exercise is to make sure that you do not overlook anything. There are, however, two kinds of lists we can make.

STATIC AND DYNAMIC OBJECTIVES

There are two fairly distinct types of objectives that we can call *static objectives* and *dynamic objectives.* Static objectives refer to fixed and solid features of the equipment. If we specify that we want a piece of equipment to be small, light weight, and use solid-state devices, we have defined some of the static properties of the equipment. If we wish to use certain parts on hand, parts that are low in cost and easily obtainable, or are close-tolerance parts, we have defined other static properties. The use of printed-circuit boards, metal cabinetry, and special dial mechanisms adds to our list. All of these properties represent visible aspects of the project. Some of our desires and choices in this category will affect the dynamic objectives we set. For example, most solid-state equipment will operate with a lower power consumption than does equivalent tube-type equipment. Nonetheless, this group of objectives is important in itself.

It is equally important to give independent thought to dynamic objectives. Among less experienced designers and builders, this group of objectives is often overlooked or, at least, not thought through in detail. Dynamic objectives specify the operational characteristics you set for the equipment. Specifying a data transmission rate of 300 baud for a computer interface is one example. Deciding that a receiver must demodulate cw, ssb, and fm, or that it must have a sensitivity of better than 1 microvolt for a readable signal are two more examples. Setting the output of a transmitter at 100 watts is still another. Just as static objectives influenced dynamic objectives, so too does the reverse hold true. High rf power output is more easily obtained with vacuum tubes than with solid-state devices at present. Data transmission will probably involve the use of integrated circuits. Table 5-1 provides some typical examples of dynamic and static objectives for different types of equipment.

Table 5-1. Examples of Typical Dynamic and Static Functions

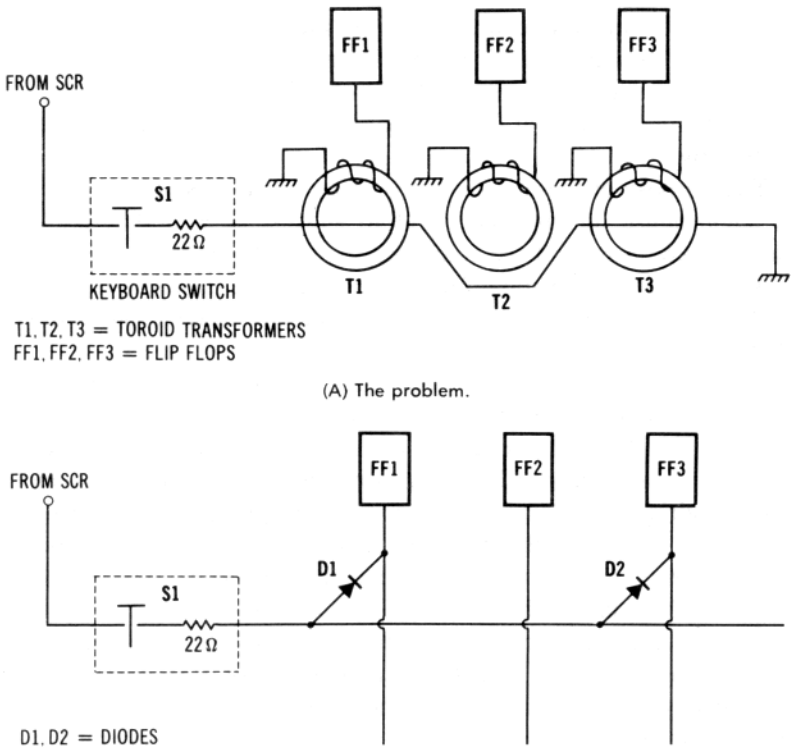
Equipment Type	Dynamic Function	Static Function
Hf receivers	Input sensitivity Selectivity Frequency range Modes of detection Dynamic range Stability Input/output impedance	Types of active devices Types of filters Power source Construction methods Dial/tuning assembly Control mechanisms Cabinetry
Hi-fi equipment	Frequency response Damping factor Hum and noise level Phono equalization Am/fm sensitivity Selectivity Image rejection Audio power	Types of active devices Types of filters Power source Construction methods Meters Dial/tuning assembly Control mechanism Cabinetry
Computer terminals	Keying rate Processing speed Interface modes/speeds Language size/limits Memory size Display modes	CPU type Screen size/type Character set Keyboard type Cabinetry Bus type
Test equipment	Sensitivity Output Ranges Metering Input/output impedance Frequency limits Range of values	Overload protection Readout method Construction methods Active devices Control mechanisms Cabinetry Lead/terminal type

Ultimately, our dual list of objectives must be combined into one. Moreover, the list must be self-consistent. In order to settle inconsistencies, we must be prepared to sacrifice some objectives for the sake of others. There is no general rule in this case except to try to always sacrifice less important objectives for the more important ones. Here are two illustrations out of my own experience.

In the early stages of planning to build a Morse code typewriter, my objectives list included the following items (among others):

1. Use a keyboard (on hand) to save money.
2. Use a series of toroid coils to set the code-generating flip-flops in accordance with a pair of articles I had read.
3. Do not use a diode matrix to generate the code since that required too much time and soldering.

However, the switches in my keyboard contained 22-ohm resistors, and this was enough resistance so that sufficient current was prevented from passing through the toroids to set the flip-flops. Fig. 5-1 illustrates how I solved this part of the problem. I had some choices. I could spend money on a new keyboard, I could cut open the switches and remove the resistors, or I could wire a diode matrix board. Since



(A) The problem.

(B) The compromise solution.

Fig. 5-1. An example of a problem and a compromise—diodes save the keyboard at the expense of the toroid coils.

I did not want to waste a good keyboard and since I did not think the switches would be reliable if cut open and reglued, I finally gave up the less important objectives (Objectives 2 and 3) and wired the matrix board.

Another compromise of objectives involved time. While designing a low-power standby transmitter for the ham shack, my original objectives included having a vfo contained in the same cabinet with the rest of the components. However, I needed the transmitter for a period of time when I had scheduled my main station equipment for a factory alignment, all to coincide with a vacation. I knew I had had not gotten far enough in the design process with the vfo to make my own deadline, although the transmitter, with its crystal oscillator which would serve as a vfo buffer as well, was ready for building. Since I had a good stock of crystals, I let time be an important factor and finished the crystal-controlled rig in time for a vacation workout. Instead of letting this compromise get me down, since I really did want a self-contained unit, I have since turned it to my advantage. Several different vfo designs have been tried with the transmitter, and I would not trade what I have learned from the experience for a perfect rig.

The purpose of these examples is to not only illustrate the process of compromise on objectives, but to suggest as well that unlike a manufacturer, many of the compromises that the home designer must make involve very personal factors. Money, time, skill, parts that are on hand or accessible, all of these and more determine our ultimate objectives.

At the same time, the process itself is not at all unlike what a manufacturer does. Executives of a corporation may decide to produce a product meeting a certain market demand. Through a process of give and take, they will develop some product specifications, along with inquiries as to what is possible. Engineering departments will respond in answer to the questions, and this may modify the specifications. Then the engineers start developing what it takes to have a product which meets the specifications. Moreover, money is just as important to a manufacturer as to the individual designer-builder. So too are deadlines, parts inventories, and dozens of other factors which have analogies to our situation as individuals. Perhaps the key difference lies in the fact that companies design through the interaction of many individuals. Our contacts are more limited, sometimes consisting only of the people we meet through the articles and books we read. Even at a distance, however, these writers help us set objectives.

The goal of the objectives list is to help us to be clearheaded about our objectives and the decisions we make. Every change we make in the list will change what we build. As the list grows and changes, we will find ourselves becoming more precise in knowing what we want. The design objectives will eventually form a list of specifications for the equipment we want to build. Clear thinking at this stage will save many a headache later on.

CIRCUITRY BLOCKS AND MAZES

Because many equipment articles begin with a schematic diagram, we can easily be tempted to make a mistake at this point. Having set our objectives for a project, it seems natural to leap into the search for circuits which will achieve them. We quickly become lost in a maze of by-pass capacitors, coil-winding instructions, integrated circuits, coupling and fan-out methods, and other details of individual circuits. Often, we spend so much time on components that we lose sight of our objectives altogether. As a result, when we do get the equipment working (if we get it working), it does not do all that we had hoped it would.

To avoid this problem, we need to insert a major step between the time of deciding upon our objectives and the time of seeking out the individual circuits which will make up the electronic aspect of our equipment. The block diagram, mentioned in Chapters 3 and 4, is the intermediate step. It will provide a means of confirming the decisions we made as to the objectives or those we will make when making revisions. It will also help us to clarify our thinking and make good decisions concerning the internal functions of the equipment that we design.

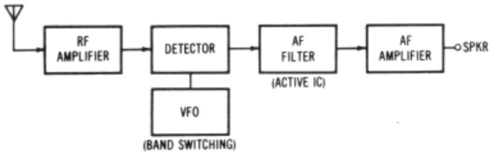
The block diagrams that we drew in acquiring information for our idea book emerged, in many cases, from examining the schematic diagrams of equipment and then supplementing those examinations with information from the text. In the case of actual design, we turn the process around. From the block diagram that we develop at this stage, we shall select the circuits to perform the functions indicated by the individual blocks.

Blocking out circuitry by stages is just one more "paper" step in the process of design. For some, almost every "paper" step seems to be a useless stumbling block that gets in the way of building. However, this step is far from useless. For almost every type of equipment—whether its purpose is communications, entertainment, computation, or testing—there are several ways to accomplish the same general set of objectives. Numerous decisions must be made concerning the best way to arrive at the objectives, and these may depend on many factors which involve skills, desires, and circumstantial limitations. Every decision we can make before buying parts will be one that saves money. In addition, every decision made now will make clearer to us just what goes into the piece of gear we are building. In turn, this understanding will help us operate and maintain the equipment more effectively.

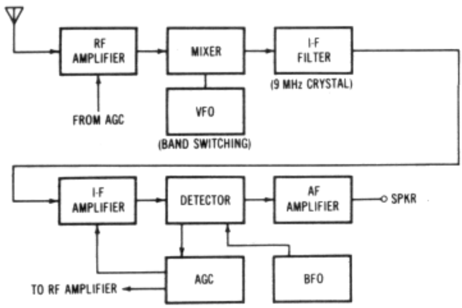
To illustrate the range of decisions a block diagram can help us make, let us examine Fig. 5-2, which consists of three block diagrams for a communications receiver for the amateur radio bands. Each is suitable for the generalized objectives of ssb and cw reception. However, from the information given in the blocks, we can see that all three diagrams are distinctly different. The top design is a direct-conversion receiver, and is perhaps the simplest of the designs from the perspective of building. The middle design is a single-conversion receiver with a 9-MHz intermediate frequency. The difference between these two designs is not just one of simplicity versus complexity. There are functional possibilities and limitations associated with each type of design. For example, the direct-conversion design is often troubled by audio images—that is, signals an equal distance in frequency on the other side of the vfo frequency. High stage gain tends to make such designs susceptible to hum from an ac power source. Selectivity, except for front-end band-pass filters, must be accomplished at audio frequencies. Only with difficulty is agc designed into direct-conversion receivers.

The design features which become more apparent when the functions of the receiver are blocked out may or may not be consistent with your list of objectives. If the design limitations noted are inconsistent with what you want from a receiver, then you need to turn to another internal arrangement to achieve the desired reception. The middle design (Fig. 5-2B) provides an alternative that meets most of the problems of direct conversion. It is less troubled by images, less susceptible to hum, capable of filtering at rf frequencies, and is a natural for using agc. However, so is the design shown in Fig. 5-2C, a double-conversion receiver with a first if in the 5-MHz range and a second if of 455 kHz.

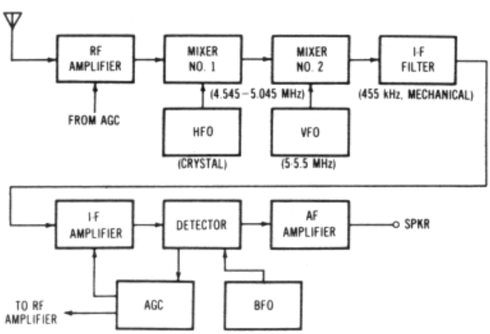
Comparing the designs of Figs. 5-2B and 5-2C leads to consideration of further functions. Stability of the single-conversion receiver may suffer from the need to bandswitch the vfo. Also, the design may



(A) Direct-conversion receiver.



(B) Single-conversion receiver.



(C) Double-conversion receiver.

Fig. 5-2. Block diagrams of receiver conversion schemes.

be prone to feed-through of 9-MHz signals. The double-conversion system, on the other hand, requires a series of expensive crystals to change bands. As specified, it also calls for mechanical filters that usually cost more than crystal filters. The decision to choose one design over the other may rest on many different kinds of factors. Cost is one possibility, and what parts are on hand or easily obtained is another. Further, the decision may rest on your confidence in dealing with various types of circuitry; in this case, your confidence in being able to tame a bandswitching vfo.

The examples given in Fig. 5-2 only sample the available techniques for designing receivers and do not go into other techniques such as up-conversion and triple conversion. They do illustrate what we can accomplish easily with simple block diagrams. First, we can set a design whose internal functions are consistent with the overall dynamic and static functions that we set for the equipment. Secondly, we can assure ourselves that the functions will achieve the objectives. Notations of frequency and other information placed around the blocks in the diagrams aid in that process. Thirdly, we can decide among alternative ways to achieve the same set of objectives, thus picking one which suits our skills and limitations, our needs, and our desires.

ELECTRONIC AND MECHANICAL FUNCTIONS

Before getting too far into the decision-making process for designing equipment, we should give some attention to the fact that there are two types of functions which are accomplished in equipment—the electronic and the mechanical. Fig. 5-2 showed only the electronic functions of the receiver designs. Nowhere in the diagrams did we mention the antenna terminals, the vfo dial, the rf and af gain controls, the bandswitch, the filter switch, the mode switch, the speaker, or the headphone jack.

The importance of the mechanical functions of a piece of equipment can often make the difference in the selection of designs. Therefore, you should depart from what you see in most magazines and books and incorporate some mechanical elements in your block diagrams in accordance with the ideas in Chapter 4. Choose a different type of symbol for mechanical functions. If you use the standard rectangle for the electronic functions, then a circle may be right for illustrating the mechanical ones.

The proper starting point is a pair of lists, one for each type of function. Electronic functions will vary with equipment type. Mechanical functions will vary also, but to a lesser degree. Switches, readout elements, variable controls, and jacks constitute the main elements in the mechanical list. The significant thing to list, however, is just where they will occur. Do not specify just an af gain control or a frequency control, but specify as well what sort of control may be involved. The af gain can be varied in steps using a switch or potentiometer. Frequency can be varied using a variable capacitor, a slug-tuned coil, or a potentiometer that changes the voltage across a diode. Each of these means will have different effects both on the circuitry used and on the method of construction. Coils and capacitors require a rigid panel construction or subcase construction, whereas, the variable-capacity diode needs no mechanical connection to the front panel at all.

Converting your lists of electronic and mechanical functions into a block diagram can assist you in thinking through a design. Figs. 5-3 and 5-4 illustrate the point with two diagrams of a fairly simple transmitter. Fig. 5-3 shows a bandswitching vfo and transmitter. Note the number of switched elements, namely all the tuned circuits throughout the transmitter. Many of the elements are switched at medium to high impedances. This necessitates that the builder use care, since stray capacitance can detune circuits, create undesired coupling, and call for special work in shielding the elements of the bandswitch to isolate the stages. Fig. 5-4 shows a transmitter with the same capability. The difference lies in the use of a mixing vfo system and separate amplifier chains. The output of the vfo and the output of the final amplifier are switched at low impedances, which creates fewer problems of undesired coupling due to the lower voltages for the same power level. The only other switching section places the V_{cc} line (a dc voltage) on the proper amplifier chain. The cost of this option is the additional solid-state devices. For most low to medium (say, 5 watts) power stages, this cost is far under the cost of the complex switching method used in the drawing of Fig. 5-3. Also, construction ought to be easier since little shielding is needed.

MAKING DECISIONS

Both the designs in Figs. 5-3 and 5-4 have good potential for becoming successful projects. For the beginning designer, I recommend the scheme in the diagram of Fig. 5-4. Some of the reasons for this recommendation will take us beyond this chapter, but perhaps a small digression may make a point. Switching is one of the most difficult facets of rf circuitry to design well. It requires special attention to the parts layout, shielding, and mechanical construction in

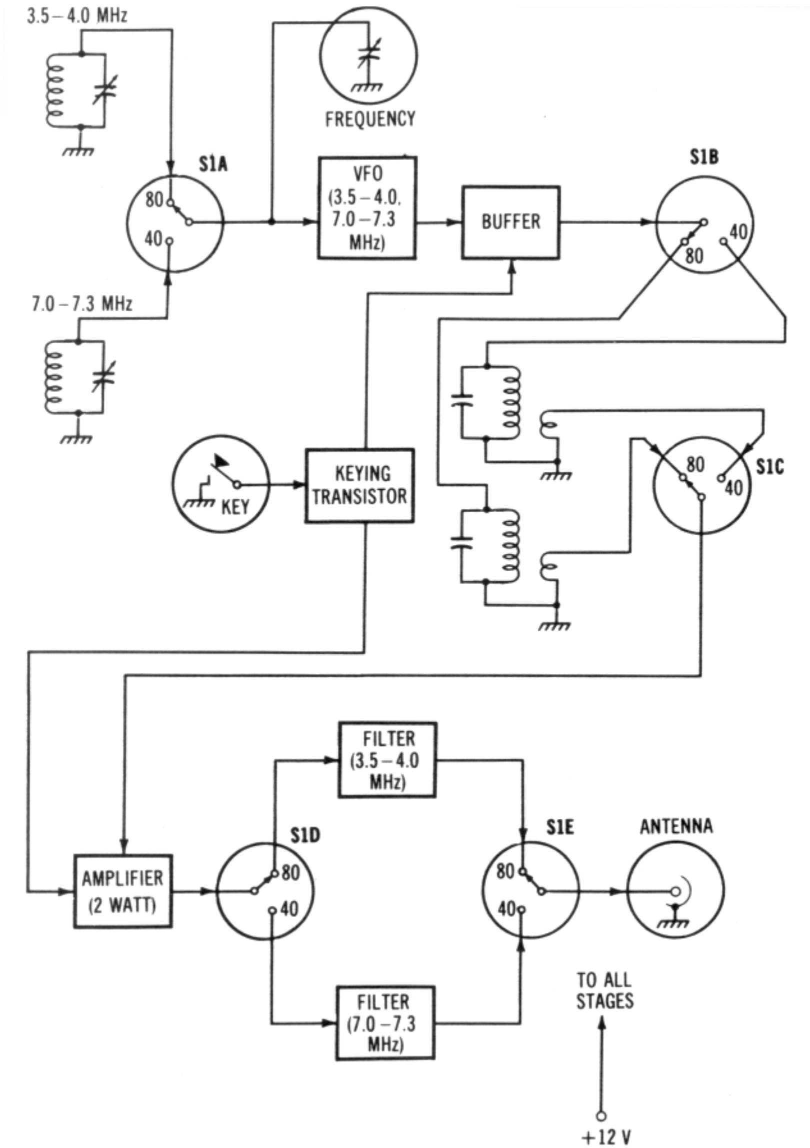


Fig. 5-3. Block diagram of a standard design low-power two-band transistor transmitter.

order for it to work successfully. Also, complex bandswitching requires that the builder test a given electronic assembly for every desired frequency band. The system in Fig. 5-4 allows the builder

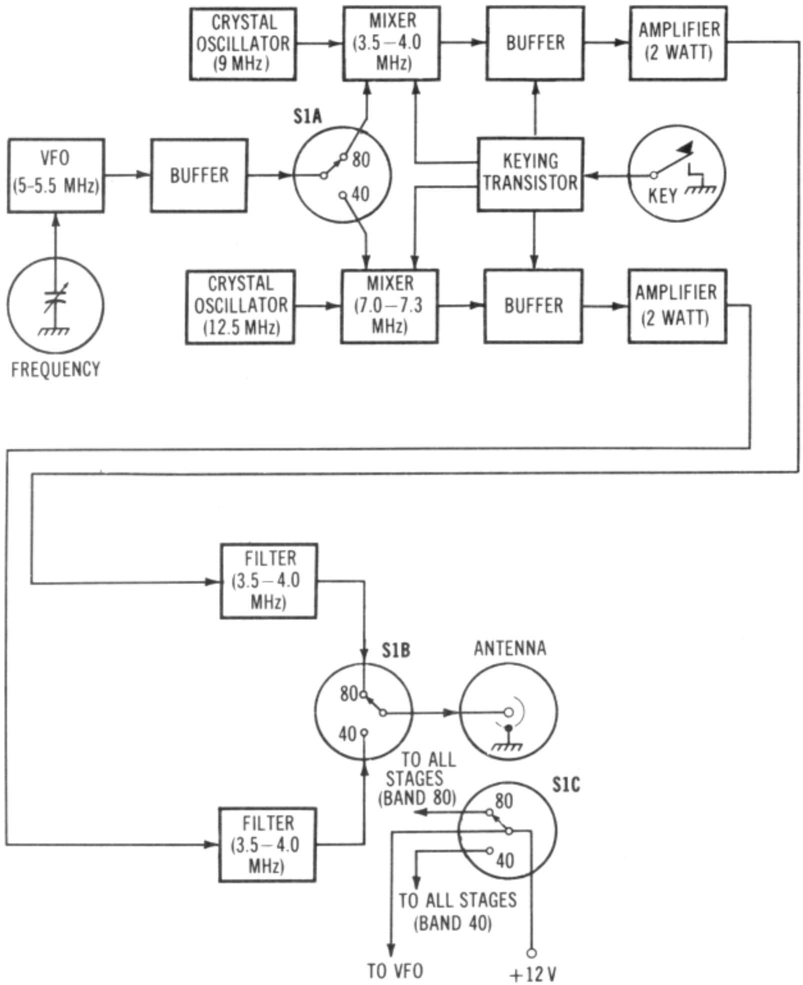


Fig. 5-4. Block diagram of a transmitter that is similar to the one in Fig. 5-3 but with simplified switching.

to design and build the equipment one band at a time. Once a band has been adjusted and tested and works well, it will operate even if another band gives trouble. In fact, one does not have to repeat the same design on each band. Since transistors tend to vary in gain with each band, separate designs for each may be desirable. Add to all of this the ease of construction, and my preference is more transistors and biasing resistors and no switches.

Similar considerations apply to other types of equipment. Articles often show single circuit boards for complex projects such as computer terminals. If possible, the beginning designer should break these down by functions into smaller boards. Each one can then be built and tested separately. Multifunction test equipment shares similar considerations, with the addition that it is often better to begin your personal designing of test equipment by separating the functions in order to achieve the proper operation of each. In each of these cases, you can combine the functions into one cabinet without increasing the size of the unit by too much over the size of multifunction units.

The fundamental principle is that as a beginning designer, no matter what your experience is in reproducing the designs of others or in kit building, you should attempt to achieve a simplicity of individual design and let complexity emerge from combinations. At a more experienced level (which your own confidence will let you know), the complex design with intricate switching within the functional blocks may be a challenge. But in the early stages, treat it as a challenge of the future.

Since many of the pieces of equipment in our idea books will be of advanced complexity, we often have to work an extra amount in simplifying our designs. This is where the block diagram aids us the most by enabling us to analyze functions on paper rather than with burned-out components. The Wright brothers are reputed to have said that they spent so much time with design drawing because what would work on paper would work when built. The same thought applies here. Even so, do not freeze all your decisions at this stage. We have to select the circuitry for the project next. That too is a paper task and, thus, we still have time to change our minds.

Chapter 6

Step 3—Circuit Selection

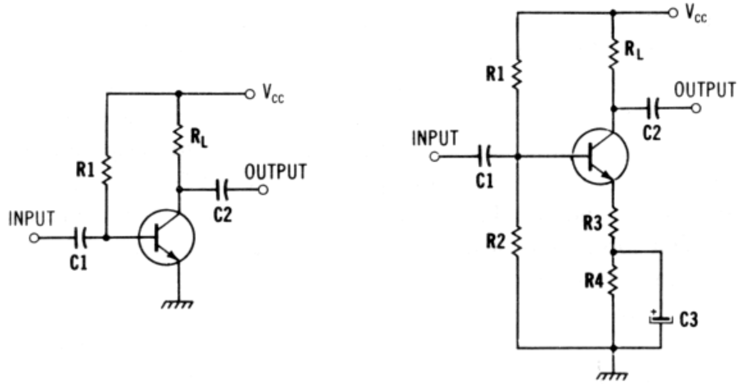
By this time, we should have decided firmly, but flexibly, upon our design objectives and on the block diagram method by which we will achieve those objectives. The time has come to fill in the blocks with circuitry. Once more our idea books will receive a workout, and so too will other sources of information that we may have.

In the idea book, we have noted circuits that interested us in the course of our reading. When we first felt the urge to design and build, we transferred all the circuits of possible interest from the idea book to the project notebook, usually by moving pages from one to the other. Our job now is to make some intelligent decisions about which circuits to use in the project.

Not all the circuits we may need will be in the idea book. We overlooked many circuits in our reading just because they seemed too common to need attention. Suppose we are building a receiver. Mixers, rf amplifiers, vfo's, and if amplifiers probably abound in our notes. However, we may be thin on circuits for audio amplifiers, bfo's, and agc circuits. Other circuits may be missing because they never interested us prior to the present project. For example, the idea of including fm reception in a projected receiver may open a new interest in ratio detectors. For whatever the reason, we may have to do some research before being in a position where we can make our selections.

The best place to research is in any of the major handbooks. If the right types of circuits are not available there, then we may need to look over the shelves of a local library or a radio store that has a good collection of books. There are many special books which provide circuit examples for special types of projects from communications equipment to computers. Besides providing the missing links in our circuit collections, they can also expand our knowledge of subjects related to our project. The increase in knowledge may result in some rethinking of objectives and block functions, but this is natural. As previously noted, paper changes are easy at this stage of the design process.

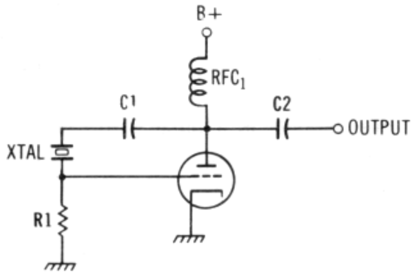
In the process of research, we should not become too enamored with new, tricky, or unreliable circuits. Most handbooks contain a large number of tried and tested circuit examples. For the beginning designer, these should be the mainstay of the project. If we can rely upon each individual circuit, then the problem of getting all of them to work in unison for a desired set of objectives will be simplified greatly. Notice that this is not necessarily advice to use the simplest circuits, in number of components or in terms of the internal construction of active devices. Reliability and simplicity of structure or components do not always mean the same thing. Fig. 6-1 shows two



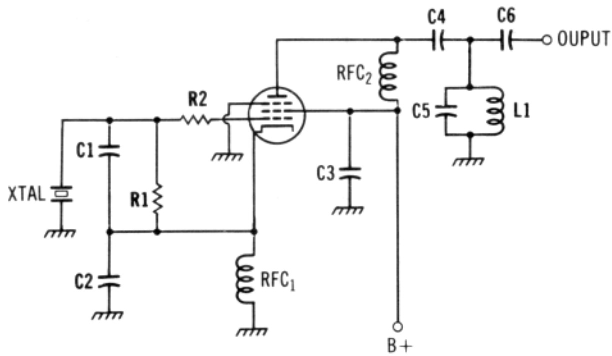
(A) A potentially unstable amplifier. (B) A stable amplifier.

Fig. 6-1. Sample circuits used to distinguish simplicity from reliability.

audio amplifiers using transistors. The amplifier circuit in Fig. 6-1B is the more reliable circuit despite the greater number of external resistors; in fact, it is more reliable because of them, since the circuit in Fig. 6-1A can turn out to be unstable. Likewise, of the two oscillators in Fig. 6-2, the one in Fig. 6-2B can be called more reliable in having a greater output for driving other tube stages. The simpler oscillator (Fig. 6-2A) must split its output between feedback and drive for the next stage, a problem the electron-coupled oscillator



(A) A Pierce oscillator.



(B) An electron-coupled oscillator.

Fig. 6-2. Sample oscillators that distinguish between simplicity and reliability.

effectively overcomes. The net result is this—think about reliability in terms of what you want a circuit to do in the application that you have in mind for the project, not in terms of pure simplicity. Translating this thought into a rational selection process is what this chapter is designed to help you do.

BASIC QUESTIONS TO ASK ABOUT CIRCUITS

As in all design work, asking the right questions in the right places makes the decision process easier and more informed. The following group of questions asks most of the important questions you can ask about circuits. Since there are now many types of devices, from the simple transistor to the complex integrated circuit, the group of questions cannot be exhaustive. However, by basing the questions on the basic amplifier circuit, we can provide a concrete example which you can adapt to other types of circuits, whether they involve different devices, such as ICs, or whether they involve different functions, such as oscillators or mixers. Just view this group of questions as a starter.

First, examine Fig. 6-3. It is a basic solid-state amplifier used for rf purposes. Initially, no information is given other than the configuration of components. As we ask the following group of questions, we will fill in the information we acquire, while the text will provide some hints on the significance of that information.

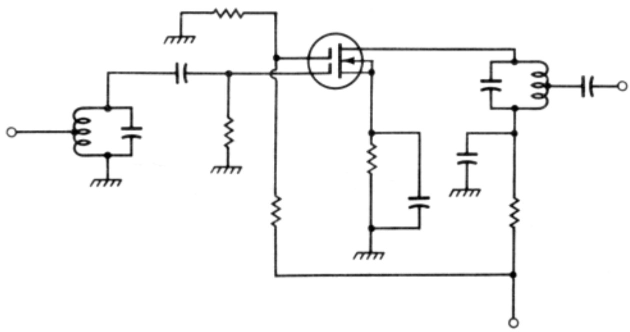


Fig. 6-3. The basic configuration of an rf amplifier.

Drive

What drive level is required for this circuit and does it require voltage only, or driving power? Since the device in this circuit is voltage driven, no power is required other than that needed to make up for losses in the passive components of the input stage. This circuit is capable of handling a fairly wide range of input voltages—from a few millivolts to about one-half a volt peak-to-peak.

The answer to the question of driving power tells us much about what the preceding stage of our equipment must be able to do. Most low level vacuum tube and FET stages require driving voltage only. Power stages and most transistor circuits require that both voltage and current be supplied to the signal input of the stage. This requires that we know something about the function of the stage and the types of devices available for use. Book and magazine articles and their associated schematic diagrams rarely give anything more than the signal voltages at certain points in the circuit, if they give anything at all. We may have to do some additional reading in order to make some educated guesses. However, articles on power amplifiers are the exception and these often provide both voltage and current values for the control element of the device; that is, for the base of a transistor or the grid of a tube. From this and other information about the circuit, we can infer the needed drive power.

Devices

What device is used in the circuit? The type of device used in the circuit tells us much about other circuit requirements, such as drive, output level, power-supply voltages, possible operational and adjustment difficulties, and cost. The device in the amplifier of Fig. 6-3 is a MOSFET, specifically a 40673 dual insulated-gate (protected) device. The drive needed is low and is voltage only, since an insulated gate effectively draws no current. The output will be good since it is a high-gain device. It operates from a 12-volt supply with good results and allows the builder to have a stable reliable amplifier.

Other devices tell us other facts. As we become familiar with available devices, we begin to think automatically in terms of associated properties. Op amps and ±15 volts are a natural pair. TTL ICs and +5 volts regulated are another. For tube-type power amplifiers, possible vhf parasitic oscillations are just as natural a thought as possible low-frequency parasitics are to transistor power amplifiers. Each of the devices we encounter also has a price tag which may influence our decision to use a circuit. Some may be difficult to obtain. Some may have readily available substitutes; for example, general-purpose audio transistors. All of this information tells us much about the ease with which we may reproduce a circuit. A few circuits may, for special reasons, be worth reproducing even if it is very difficult to do so. But most should fall into the easy category if they are candidates for the equipment that we design.

Biasing

What voltages are needed for biasing, and what current levels are required for each bias point? In the present case, a single 12-volt supply will fill our needs. Current requirements are low. Gate 1 requires virtually no current. Gate 2 is fed from a voltage divider, and the current it draws can be calculated via Ohm's law from the resistor values. The source and drain currents should be close in value and should amount to just several milliamperes.

The sum of all the answers will tell us what the total circuit will draw from the supply. Adding together all the requirements for each of the circuits will tell us the total power requirement for the equipment. Also, add in the panel light requirements and other features that do not directly reflect the operation of the circuits. Then, add a minimum of 50% as a safety factor, since every piece of equipment will have power losses through passive components which we fail to take into account in our addition. The power supply itself will have some losses.

Not only are the total power requirements important, but so too are the types of voltages that we will need. If we combine MOSFETs, TTL ICs, linear ICs, and op amps in the same device, our power supply grows in complexity due to having to provide many different voltages at differing current levels. These are not insurmountable design problems, but they do present us with a choice—are there acceptable circuits that use devices which permit a single power-supply design or does the selection of the right device for the right place require us to think in terms of a complex supply? We may be forced to some kind of compromise, as, for example, limiting our design to devices that are able to operate with positive voltages of 12 volts or less. This is a common compromise for equipment designed for use in automobiles.

Biasing needs also tell us something about the filtering and regulation requirements of our power supply. High-gain stages with low input power or voltages require well-filtered power supplies to prevent hum pickup and amplification. Power stages, especially for voice communication, demand well-regulated supplies to hold distortion to a minimum. Oscillator stages require an even greater regulation to prevent frequency shifts as the load changes. Thus, it often pays not only to note voltages at bias points, but to note any special feaure about the voltages as well.

Fig. 6-4 sums up the information we have acquired about our circuit so far. Note that even at this stage, we are setting demands on other parts of the total design.

Output

What output level and type will the circuit provide? The circuit in Fig. 6-4 provides a low power level but appreciable voltage compared to the input level. In general, then, it is most useful for driving another low-powered stage, one that is either voltage or power driven.

Output levels may be given either in terms of voltage or power, depending on the function that a circuit is performing. Usually, rf power amplifiers have their outputs specified in terms of power. Since this power level is given in conjunction with a certain impedance, we can calculate the rms value of the voltage using Ohm's law, and from

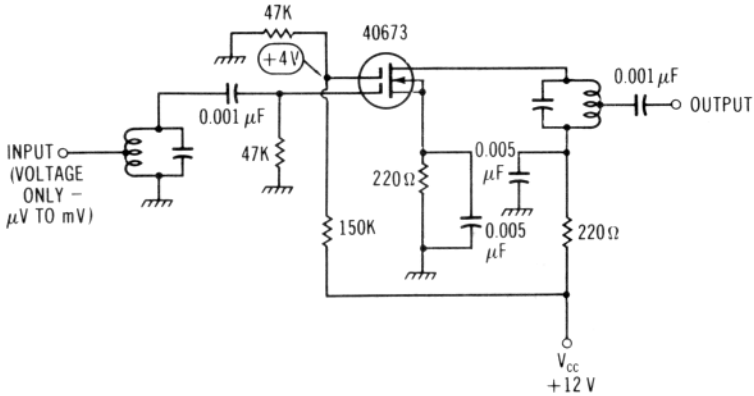


Fig. 6-4. An rf amplifier circuit containing only part of the required information.

this we can get peak and peak-to-peak voltages, if we need them. Low-level stages usually do not provide sufficient power to make this a useful specification. Thus, we may find an rf voltage reading on the schematic, in a chart, or in the text. If not given, we can usually guess at a "ball-park" value from what we know of the device or the stage gain. This information, in whatever form it is given, is useful in relating the circuit to those that follow or to the ultimate load of the equipment that we are designing.

Impedance

What are the input and output impedances? In our circuit, the input impedances are very high, and the output impedance is moderately high. For most uses to which this amplifier would be put, this information is enough. For example, it is enough to tell us that we may directly drive another high-impedance device with little loss. If we want to drive a low-impedance device, we will have to insert a step-down transformer or other impedance-transforming mechanism. Converting the tuned-circuit coil into a transformer, with a few turns over the cold end of the coil, might do the job in this case.

The most careful job of impedance matching must usually be done when impedances are low to medium. The author of an article on a circuit might have driven an FET, whereas you may contemplate driving a transistor. The circuit difference may require impedance matching. Therefore, if your use of a circuit is not the same as that of the author, you should be very conscious of the output impedance of the circuit and the input impedance of the next one. In some cases, as with higher powered transistor amplifiers used for rf frequencies, impedance matching must be carefully done. The same holds true with speakers and high-fidelity amplifiers.

Components

Are there any special components in the circuit? The idea of special components may be relative. Toroid inductors are special for some builders, natural for others. Various types of ICs—mainly the ones we have not yet used in a circuit—may be special for all of us. More generally, the special component may be anything in the circuit from the active device to the biasing network. In this circuit, the only special component is the toroid coil in the output circuit (Fig. 6-5).

The thing that makes a component special is whatever it is that calls it to our attention. Its value may be critical. It may be part of an unfamiliar technique. It may be costly or hard to obtain. It may be crucial to proper circuit operation. Crystal or mechanical filters are special since they represent major expenses in any project. Surplus components are special since they may not be available after a certain period of time. The toroid coil was noted in the circuit of Fig. 6-5 because it represented a component which we might want to change if, say, a slug-tuned coil form is on hand. The coil winding would have to be recalculated and, in general, we should not expect as high a Q as with the toroid coil. The questions raised by the components of this circuit are not serious ones, but we would have to answer them should we choose this circuit. Since we have added considerable data to our circuit diagram of Fig. 6-4, let us sum them up on the drawing of Fig. 6-5.

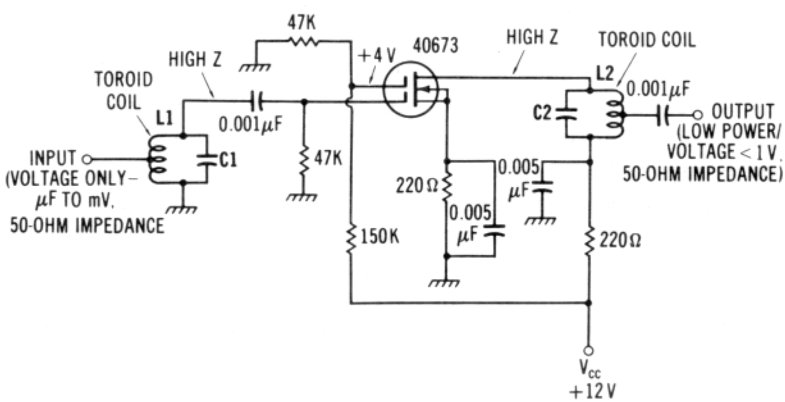


Fig. 6-5. The circuit of Fig. 6-4 with additional information (14 MHz operation).

Tolerances

How rigidly are components specified? Outside of the tuned-circuit values, there are no rigidly specified components in the circuit of Fig. 6-5. In fact, almost all the values can be varied by 10% to 20% without changing the performance of the circuit very much. In addition, the tuned-circuit values are also changeable as long as a desired resonant frequency is obtained.

However, in many other types of circuits, components may be closely specified. Builders of solid-state vfo's often specify polystyrene capacitors for the feedback voltage divider; these capacitors have excellent temperature stability. In some amplifiers, the use of toroid coils may represent a rigid specification in order to make use of their "self-shielding" properties. In other cases, the builder may only use them because they are on hand. Some of the potentially rigid specifications include component value, voltage and/or current rating, construction or material, size, and placement with respect to other components in the circuit. A note should be made of any of these specifications if they are important to the circuit.

Associated Circuits

Are buffer or isolation stages associated with a given circuit? If they are, do not omit them without first examining their function and necessity. In our circuit, we need do nothing, but with many other types of circuits, this may be an important consideration.

Oscillators often use buffers for both isolation and for impedance transformation. In amplifier trains, especially when operated on the same frequency throughout, untuned buffers that follow the low-power sensitive stages can reduce the chance of feedback becoming an oscillation. These considerations take on new significance with the growing shift to fully solid-state equipment. Transistors and resistors are inexpensive and, thus, cost is no deterrent to incorporating buffer stages. The same could not be said for tubes, where the heat per unit also discouraged any extensive use of buffer stages.

In general, design thinking has changed with the transition from tubes to transistors. Heat, size, and power requirements for tubes generally dictated that we used the fewest number that would perform the essential functions. In contrast, transistors are small, light, cool, low in power demand and inexpensive. Therefore, we need not operate them at maximum gain. Instead, we can use combinations of transistors to ensure that a circuit operates over a needed range, whether the range is a frequency spread, a span of agc voltages, or whatever. For example, tube circuits often used a diode-derived agc circuit directly applied to the amplifier grids. Solid-state receivers might use a combination that includes a diode, an IC, and a two-transistor dc amplifier.

The moral is that you should select a circuit because it will reliably perform its intended function, not because it appears to be simple in terms of the number of components. This advice may seem to be at odds with the last chapter, where it was suggested that simplification of a certain kind is desirable. In fact, the two points go hand in hand. If you simplify the overall unit complexity, you are freer to select more complex circuits (although reliable ones) and still have the best chance that the circuits will work as intended. This fact results from reducing the number of possible external causes of circuit misoperation. There is no precise rule to tell us when an overall design, as shown in a block diagram, is too complex, or when we have chosen too simple or too complex a circuit. The procedure that must be followed is to examine your own capabilities with respect to making circuits work and, also, with respect to putting them into a complete pattern to make up the entire piece of equipment. Remember that although equipment manufacturers may give us many good ideas for our own designs, we do not have to copy their complex techniques of putting the maximum number of functions into the smallest space.

Since the questions asked under "Tolerances" and "Associated Circuits" have added no new information to the amplifier circuit we were questioning, Fig. 6-5 gives us the whole story that we need to know, when deciding whether or not to use the circuit in our project. Questions similar to the preceding eight questions will apply to oscillators and mixers. Digital ICs will require a somewhat different set of questions, but the questions for linear ICs, especially in amplifying, oscillating, and mixing applications will be much the same. The TTL and CMOS devices, presently the two most common types of digital ICs, have fairly standard supply-voltage requirements, few impedance concerns, and little associated circuitry. However, they do require that attention be paid to details such as fan-out (the number of devices to which the output is fed), current sinking in each state (if the device drives a nondigital load, such as a lamp), timing requirements (especially for sequential events), and forbidden states (two or more incompatible inputs). With these thoughts in mind, the amplifier list is easily modified to handle these devices or any others that you may encounter. The basic question to begin with is this—"What do I have to know to make the circuit work correctly and reliably?"

MODIFYING CIRCUITS

In some instances, we may be able to select one of the circuits in our project notebook and apply it directly to the equipment we are designing. However, in most cases, we will have to modify the circuit to some extent to make it suitable for our purposes. The question which comes to mind is how far may we modify a circuit and still hope that the circuit will do its intended job.

To some extent, we can modify extensively without concern; and as a matter of course, we often do so in the process of building. Let us use Fig. 6-5 as an example. In building the circuit, we discover that we have no 150,000-ohm resistors, so we substitute a 180,000-ohm resistor. If we run out of 0.005-μF capacitors, we might try a 0.01-μF unit. The idea of replacing the toroid output coil with a slug-tuned unit was discussed earlier. This requires that we either calculate the windings or experiment until we can resonate the coil on the desired frequency with some value of capacitance.

These examples of common modifications strongly suggest that we should feel free to modify. However, there are limits to this freedom. So far, most of the modifications called for parts that are within the tolerance limits of the circuit itself. Suppose we wish to make other modifications, such as lowering the gain of the amplifier or changing its operating frequency by a great amount. Can we achieve these modifications with confidence that the circuit will still work?

The answer will depend on a combination of factors, which we can summarize in a series of questions:

1. How much do I know about the device and the circuit?
2. Do I have some specifications on the active device?
3. How much math am I willing to do?
4. Am I willing to check out the modification experimentally before designing it into the unit?

Few of these questions will have yes-no answers, but they do indicate a procedure that we can follow to determine whether or not it is worth our trouble to try to modify a circuit. Again, let us use Fig. 6-5 as our starting point. With the values given, the amplifier should operate at 14 MHz, if we choose the correct values of L and C for the output circuit. Our project now will be to determine whether we can modify the circuit to operate at 1.8 MHz and, also, reduce the stage gain.

Our knowledge of amplifier circuits in general tells us that certain changes must be made. We should raise the value of the by-pass capacitors. The coil and capacitor require redesign to resonate at the desired frequency. Since the band width of 160 meters is a greater percentage of the frequency, we may want to lower the coil Q. This will also lower the stage gain a bit. These changes require only a general knowledge of amplifier circuitry and, as yet, have not attacked the active device.

Specifications for the 40673, and similar MOSFET amplifiers having two gates, tell us that a small positive voltage on the second gate yields the greatest gain. From this, the way to decreasing stage gain is clear—reduce the voltage on Gate 2. One way to do this is to choose new values for the voltage-divider network so that a smaller positive voltage appears at the gate. This calculation requires only the simplest arithmetic. Since the gate effectively draws no current, the two resistors will simply provide a voltage ratio between them. For still lower gains, we may need to place a negative voltage on Gate 2.

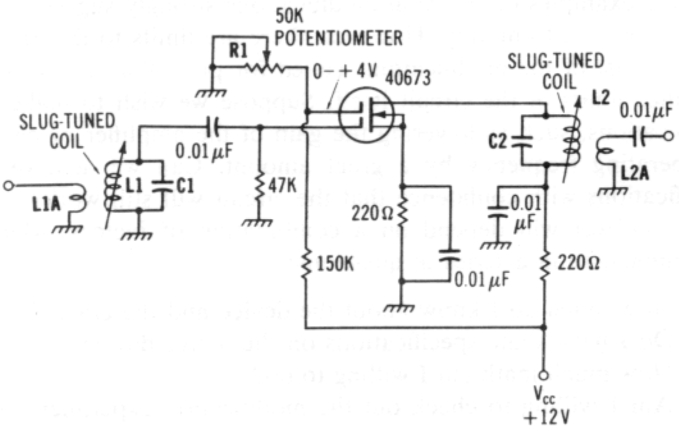


Fig. 6-6. Circuit in Fig. 6-5 modified for 1.8 MHz operation.

Fig. 6-6 shows the proposed changes. Before using such a circuit in a design, we should verify that it will work. For this, we have two methods. The first involves checking through our idea books and handbooks to see if such a circuit has been tried by others. The second method is more direct—build and evaluate a test version of the circuit.

To do this, we may want to replace R1, in Fig. 6-6, with a potentiometer in order to find the value that yields the desired gain. If everything works on the test bench, then it should also work out in the design.

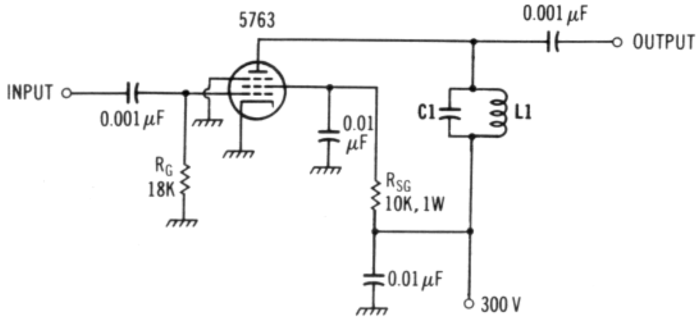
Not all circuit modifications are as simple as this one. Some require more calculations in order to figure the values we must use. Some phenomena only show up in certain frequency ranges and, therefore, our bench model of the circuit may give us a few surprises. We may often overcome these by experimenting with values but, in each case, we should try to understand why these values work. This aids reliability by providing us with the knowledge that will later help us troubleshoot the circuit.

There comes a point, however, when the calculations we must make may extend beyond our mathematical abilities. Then, we are faced with a choice—either choose a circuit which does not require such extensive mathematics or learn the math we need to know. (There is a third choice, but we cannot always rely on our friends who have a talent in mathematics.) Whichever choice you make, do not feel you are letting down on the design process. Like metal work, soldering, and panel painting, math is a skill. If we do not have it, we compensate by choosing another route to achieving our design goals. And, like any of the other skills, we may gradually acquire more skill with the more designing and building that we do.

DESIGNING CIRCUITS

Just as there is no hard line between selecting and modifying a circuit, so too is there no hard line between modifying a circuit and designing one. It is all a matter of degree. The entire process is not unlike the process of designing equipment.

Circuit design is close to circuit modification in this way. Suppose we choose a type of circuit that we wish to use, say, a Colpitts oscillator or a class-A amplifier. By using the specification sheets for the active device that we choose, we can calculate the values for all the external components. This is one form of design that is fairly common, and many formulas and collections of formulas exist to permit us to do the job. Fig. 6-7 shows an example of a class-C amplifier for 14 MHz that uses a 5763 pentode tube with control-grid self-bias. The task of design in this case is not difficult, since all the calculations are easy. All of the data is available from tube tables, and there are established circuits in handbooks against which to check our results.



FROM TUBE TABLES:

$E_{PLATE} = 300\text{ V}$

$I_{PLATE} = 50\text{ mA}$

$E_{SG} = 250\text{ V}$

$I_{SG} = 6\text{ mA}$

$E_G = -42.5$

$I_G = 2.4\text{ mA}$

$R_{SG} = \dfrac{E_{DROP}\text{ OF } 50\text{ V}}{I_{SG}\text{ OF } 6\text{ mA}}$

$R_{SG} = \dfrac{50\text{ V}}{0.006\text{ A}}$

$= 8333$

$= 10\text{K, APPROXIMATELY}$

$P = 50\text{ V} \times 0.006\text{ A}$

$= 0.3\text{ W (USE 1 W)}$

$R_G = \dfrac{42.5\text{V}}{0.0024\text{ A}}$

$= 17708$

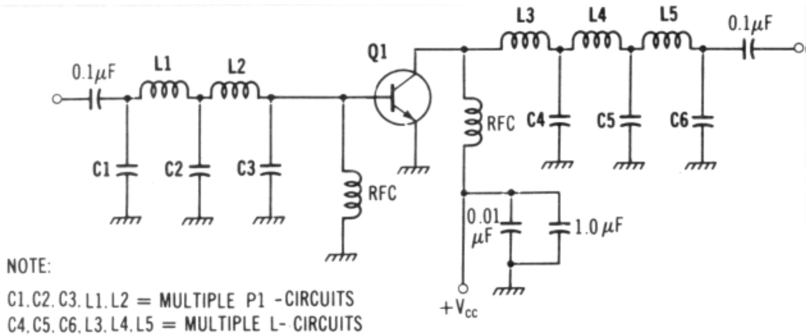
$= 18\text{K, APPROXIMATELY}$

Fig. 6-7. Example of circuit design using readily available data from handbooks.

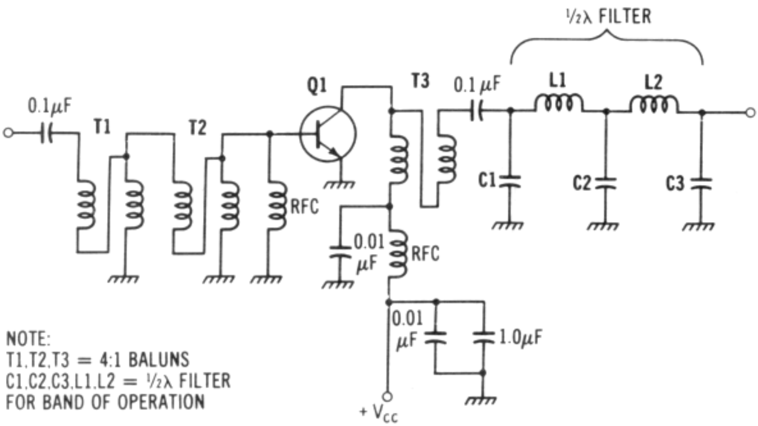
In fact, the work of design is scarcely more than what we did in modifying the MOSFET amplifier earlier in the chapter.

Design becomes more difficult when one or both of two things happen. First, if the techniques we wish to use in a circuit are of uncertain reliability in our initial conception, the calculations we make, however easy and sure, may not yield a usable circuit. This proved true in early designs of moderate power-transistor amplifiers for rf use. Traditional tube techniques, such as the use of pi-type output networks, did not yield maximum efficiency and stability. Many circuits have since been replaced with circuits more suited to the low Q of transistor power amplifiers (low-voltage, high-current, and broad-banded devices). For example, the use of broad-band balun input and output circuits is common, and the harmonic content is controlled by subsequent half-wave filter sections. Fig. 6-8 shows the contrast in the circuits.

The problem here lies in deciding when to give up a circuit configuration and go on to another one. In fact, which circuit to go to is often the toughest problem for the less experienced builder, since the unworkable circuit usually shows itself as soon as it is built and tested. Therefore, for any given project, it is probably best for the new designer-builder to rely upon the proven circuits. Modifications are



(A) Narrow-band operation.



(B) Wideband operation with filter.

Fig. 6-8. Contrasting methods of operation for transistor power amplifiers.

certainly possible but, in all cases, you should carefully weigh your own confidence in making modifications before committing yourself to incorporating a circuit into the overall design. Whenever you are in doubt as to whether or not a circuit will work in the final design as planned, build a test model first and see.

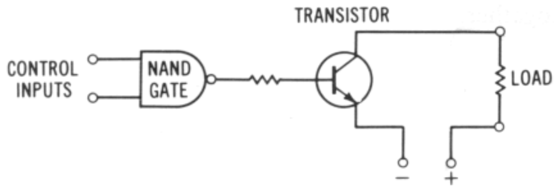
The second limiting factor, in our efforts to design our own circuits, is often the level and the amount of mathematics that must be done to design a circuit. Even though calculators have become sophisticated and have become cheaper and easier to use, the need to solve a whole cluster of problems just to arrive at circuit values tends to destroy the confidence that we should have in the end product. Too, with some types of problems, there are no easy formulas to apply.

Some of the more complex formulas of design require that we make certain assumptions about the circuit and, unless our knowledge of devices is fairly high, we cannot trust those assumptions.

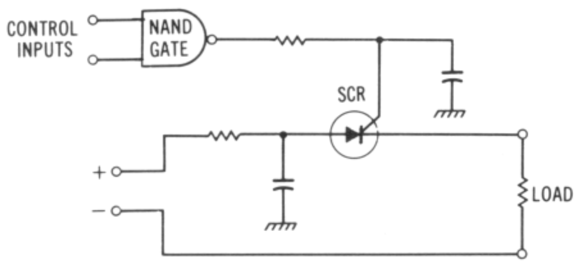
Whenever these types of factors apply, we should step back and try something that is more promising and proven. In fact, for most pieces of equipment that you may wish to design, virtually every circuit that we might need can be selected from readily available reliable circuits. The only modifications that we should have to make are those associated with frequency changes, power levels, or other equally straightforward factors. At the same time, we should not give up the idea of designing circuits. Rather, we should reserve that desire for the time when we have the urge to breadboard and experiment. This is another whole world that we can gradually conquer and, like equipment design, it can be both fun and instructive.

The elements of circuit design parallel those of equipment design very closely. First, set the circuit objectives and parameters. In other words, what sort of circuit do you wish to build, at what power, impedance, bias, and output levels? Second, determine the general way that you want to go about making the circuit achieve the objectives or work within the parameters you have set. This may involve methods and levels of bias, methods of coupling input and output, methods of frequency determination, and methods of impedance transformations. Third, calculate the values of the circuit components for all elements of the circuit that are external to the device. With this set of values, you can acquire parts and design the circuit layout for a test model. For test models, choose a method of construction as open as possible that is consistent with the requirements that the frequency of operation may impose. Next, build and test the circuit, beginning first with a static test of applied bias values and moving to signal voltages and currents. Then be prepared to analyze the results, good or bad, in order to revise and try again, using either new values of components or new ideas.

These steps will vary from one type of circuit to another, depending upon the objectives of the circuit and the kind of device you are using. Transistors and SCRs used in switching circuits have different requirements and permit different modes of operation. Hence, the circuit requirements and designs will differ. Fig. 6-9 illustrates this difference. Basically, the transistor switch follows the output of the NAND control gate. The SCR, on the other hand, conducts when the gate current rises above a certain level and will continue to conduct until the voltage across the SCR drops below its conducting level. The resistor-capacitor network at the SCR anode permits the main-line voltage drop which, in turn, allows the gate to regain control. Similarly, tube and transistor amplifiers require different methods of bias and different input and output circuits for optimum operation. In the realm of integrated circuits, the requirements for a given mode of operation may be specific to a given device with no possible way of summarizing the differences from another type of device.



(A) Transistor switching circuit.



(B) SCR switching circuit.

Fig. 6-9. Typical switching circuits for dc loads.

Circuit design is a subject to which an entire book could be devoted. However, for now, treat it as a side adventure to our main purpose, which is to set up a procedure that will result in successful home designed and built equipment. The role of individual circuits in this process is to provide the individual electronic elements which will fulfill the functions noted on the block diagram, and these functions together permit the entire unit to meet our objectives. The simplest way to arrive at circuits that will do the job we want is to select from among the tried and proven circuits, performing the fewest possible modifications. The modifications we do perform, at least as beginning designers, should be as straightforward as possible. Sometimes, more drastic measures have to be taken in order to arrive at the circuit that is needed to make our unit work, but the wealth of circuits that are available in magazines and handbooks should make these instances rare.

With these thoughts in mind, we should now be ready to select the circuits to make up our design. The circuits can be chosen and a tentatively overall schematic diagram (or a series of diagrams if the unit is complex) can be constructed. Before this is called the finished design, however, we should pause to think through some important questions. Those questions involve how the circuits will interact when connected together.

Chapter 7

Circuit Interactions I— Drive, Matching, Switching

We often carefully pack our suitcases for a trip so that what we will need most is easily accessible. Then, we load the bags into the trunk of the car with only the thought of making them all fit. At the first stop, it is discovered that what we need is in the bag that is buried underneath all of the others. In short, we carefully designed each suitcase, but then failed to think about how they would interact when loading them into the trunk of the car.

Home designer-builders often make a similar mistake. After circuits are carefully selected and modified, they are put together with the assumption that if the individual circuits work, then the entire collection of them should do so as well. We are just as often surprised when the whole unit just sits on the workbench consuming power and doing nothing, or else, doing everything wrong.

As we assemble the selected circuits into a complete schematic diagram, we can take some steps to evaluate the interaction of the circuits. These easy steps will allow us to be confident that the connections between circuits will be the right ones. If any doubts arise as we think through the interactions, we can take corrective action then. This is not the time to try to examine every possible interaction. Some must wait for a later stage in the design process. For the present task of assembling the circuits on paper, we should work with three main areas of interaction—drive levels, impedance matching, and switching. Each of these subjects has been mentioned before in connection with either block diagrams or circuits. In this chapter, we will see them in a new light, one which will give them added significance. We will also take a look at some digital parallels to these considerations, namely loading, fan-out, interfacing, and sequencing. Between these two sets of thoughts, we should be able to adapt our ideas to almost any kind of circuit train that may be encountered.

There are three reasons why we need to examine these matters at this point. First, we have enough information to analyze the situation fairly accurately. Had we tried it before selecting circuits, we would have been speculating and trying to cover too many different possibilities. Second, we can take corrective actions before committing ourselves to purchasing any parts or laying out parts on a chassis or circuit board. This will leave us free to do those steps using a complete design, rather than trying to squeeze in a change later. Third, the first two reasons illustrate once more the principle upon which good design is based—asking the right questions in the right places.

DRIVE LEVELS

Every stage of a piece of equipment must supply some sort of signal to a load. In most cases, the load will simply be the next stage of the equipment, with some form of an output stage supplying a final load. Commonly, we think of the final load as something external to the equipment, such as a speaker, an antenna, or a piece of equipment under test. The equipment itself will have internal final loads, such as digital readouts, indicator lamps, and metering circuits.

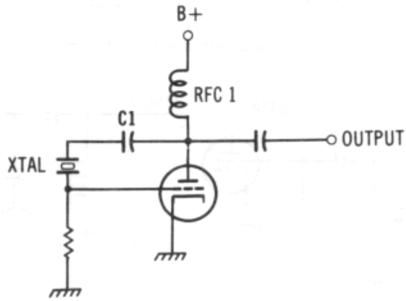
Equally, almost every stage in a piece of equipment will have to be driven by some preceding stage. In the case of mixers and gates, there may be more than one driving stage. Even ac power supplies may be thought of as driven by a line source. The exception to this rule is the oscillator, which is self-driven.

Drive level is, therefore, a very important focal point for our thinking when we reach the stage of design where we must connect several circuits into an overall diagram. With respect to the load—whether it is an external device or the next stage—we want the drive level to be neither too high nor too low. Ordinarily, there is a range of values that will work satisfactorily, but it is perhaps easier than we may think to have an excessive or insufficient level of drive.

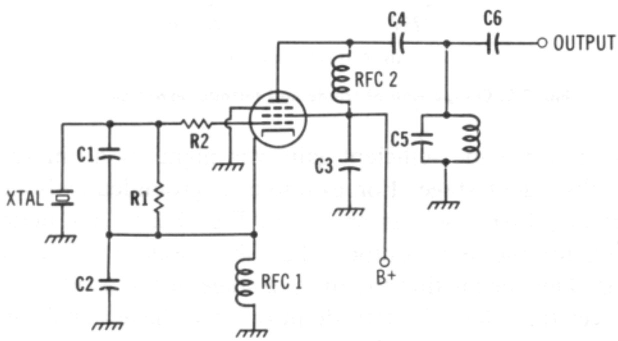
Drive level can be measured in terms of power or voltage for most of the applications that involve linear circuits, that is, circuits which amplify. For high-impedance small-signal devices, we most often use a voltage figure. For transistors, we must think in terms of power since transistor amplifiers are current driven. Equally, for many high-power amplifiers operated in class-AB_2, -B, or -C, drive power is also a major consideration.

In general, there are only two possible problems involving drive level. It will be either too high or too low. If the output of a stage is too low, many of the amplifiers that might follow that stage will, then, not have the expected output. In a receiver, this condition will produce a low audio output or, perhaps, no output at all. In a transmitter, the power to the antenna may be less than desired. If the signal is modulated and if the low drive appears in an audio stage, then modulation will be weak. In some designs, the absence of significant drive can produce destructive conditions, such as in a self-biased class-C amplifier.

The solution to the problem of drive levels that are too low sends us in one of two directions. First, we might replace the driving stage with



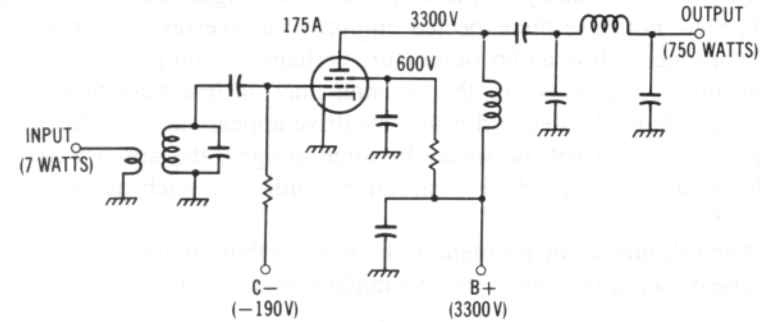
(A) Pierce oscillator.



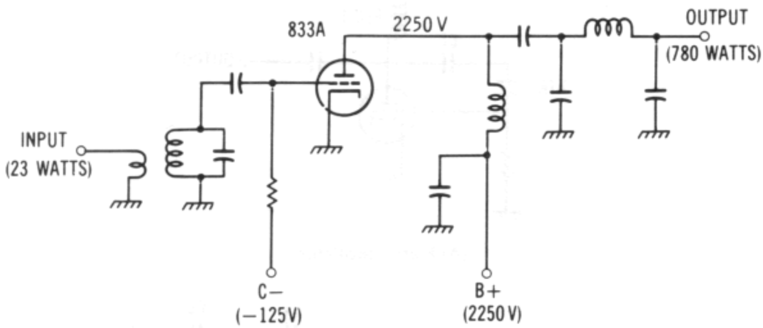
(B) Electron-coupled oscillator.

Fig. 7-1. Comparison of a Pierce and an electron-coupled oscillator.

a circuit which has a higher gain. Fig. 7-1 shows one example that was given earlier in the book. The output of the oscillator in Fig. 7-1A might be marginal in driving the next stage. However, the electron-coupled oscillator in Fig. 7-1B will have a greater usable output. In tube circuits, replacing a triode amplifier with a tetrode or a pentode stage will usually solve drive problems. If the multigrid



(A) A grounded-cathode tetrode amplifier.



(B) A triode amplifier.

Fig. 7-2. Comparison of triode and tetrode power amplifiers.

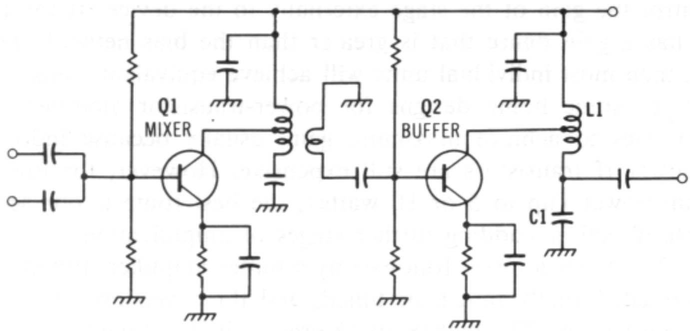
tube does not provide sufficient gain, we might try a different circuit for the subsequent stage. For example, a grounded-cathode tetrode rf power amplifier, such as shown in Fig. 7-2A, has better power sensitivity, for the same output, than the triode amplifier shown in Fig. 7-2B. This means that the driving stage of the triode must supply more power than does the tetrode in order to have equal outputs.

Similar techniques might be applied for transistors but, in general, this is unwise. Because the gain of transistors varies so widely from unit to unit, the bias circuits used for class-A operation are designed to control the gain of the stage externally to the device. If the transistor has a gain figure that is greater than the bias network design figure, then most individual units will achieve equivalent gains in the circuit. In some home designs for power-transistor amplifiers, the builder tries to achieve maximum gain, usually because individual high-power rf transistors are still expensive. However, for low and medium power (up to 5 or 10 watts), the best route is our second possible direction—adding further stages of amplification.

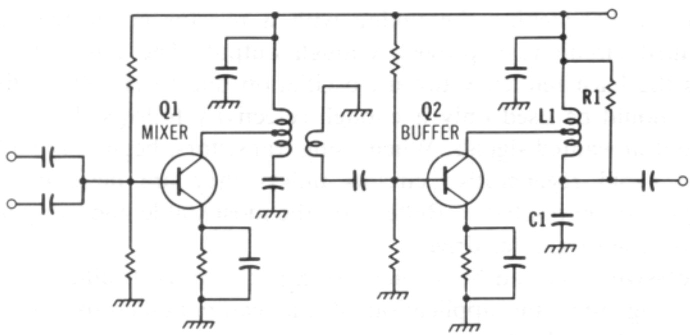
Fig. 7-3 shows a mixer followed by a buffer amplifier. Buffers may be untuned, broadly tuned, or tuned, and three versions are shown in the illustration. The higher the Q present in any tuned circuit, the more output will be achieved from a stage and the greater will be the reduction of spurious and harmonic signals. However, we often do not need to drive a buffer to the maximum that a circuit will permit, so broadening the tuning with a resistor connected across the tuned circuit may provide enough output. The untuned buffer shows the least tendency toward oscillation due to circuit feedback, but it should be used only if enough selectivity follows the stage to filter out unwanted signals. When using transistors, beginning builders should avoid regenerative circuits unless they are designing a Q multiplier or an oscillator. Buffers are the most stable and inexpensive way to achieve greater drive.

Excessive drive can be as much of a problem as insufficient drive. Depending upon the application, it can cause numerous problems, some of which the beginning designer-builder might not recognize. For example, excessive drive to an rf power amplifier can cause distortion to an ssb signal. If grid drive is too great, grid current may rise to destructive levels. At a lower power, distortion and destruction are both possible, especially in sensitive transistor stages. In some cases, the problem will not show up directly as an audible distortion, but due to squaring of the waveshape, harmonics of a signal may develop. In transmitters, this can appear as out-of-band rf signals. In receivers, unwanted signals may mix with normal oscillator signals to produce "birdies," tones that are found here and there as the receiver is tuned across a band. In test equipment, where signal purity may be part of the specifications of the equipment, distortion caused by overdrive may defeat the purpose of the unit. Too much is never better than just right.

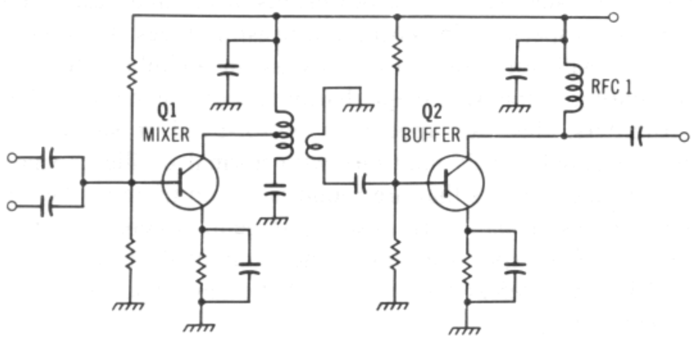
Combatting excessive drive is a problem with three common methods of solution. First, we can get rid of some of the output. Fig. 7-4 shows an example of an amplifier that delivers power to the next



(A) Tuned buffer (highest output).



(B) Broadly tuned buffer.



(C) Untuned buffer (lowest output).

Fig. 7-3. Use of buffer amplifiers to control drive to other stages.

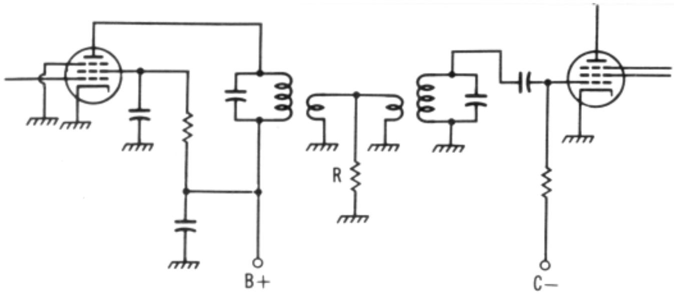


Fig. 7-4. The use of a swamping resistor (R) to control the drive level.

stage. A swamping resistor (R) is in parallel with the load and uses some of the power so that only the right amount of power reaches the load. In general, this technique is not preferable since it wastes power by transforming it into heat which the equipment must either suffer or get rid of. In most cases, there are better solutions.

One of the remaining ways is not only a better solution, it is also exactly the reverse of one of the strategies used for curing low drive. We can either replace the driving circuit with one of lesser gain or output, or we can replace the driven circuit with one that is less sensitive. Changing from the circuit in Fig. 7-2A to the circuit in Fig. 7-2B takes us from a power-sensitive circuit to one that requires more drive power for the same output. Also, we can apply some of the techniques used in the discussion of buffer amplifiers to produce less gain from a stage by broadening the tuning of the stage. Changing the bias point of a gate, base, or grid, as was shown in Fig. 6-6, can give us a similar result. The technique that we use to redesign a stage in order to produce a lower gain will depend upon how much we need to reduce the gain and how strict the other specifications may be. If freedom from harmonics is a major consideration, then we will have to use a means other than the broadening of the tuned circuits, unless we are willing to add filter sections to the design.

The third way of reducing the gain of a stage is through the use of negative feedback or degeneration. Fig. 7-5 shows an amplifier which accomplishes negative feedback in two ways. First, since the emitter resistor R_e is without a bypass capacitor, the signal in the emitter-collector circuit passes through the resistor and part of it becomes transformed into heat (though not enough to concern us, as did the heat of swamping resistors). Thus, for the same amount of drive, the stage produces less output to the succeeding stages. Secondly, the resistor between the collector and the base, R_{fb}, provides a negative

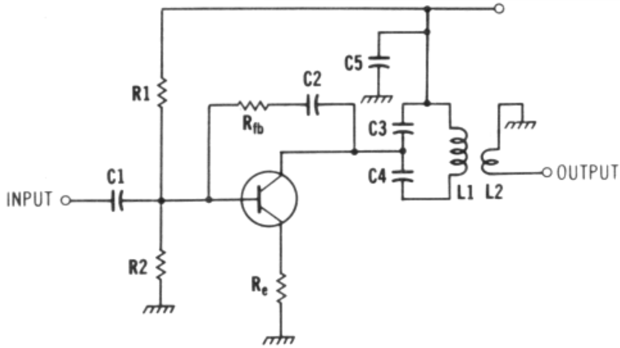


Fig. 7-5. Reducing stage gain through degeneration.

feedback, which is a small portion of the output that is out of phase with the input. Thus, it cancels that much of the input. This, too, reduces the amount of output for the same amount of drive.

These techniques should not be reserved just for the final or output stage of a piece of equipment. Instead, they can be used at every stage of a train of amplifiers to control the gain so that it does not become excessive. The use of these procedures prevents excessive drive from becoming a problem. If you design them into your equipment, the net result may well be a device that has an extra stage. However, your design will likely show little sign of instability, as well as furnishing a processed signal that is free of distortion or unwanted side products.

This section has not surveyed all of the means for controlling drive, but it gives enough of them to permit solving most of the beginning design problems that we may encounter. Even experienced designers have been caught short in this department. If drive levels catch us short, impedance matching problems sometimes devastate our design urges. Often, it is not the case of the stage delivering the wrong level of power, it just delivers the power at the wrong impedance so that it cannot be effectively used by the following stage. Let us look at a few of the common problems and cures in that department.

IMPEDANCE MATCHING

Maximum power is transferred when the impedance of the source matches the impedance of the load. Also, the proper operation of some devices that we may want to use in our equipment may depend upon their being properly matched to that which precedes or follows. Antennas, power amplifiers, and some crystal and mechanical filters are a few examples of what we think of when we think of a requirement to match impedance. However, in designing a piece of equipment, we should think of virtually every link between the circuits that we select, if for no other reason than to satisfy ourselves that the impedance match is right for our design.

In the days when tubes were the important items in electronics, the interface between low-level circuits was of little problem. Since tubes have high input and output impedances, simple coupling methods often sufficed. Also, since tubes are voltage-driven devices in most low-level circuits, we only needed to ensure that we had an adequate peak-to-peak signal voltage and, thus, did not concern ourselves with driving power. (In transmitters, of course, power was a major consideration.) Fig. 7-6 illustrates the simplicity of coupling.

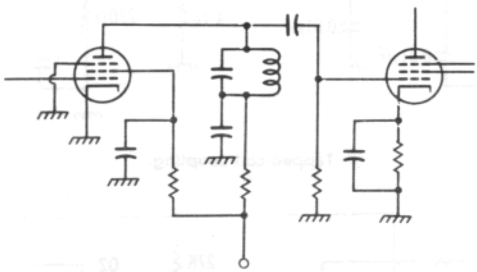
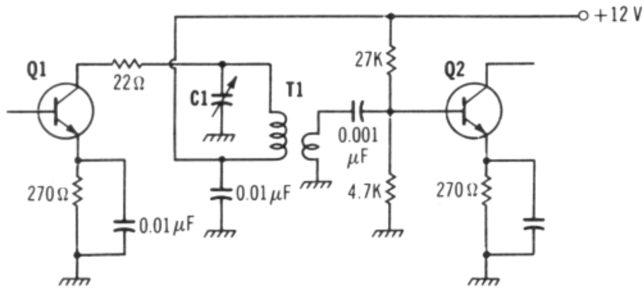


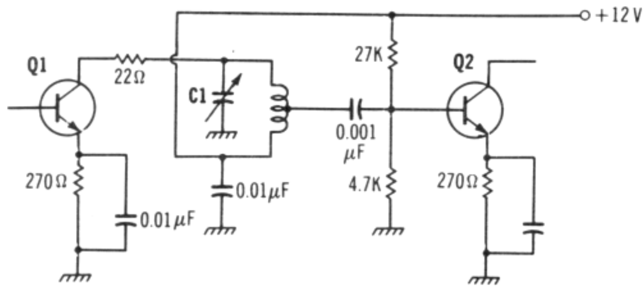
Fig. 7-6. Simple high-impedance to high-impedance vacuum-tube coupling.

However, modern solid-state design has reawakened us to the fact that impedance matching is not just a matter for final power stages and antenna inputs and outputs. It is a matter for every stage. Transistors operate at moderate to low impedances, depending upon their power levels. Devices for which close matching is crucial have become more numerous and more natural to our design thoughts. Thus, it will pay dividends to look at some of the means that we have to match impedances between stages.

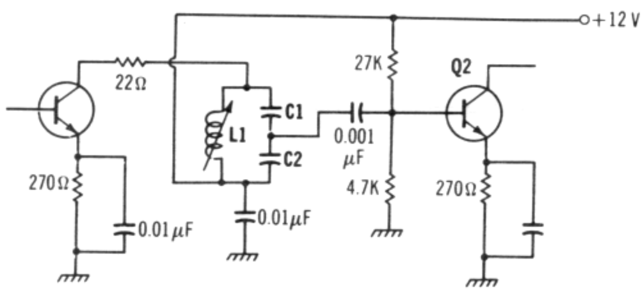
The most common ways to transform impedance downward in tuned-circuit stages are with the use of a transformer or a tapped coil. Figs. 7-7A and 7-7B illustrate the principle. In both cases, the turns ratio is the square root of the impedance ratio, although some experimentation may be needed in all cases to find the right tap point or the right number of link turns. The third method (shown in Fig.



(A) Transformer coupling.



(B) Tapped-coil coupling.



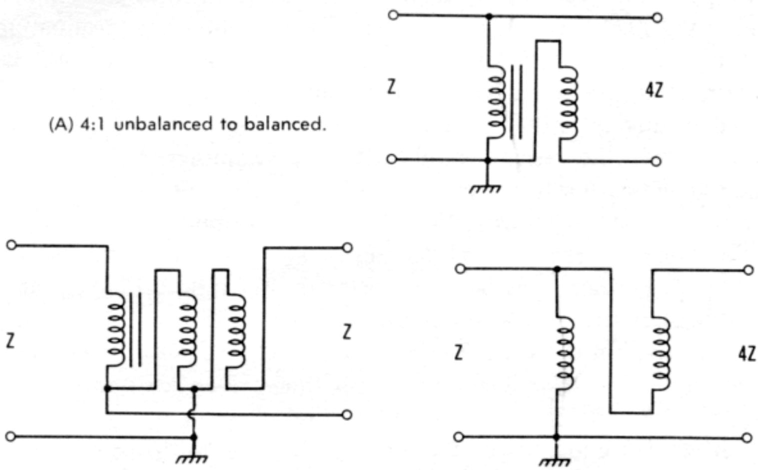
(C) Capacitor-divider coupling.

Fig. 7-7. Common coupling methods.

7-7C) is growing more common. The capacitor-divider system is equally effective with the others, although it must be remembered that the value of capacitance needed to resonate with the coil (at the desired frequency) will be a value that is determined by the formula for series capacitors and not the value chosen for either one of the capacitors.

Since transistors are relatively broad-band devices—that is, they show a low Q and have gain across a large frequency spread—transmission-line transformer design is growing in popularity for impedance matching. This is especially true in power-amplifier design, where the input and output impedances may be only a few ohms. Transformers (often called baluns) may be wound on either air or solid cores, with ferrite cores being much used. They may also be linear, resembling ordinary coils, or wound as a toroid coil. The latter form is usually used in conjunction with a ferrite core. Fig. 7-8 illustrates three common versions of a balun.

Impedance matching can also be obtained by using some traditional circuits. Three versions of L and pi circuits, which are familiar to

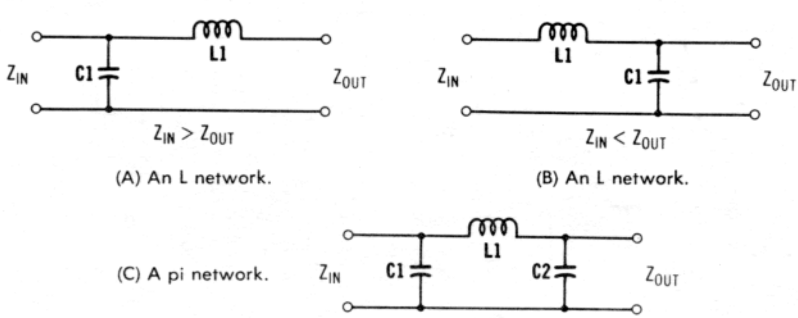


(A) 4:1 unbalanced to balanced.

(B) 1:1 unbalanced to balanced.

(C) 4:1 unbalanced to unbalanced.

Fig. 7-8. Three common balun designs, usable in either direction.



(A) An L network.

(B) An L network.

(C) A pi network.

Fig. 7-9. Simple versions of L and pi matching networks.

us because of the designs of transmatches and transmitter final amplifiers, are illustrated in Fig. 7-9. There is no rule which forbids us from using them in low-power stages in miniaturized form. They work quite well, and handbooks will provide the formulas for designing them.

When input or output levels are of a high impedance, as they are with FETs and many other devices, we may need only voltages to provide a driving signal. However, intervening devices, such as filters, may call for lower impedances. In some cases, terminating resistors may suffice for impedance matching. Fig. 7-10 illustrates the idea with the input of a filter fed from a high-impedance signal. The terminating resistor, R_T, is effectively in parallel with the source, which is the output of the amplifier. The very high impedance of the source, let us say 100,000 ohms, in parallel with the 600-ohm terminating resistor yields an effective impedance of 596 ohms. In other words, the terminating resistor determines the impedance that the filter sees. Note that this technique is for low-level driven circuits since, in power circuits, the resistor would act as a swamping resistor. This was discussed earlier in the chapter.

These are not all the ways there are to match impedances between circuits, but they provide a collection of ideas to bring attention to the subject. Perhaps it is best to master only a few techniques at a time and to experiment with new ones as the need arises. I have my own favorites, but they fit the kinds of equipment I like to build. You will develop your own techniques with time. Since no one method is best for all circumstances, it will not take too much time before you will have a good stock of techniques at your fingertips.

It is also possible to cut the drive level from one stage to another by purposely mismatching the circuits. This procedure, however, can

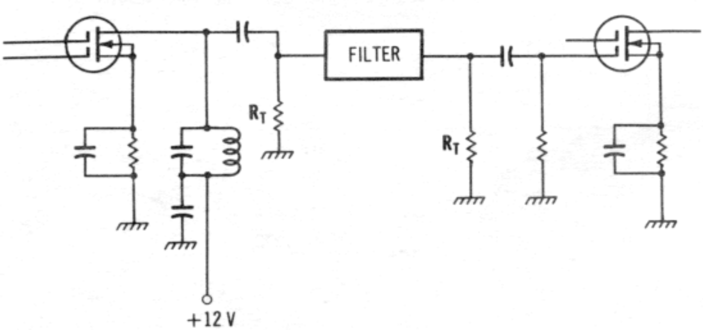
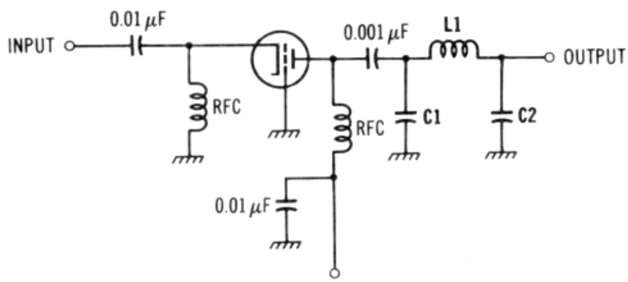
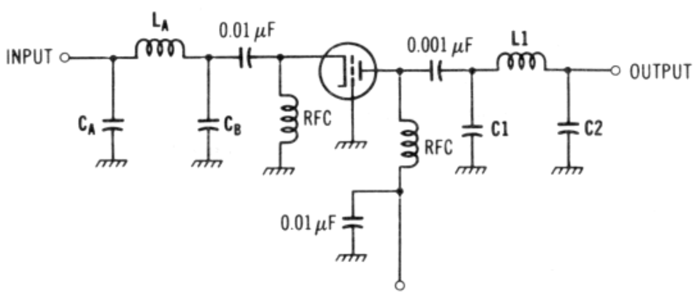


Fig. 7-10. Diagram illustrating the use of terminating resistors.

be the source of other problems, such as the distortion of the waveshape. Although the waveshape may make little difference between the stages of a cw or fm transmitter, under certain conditions, the effect of a mismatch between stages of an ssb transmitter can be distortion. Many early grounded-grid linear amplifiers that were used for high-power ssb fed the cathode of the tube(s) directly, as shown in Fig. 7-11A. The addition of pi-network input sections not only increased the sensitivity of the amplifier, it also cut distortion products. Thus, while the principle that power transfer depends upon an impedance match is a tempting one to use when we wish to reduce the power fed to a stage, we should use it with caution.



(A) Without input matching.



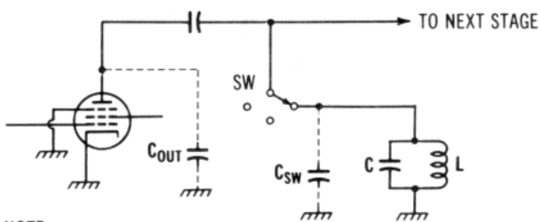
(B) With input matching.

Fig. 7-11. Grounded-grid amplifier circuits.

SWITCHING

Drive levels and impedance values are the two most significant electronic considerations for circuit interaction. However, we often insert a mechanical consideration by choice—the switch. This mechanical device has electronic consequences. A switch is not just a device which routes electrical current from one circuit to another. It is also a design creature with size and danger. Well-tamed, it can help make circuits do just what we want them to do. Uncared for, it can ruin the best design. Because switches have size and take up space, they alter the physical layout of a circuit. Often, they must be placed a distance apart from the circuits that they control and, thus, require leads which run to and from the circuits. The very size of the switch contacts can alter the circuit from our design plans. With these properties in mind, let us look at some of the dangers of switching and, then, at some ways to cure them.

The leads and contacts of switches have size and, thus, can form one plate of a capacitor. The other plate may be something else in the circuit, perhaps the ground or a dc line. Part of the capacitance of a tuned circuit that is connected to a switch will be in the leads, and this can lower the Q of the circuit, as shown in Fig. 7-12. In cir-



NOTE:

1. C_{OUT} = OUTPUT CAPACITANCE OF TUBE.
2. C_{SW} = CAPACITANCE TO GROUND OF SWITCH AND LEADS.
3. C_{TOTAL} (IN PARALLEL WITH L) = $C_{OUT} + C_{SW} + C$.

Fig. 7-12. Distribution of capacitance in a tuned circuit.

cuits with small capacitance values, the entire capacitance required for resonance can sometimes be found in the switch leads and between the coil turns. If the circuit appears in the frequency-determining part of a vfo, the lowered Q may hinder good circuit operation. In addition, the slightly different placement of the contacts with each resetting of the switch may prevent an accurate frequency readout. Finally, some of the signal may be coupled into dc lines and show up elsewhere in the equipment, where we do not want it. Many manufacturers have over the years worked out mechanical designs which overcome some of these problems. For the new builder-designer, reproducing these techniques may not be possible. The trick is to design ourselves out of this problem cluster.

Fortunately, switching problems occur most prominently under a combination of two conditions:

1. Where the currents switched are at rf frequencies.
2. Where high-impedance circuits are switched.

Eliminating either one of these conditions goes a long way toward bringing the problems of switching under control. There are ways to eliminate each problem, and even ways to minimize both.

A diode switching scheme is shown in Fig. 7-13. When the diodes are biased in one direction, signal current can flow through the pair labeled D_A. When the bias is reversed, pair D_A will show a virtual open circuit, and pair D_B will then conduct. Lines to the front panel carry only direct current. The basic idea can be expanded for many circuits. However, even sensitive signal diodes have a voltage drop. They also have power limitations. Hence, this circuit is not a universal cure for switching problems.

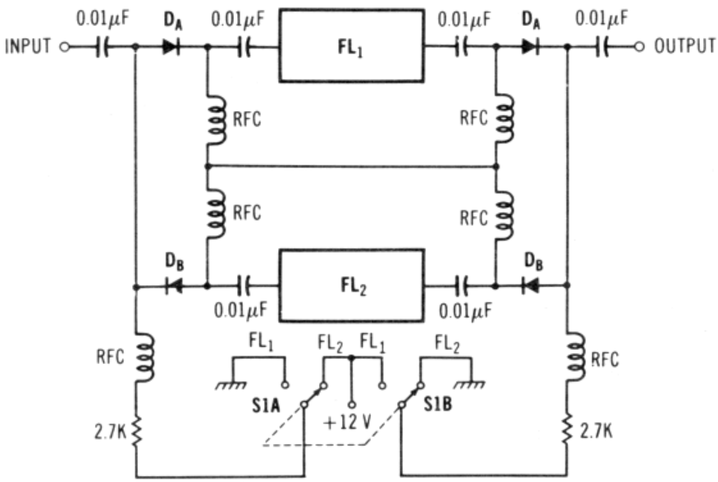


Fig. 7-13. A diode switching scheme for two filters.

A second method is to transform all switched signals to a low impedance. For the same power, the lower voltage of a low-impedance signal will provide less capacitance to surrounding objects than a high-impedance signal will. In addition, we may often use coaxial cable to shield the lead runs to and from the switch, and the low-impedance signal will provide a good match to the cable. Fig. 7-14 illustrates the principle. However, like eliminating the rf from the

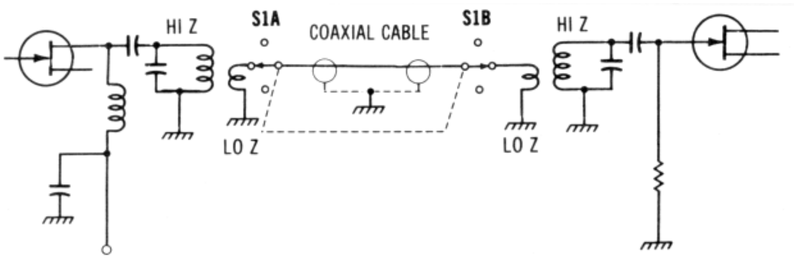


Fig. 7-14. Basic example of low-impedance switching.

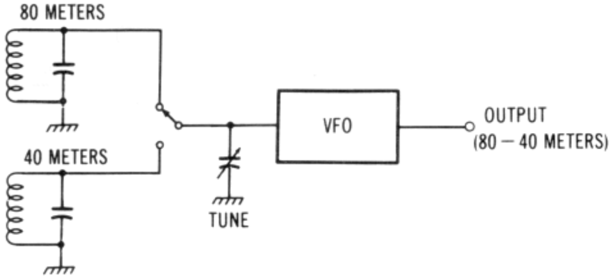
switched lines, low-impedance lines have their limits, too. Often the circuit we want to switch cannot be transformed to a low-impedance state; for example, when we want to switch bands with a vfo.

If neither method will work, we can try to move the switching point to a place where one of the two techniques will work. In this case, rather than switching the tank circuit of a vfo, we can use a mixing scheme. This allows the vfo to always operate on one frequency. Then, by changing the crystals in a second oscillator, we move the switch out of the vfo altogether and to a more controllable point. Fig. 7-15 will give you an idea of how this might work.

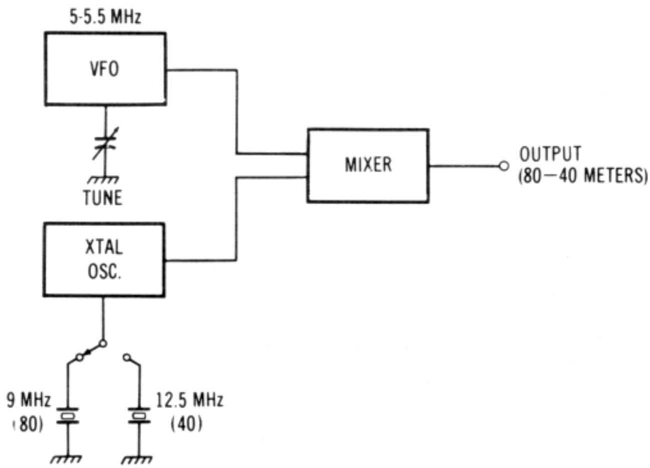
The ultimate solution is to minimize the use of rf switching. As noted in Chapter 5, manufacturers may design complex switching circuits that through engineering refinement of overall equipment design will work reliably and well. The new designer-builder does not usually have access to many of the techniques of the manufacturer, nor to the information which yielded the final design. Consequently, the suggestions in Chapter 5 are still the best means for the home designer to use to prevent switching problems from arising. Fig. 5-4 gave one example of how to substitute stages for switches in a transmitter. Another example, this time a receiver, is illustrated in Fig. 7-16. We can try to design an rf amplifier that will operate well on many bands by using a method of switching tuned circuits (Fig. 7-16A), or we can design separate converters for each band and switch only the low-impedance input and output lines (Fig. 7-16B), as well as the dc power to each one. The latter scheme minimizes any potential switching problems (although it may involve other design compromises).

DIGITAL INTEGRATED CIRCUITS

The interactions we have explored so far in this chapter apply predominantly to linear devices, that is, to circuits used as amplifiers.



(A) Switching frequency-control circuits.

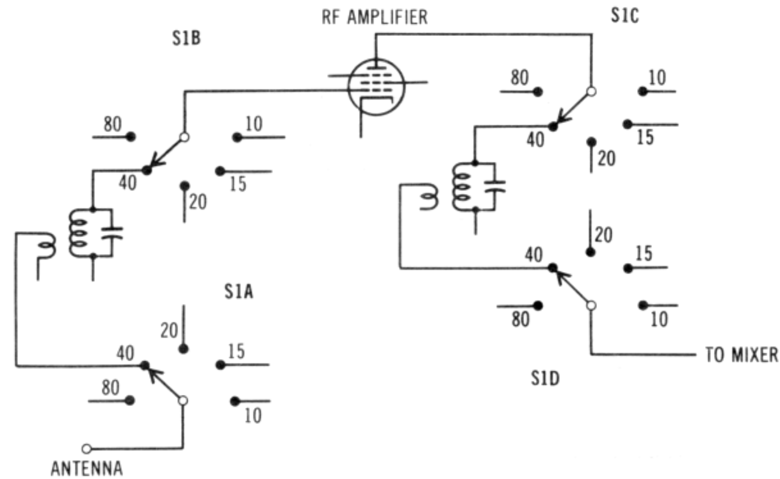


(B) Switching crystals.

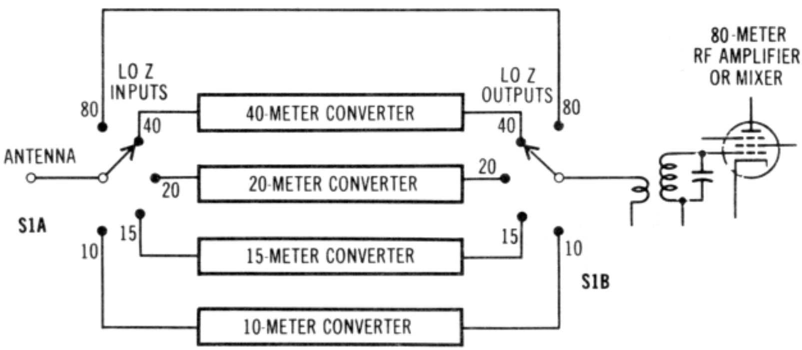
Fig. 7-15. Redesigning a circuit to place switches at points of minimum problems.

There are parallel problems which can occur with equipment that uses digital integrated circuits. We can loosely classify the problems as loading, fan-out, interfacing, and sequencing. Let us look briefly at these problems, one at a time.

Indirectly, drive capability is a consideration for digital devices as well as for linear or amplifying circuits. When one IC drives another of the same series—for example, a 7400 gate feeding a 7404 inverter—little problem exists. The individual ICs of a series are well matched. However, problems arise when the IC has to drive some other kind of load. Digital devices have a sinking current. This is the amount of current which may pass through a terminal and its complex circuitry without destroying the device. This current should



(A) Switching tuned circuits.



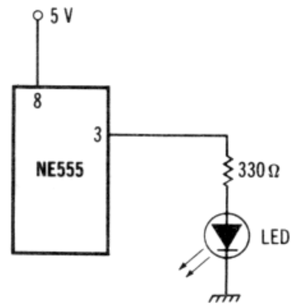
(B) Switching converters.

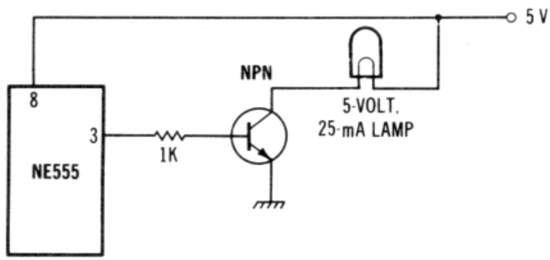
Fig. 7-16. Receiver band-switching methods.

never be exceeded. If a design requires that you drive a load which exceeds this current or whose current is uncertain, then you should employ an interface circuit.

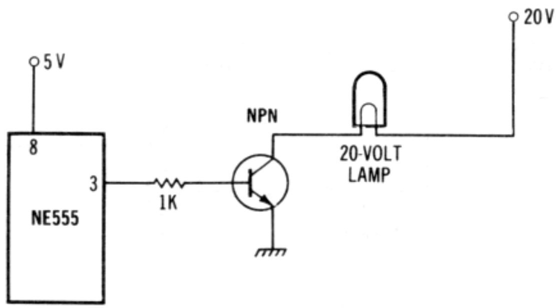
Fig. 7-17 shows some examples. The output from pin 3 of the NE555 Timer can easily drive the LED shown in Fig. 7-17A. However, if the driven device exceeds 20 mA, as it might for some incandescent bulbs, a transistor circuit should be used, as shown in Fig. 7-17B. The current rating of the transistor should be greater than the load current. This circuit is adaptable to cases where the load also requires a voltage different from the digital supply voltage,

(A) Direct-drive circuit.





(B) Indirect-drive, common-supply circuit.

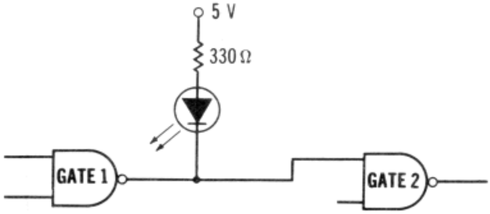


(C) Indirect-drive circuit with separate power supplies.

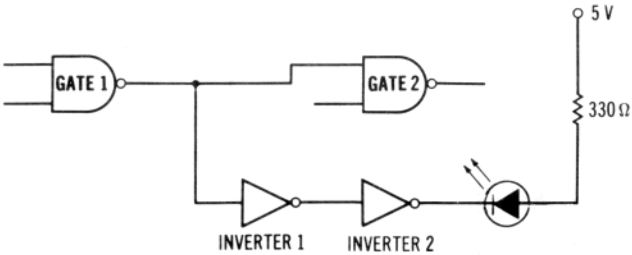
Fig. 7-17. Driving discrete device loads with integrated circuits.

so long as the transistor ratings exceed the voltage required by the load. The illustration in Fig. 7-17C shows just this situation, which is common to many solid-state keyers whose output must control high positive or negative voltages.

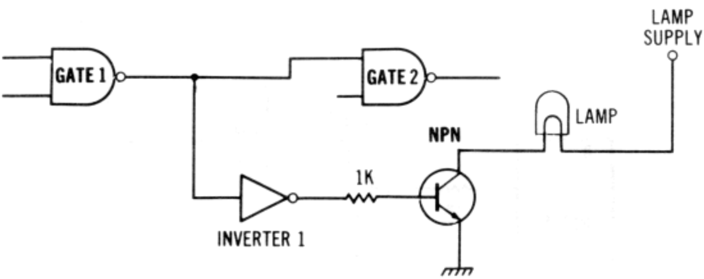
Fan-out is a problem closely related to drive capability. Unless we pay attention to it and stay within limits, we may not be able to drive the succeeding stages of our equipment reliably. Fan-out refers to the number of devices (of the same digital series) to which a given device can reliably provide a signal. The output of most TTL gates



(A) Driving dissimilar loads.



(B) TTL isolation.



(C) Transistor isolation.

Fig. 7-18. Isolating non-TTL loads from TTL circuitry.

is rated at 10, which means that one TTL gate can drive the input terminals of ten other TTL devices. There are some TTL devices with a fan-out of 30. In most of the equipment that we will design, even a rating of 10 will exceed what we will normally do with any device.

Problems usually occur when we try to drive, in addition to ICs of the same series, other devices whose input is unlike the input of the driving IC. Such devices may use almost all of the capability of the driving IC. One way around the problem is to use a pair of inverters to isolate the irregular load, as shown in Fig. 7-18B. The 7400 gate now drives two TTL devices, and an inverter drives the

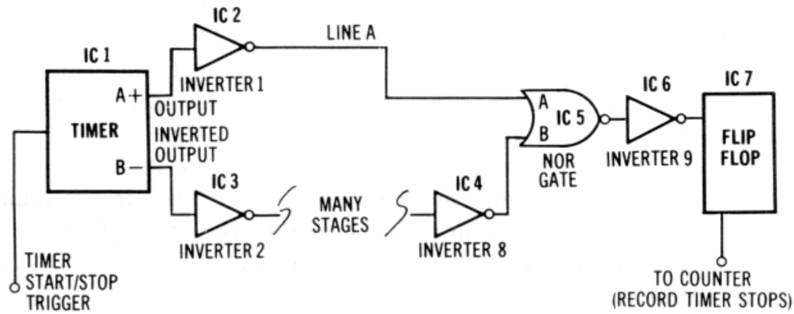
LED. Another solution is similar to that shown in Fig. 7-17C, namely, adding a transistor switch to control the non-TTL load. As shown in Fig. 7-18C, these two ideas can be combined to ensure isolation. Note that in every case, the TTL configuration is set up to permit the lamp to light when the output of Gate 1 is in a low state.

A similar problem occurs when trying to use more than one series of ICs in the same design. The two most popular series in use today are TTL (transistor-transistor logic) and CMOS (complementary metal-oxide-semiconductor) ICs. Some designs still use RTL (resistor-transistor logic). Each of these series requires a different supply voltage—for TTL, 5 volts; for RTL, 3.6 volts. CMOS ICs operate from about 5 to 15 volts. These series may drive each other only when special care is taken. For example, an RTL device driving a TTL gate should drive no other RTL device simultaneously. If a CMOS device is to drive a TTL integrated circuit, the CMOS device should operate from the 5-volt supply of the TTL device. The TTL device, on the other hand, will generally trigger CMOS devices.

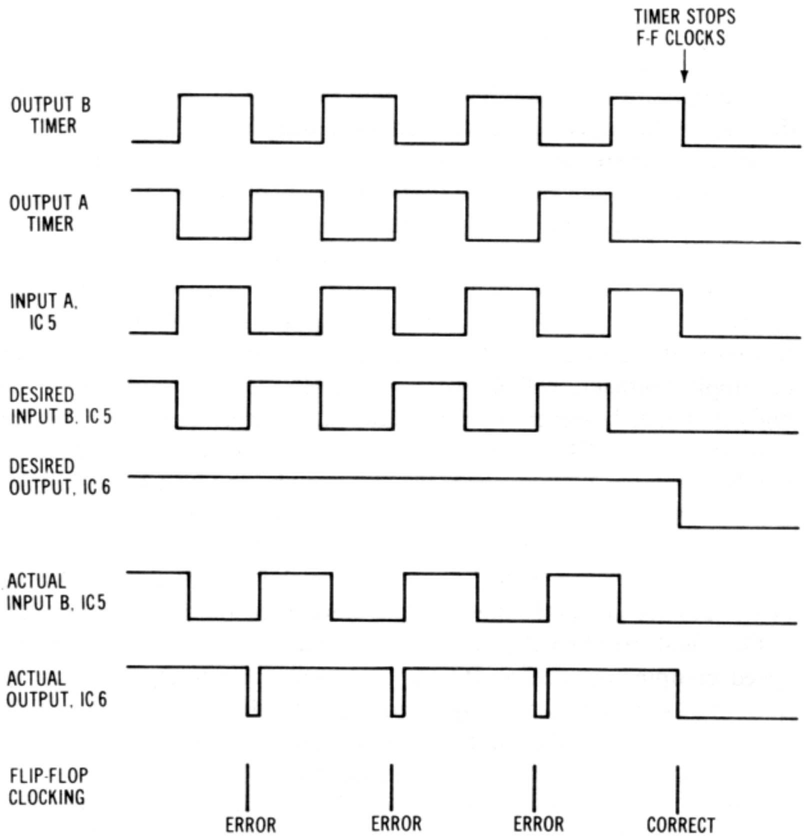
In cases where you must use devices from more than one series, you should consult various handbooks to find out what precautions to observe when going from one device to the next. These handbooks often contain interface circuits, which may consist of a special device in the series. The best solution, however, is to stay within the same series for the entire design. For many applications, CMOS, with its low current requirements and its ability to operate over a wide range of supply voltages, will fill your needs. The greatest versatility and highest speed, however, you will find in the wide variety of devices that are in the TTL line. Where you can provide an ac-powered regulated supply voltage, TTL devices may be the best bet. IC handbooks, which you will find in ever-growing numbers, usually contain basic data sheets that will ordinarily specify the compatibility of any other type of device with TTL ICs. This shows that the TTL-series of devices are currently the standard device for the digital IC field.

One final problem that you may encounter is sequencing. In low-speed equipment, such as RTTY or Morse code teletypewriters, sequencing is usually not a major problem. At higher speeds, especially those approaching the limits of the device, the sequencing problem can put unexpected glitches in your design.

Fig. 7-19 provides an illustration of the problem. The timer provides pulses that pass through several gates before recombining in the NOR gate (IC 5). Line A passes through only one gate; line B passes through many. Each device has a certain propagation time,



(A) Simulated circuit.



(B) Waveforms.

Fig. 7-19. Hypothetical example of the effect of propagation delay times.

which is the time it takes for a signal to be processed in the device and the appropriate output to appear. Through a string of devices, the propagation delay is cumulative, although it may amount to only a few nanoseconds per device. Note that NOR gate IC 5 and inverter IC 6 clock a flip-flop on the negative edge of a pulse. As long as the timer is pulsing, the gates ensure that inverter IC 6 has a positive output. Or, so it appears. If both inputs of NOR gate IC 5 go negative, the output of inverter IC 6 will also go negative, thus clocking the flip-flop. Now examine the train of waveforms in Fig. 7-19B. As propagation delays create a lag in the signal on line B, the possibility arises that a very brief period exists in each swing of the timer for the output of inverter IC 6 to go negative. That may be all that is needed for erratic operation of the flip-flop.

There are two cures to this type of problem. Either reduce the delay times in line B or increase them in line A. A series of inverters in line A would increase its delay times to equal those of line B. The delay times of line B might be decreased either by redesign or by the use of higher-speed devices. TTL devices occur not only in the regular series of devices but, also, in high-speed and low-current variations as well. Before combining these different variations, check a handbook for any necessary precautions.

Checking handbooks has been one suggestion given for every inter-circuit problem that we have examined in this chapter. The suges-tions that have been made are only those which are the most com-mon, and there are always more ways to solve problems than any one chapter can describe. The solution you will need may not be here, although the suggestions given in this chapter should solve about 80% of most problems.

The primary lesson, however, is that problems about the interaction of circuits should be examined before any building begins, wherever possible. Those problems concerning drive levels, impedance match-ing, and switching, as well as their digital counterparts, are best ex-amined in the process of putting circuits together on paper. You can design your solutions into the overall circuit diagram which will become your electronic building directions. By minimizing these prob-lems now, we maximize success later.

Now, finally, we can move on to planning the actual building of the equipment. Our design work will also move from the purely elec-tronic phase to the mechanical phase.

Chapter 8

Steps 4 and 5—Parts and Layouts

By now, we have gotten serious about the project we have in mind. The work we have done to develop a full electronic design must now be translated from the schematic form into plans for action, for expense, and for physical labor. In short, we are at the stage of planning where we have to buy parts and design the physical layout of the equipment.

Most of us are prone to give these areas of design too little thought. Yet, the success of our entire project may depend upon how carefully we think about acquiring the parts and plan the layout of the parts. If we start a project with the mere hope of getting all the parts, then the unavailability of one or two items may stop us in our tracks halfway through the building process. The redesigning of circuits to compensate for errors or changes is much harder after we have already drilled the chassis holes or etched the circuit boards than it is when we still have a free choice of the mechanical work details. In addition, it is rarely possible nowadays to begin at one end of a chassis and work our way through to the other end, putting parts wherever they seem to fit as we go. For most of us, the equipment design must become a finished unit, neatly enclosed in a cabinet and attractive enough to pass inspection by fellow hams and hobbyists, or even by parents, spouses, and others that we live with. There is a sense of pride attached to a job which not only *is* well done, but also *looks* well done. This pride is not misplaced. The better we build, the more reliable the equipment will be and the easier it will be to maintain.

This chapter will explore some basic ideas about acquiring parts and designing layouts from the perspective of design. The two skills involved are making lists and sketching accurately. By the time we have completed the work on this phase of design, we will not only have developed our strategies for this project, but we will also have acquired some detailed knowledge of parts and their interrelationships. That knowledge will shorten the work of future projects and, perhaps, serve us in several other ways.

ACQUIRING PARTS

Depending upon the project we choose, acquiring parts can be one of the most frustrating stages of the entire design process. Finding what we need at a price that we can afford in a reasonable length of time from reliable sources is a tall order. No one dealer seems to have everything we need. Some components appear too expensive. We cannot tell from local advice whether the magazine ads we wish to answer were placed by conscientious dealers. Some parts seem unavailable from any dealer.

Part of the problem that builders face in acquiring parts stems from the variety of components now available. Not so long ago, say about 20 years, we could build what we wanted from coils, capacitors, resistors, tubes, sockets, transformers, wire, and jacks. Television necessitated the addition of a cabinet, preferably metal. Surplus parts and units we could cannibalize came on the market as the government rid itself of materials used in World War II and Korea. Our limited building desires—mostly receivers and transmitters—plus the availability of standard parts made acquisition relatively easy. This ease in acquiring parts might have continued if hams and hobbyists had not decided to build more than just transmitters and receivers. Now, they insist on building keyers, frequency counters and readouts, synthesized vfo's, and even computers. Little wonder that dealers cannot keep up with the demand for parts.

Thousands of transistor types and a growing inventory of ICs make it impossible for one dealer to carry everything. Most locally available parts are packaged in "blister" packs and handling costs have risen so much that these parts are expensive. Fewer and fewer mail order houses wish to fool with open bins of resistors or with a small parts order. Fortunately, the situation is improving for many kinds of parts, so that there are many good sources for ICs and computer parts. A few individuals have begun to specialize again in parts for rf equipment, and some manufacturers continue to serve hams and hobbyists by making their parts available through many outlets or even direct from the factory. In short, the parts are available, but it takes careful planning to acquire them efficiently.

The parts order for one project may involve orders to several parts houses. It is very necessary to make the initial order as complete as possible since many parts houses have a minimum order policy and charge a handling fee. Of course, it is inevitable that you will forget to order the one small but crucial part that is available *only* from the company with a $20 minimum but, in that case, what better time is there to stock up on everything that you "might" need for the next project? However, it is possible to reduce your chances of having to make such an order. It is necessary to take only three very simple steps to do this.

Step 1—Make a complete list of every conceivable part in the equipment. This list will contain not only all of the obvious components, but will also include the easily overlooked parts. Commonly overlooked parts are small resistors and bypass capacitors; these we often forget or miscount since they are mentioned only on the schematic. Other necessities include the mechanical pieces which hold the electronics together—things like screws and nuts, spacers, cabinet feet, panel decals, knobs, cable connectors, and solder. Some of these items are not in the equipment, but are needed in order for us to use the equipment. Some parts are minor but necessary mechanical items which at first sight do not connect up to the electronics. Others are just items that we think we have plenty of until we actually start to look in our parts drawers.

Table 8-1 shows a typical listing. This chart covers only a small number of the total parts that might be needed for a project, but it does illustrate the process of making up the parts list. The left column contains the parts specified in the text, schematic diagram, etc. With the parts designation are either the manufacturer's or the supplier's numbers which we may have gotten from articles in our idea book while selecting the circuits. This information will help us fill in the set of right-hand columns.

Step 2—Read catalogs, fliers, and parts ads in the latest magazines. As you read the ads, fill in the columns. At the top, designate the supplier. In the column, beside the part, fill in any useful information if the supplier has a part. Some of the useful information may be the page number of the catalog, the price a supplier charges, and the minimum quantity the supplier requires on an order. There will

Table 8-1. Sample Parts List For Project

Required Parts	A $15 Min. or $2 S.C.	B $2 S.C.	C $10 Min. or $1 S.C.	D $10 Min.
2N3772 (critical)	1.50	—	—	—
2N6109 (2)	—	.50	.50	.45
74181 IC (3)	2.10	2.55	—	—
74165 IC (1)	—	1.40	1.40	1.35
Transformer, 24 V @ 6A	—	—	8.00	9.50
Capacitor, 5500 μF @ 35 V (2)	1.95	2.00	1.75	1.80
Relay, 12 V dpdt (RS 275-206 or equiv.)	—	5.00	—	4.50
RFC coil, 100 μH (RS 273-102 or equiv.)	1.20	—	—	1.00
Rotary switch, 2-pole 6-position (2)	—	1.50	1.35	—

1. A, B, C, and D designate the different suppliers.
2. Headings specify a minimum order and/or a service charge.

still be decisions to make when ordering parts, and this type of information will help us make them.

Reading catalogs is an honored and useful custom all by itself, since the specifications for equipment and parts can tell us much about these materials, even if we never have occasion to buy them. Not only is this good information that we can pass on to others as the need arises, but it is also information that tells us much about the current state of the art, especially with respect to the physical aspects of what we too often only know as symbols on a schematic diagram. How big are polystyrene capacitors? What voltages can a manufactured slug-tuned coil safely carry? What is the size difference between a regular and a low-profile IC socket? The answers to these and to dozens of other questions can be found in catalogs, but hardly ever in articles or books. In the abstract, they may sound like unimportant questions, but in planning a piece of equipment, it may be necessary that we have an answer. Thus, we will slowly accumulate a wealth of information without trying.

Step 3—Distribute the orders so as to acquire all the needed parts and still meet any supplier requirements. In some instances, you may actually be able to acquire all the parts you need from one source. If so, congratulations! If not, the wisest policy is to order significant amounts from each necessary supplier. We define a necessary supplier as one who has parts on the list that no one else has. In Table 8-1, supplier A has certain transistors not advertised by others. For this project, he must receive an order. In addition, we will order parts to meet his $15.00 minimum order requirement to avoid paying a $2.00 handling fee. For the remainder of the parts, we will split the order between suppliers C and D. It is not necessary to order from supplier B, and if we did order from B, then either supplier C or D would receive orders that were under their minimums. However, in some cases, the selection of suppliers will boil down to personal experience from other orders or to simple preference. Experience can tell us much about the possibility of receiving backorders or out-of-stock notices, about what we can expect in service, and about the willingness of the supplier to work cooperatively with us when problems arise.

You should keep on hand a reserve list of parts that you would like to have. Adding it to an order can put you above the minimum order requirement and save you the cost of a service charge. If your chart does not force you to make use of all of your reserve list, save it for the future. If one or more of the dealers is out-of-stock on certain parts, then a follow-up order may be needed to another supplier. Since the order is likely to be small, the reserve list can help you avoid paying special charges or buying unneeded parts.

YOUR JUNK BOX

The junk box—to use it or not to use it, *that* is the question! Very quickly, while developing skills in electronics building, almost all of us develop a large array of parts. Occasionally, we overorder or make use of our reserve list in order to have parts on hand. We attack parts sales at ham fests. We dismantle old equipment, both home brew and commercial. People, as soon as they learn that we build electrical stuff, give us things that we do not know what to do with. However we store this material—in cigar boxes, jars, commercially built parts bins and drawers, or homemade workbench cabinets—this is our junk box. Now, before mailing off the orders, a trip to the junk box is in order.

After having come this far in the design process, we often fidget a bit about whether or not to use junk-box parts in our project. We wonder whether or not the part is still in good condition. (However, there is often an equal likelihood that a new part may be bad.) To calm our fears, there are a few questions that we can ask ourselves to help decide whether or not the junk-box components are usable in our project. Here are a few:

1. Is the part still in good condition? Our eyes tell us quickly if the part is good physically. Its electrical properties may require a test. An ohmmeter and a grid dip meter will provide a screening test for most components, although they will not thoroughly test the part. The ohmmeter will provide continuity checks, while the grid dip meter will supply coil and capacitor values by combining them into tuned circuits.
2. Is the part expensive if bought new? If so, and if the part appears to be in good condition, then we have a case for using it.
3. Did the part come from a reliable source? An old tv set that exploded and burned is not a good source of parts. A trusted fellow builder is a good source.
4. Is the part hard to get new? It may pay to take a chance with the part on hand.
5. Can the part be tested in a breadboard circuit? If it passes this test and if we do not ruin it taking it out of the breadboard circuit, then we should by all means use it.

There are also some questions which tell us when not to use a part.

1. Does the circuit call for precise values or some other rigid specifications? If so, then a new part, one which has not been soldered and unsoldered several times, is more likely to meet the specifications in our equipment.
2. Will the shape, lead length, or other physical characteristics of the junk-box part force us to build a circuit in ways that we prefer not to build it? If so, then we should reject the part unless this consideration is overshadowed by matters of expense or ease of purchase.
3. Are there any worries about either the part or the circuit it will be used in? Confidence is an intangible factor, but it does affect the success of our projects. If a new part will give us confidence that we can make the circuit work, then we should buy the new part.

From these starter questions, we can go on to add others in accordance with our design and the state of our junk box. Obviously, there is no clear yes/no answer to the question of using junk-box parts. The less important the project, the more we will want to use what is on hand. It boils down to a matter of judgment and, at some time or another, we will all get burned in trying to use junk-box parts. However, with the prices of today, they are worth trying, wherever possible.

CRUCIAL, NEEDED, AND DESIRABLE PARTS

As a further guide to thinking about parts orders, let us divide the parts for a project into three categories: crucial, needed, and desirable. Each category will have a different impact upon a project, both in terms of the design work we have done so far and in terms of the work still ahead.

Crucial parts are those without which an entire circuit may need to be replaced. If we are unable to obtain a special power transformer with a certain winding, then we may have to rethink an entire set of amplifier stages or rethink the entire power-supply design. If what we can obtain is not the size that we anticipated from notes in our project notebook, then the physical layout and the cabinet may have to be altered. There is probably no part so crucial as to kill an entire project, but the absence of certain parts can send us back a few steps in the design process.

Needed parts are those whose absence may require some circuit or construction modification. Changing from toroid coils to slug-tuned coils may demand that we give some thought to shielding and to the consequences of a lower Q in the tuned circuit. Altering a digital circuit so that it uses a 74193 IC instead of a 7493 IC will require attention to the pulse edge used to trigger it. Neither of these minor design changes may be too significant, but they do call attention to the affects of problems in procuring parts.

Desirable parts are those which, in your design and with respect to your objectives, may have adequate easily obtained substitutes that will do the job just about as well. A vfo with silver-mica capacitors rather than polystyrene units will work satisfactorily in some equipment, especially when it is not subjected to great temperature changes. A digital ohmmeter of good accuracy may let you match some 5% tolerance resistors when the specified 1% units are not available. In short, a part is classified as desirable if a substitute will allow you to build a circuit without design changes.

The point in making these distinctions is similar to the point of looking into your junk box. It will alter the basic pattern of ordering parts. To receive all the desirable parts and fail to receive certain crucial parts from suppliers may force you to redesign sections of your equipment and, thus, add some brand new parts to the junk box. Therefore, if you have any doubts about the accessibility of crucial parts, you should stagger your parts orders to receive them before you order the remaining parts. This advice may, in some cases, conflict with the previous advice about the distribution of orders in order to obtain everything. Which procedures you give priority to will depend upon your confidence that the crucial components will come through and on how much you can afford to pay in a premium for small orders.

In addition, it is good practice to order all the major electronic components before ordering the cabinets and chassis. To discover that your chassis and circuit board require a 4 × 5 × 6¼-inch cabinet when you have just bought a 4 × 5 × 6-inch cabinet only adds one more aluminum case to all the extra parts that you have been putting in the junk box. You may wish to put off buying the chassis, cabinets, and other mechanical mounting materials until after the next step of planning your layout. Then you will be sure that everything will fit.

However, do not feel too badly about violating this warning; nearly every builder does it at one or another time. I have three or four small boxes and cabinets just awaiting projects designed to fill them.

DO YOU NEED TO BREADBOARD?

Many builders follow a rule of breadboarding all circuits before constructing the final version of a piece of equipment. Others work directly on the final unit. Unless you are confident in both the circuits you have selected and in their interaction, some breadboarding may be useful. If a circuit is new to you, or if you have designed some modifications in a circuit taken from the idea book, then a breadboard model will be almost essential.

How to breadboard depends on many factors. How critical are matters such as lead length? The answer to this question may determine whether some parts are reusable in the final version. How expensive are parts? The answer here may determine whether or not you can afford two sets of some of the parts—one for the breadboard version, one for the final unit. How common is the circuit and how much confidence do you have in it? A common circuit used by many designers may bypass the breadboard stage. How many adjustments are available to you when you build the circuit? If there are many, then the circuit can usually be brought to proper operation in the final unit. If fixed components are used throughout a critical circuit, then a breadboard model is in order.

Breadboarding, besides being a test of circuit operation, is also a valuable aid in planning your layout for the final unit. On a breadboard, you can easily change the parts placement to discover both desirable and undesirable interactions. Notes on these matters should find their way into the final layout sketches. Handling the parts that go into a circuit may also tell you important facts needed for the final version—fragile leads, sensitivity to soldering heat, ease of mistaking one part for another, and a host of other details will provide good warnings in developing step-by-step notes for use in construction.

With the passing of true breadboards and gigantic components for all but the most powerful of circuits, the variety of breadboard techniques has become almost as large as the number of builders. Some use commercially available spring clips, although these are limited to non-rf use in most cases, since the lead lengths can cause problems at higher frequencies. Some builders use a matrix of tie-point strips to which components are tack soldered (that is, soldered without solid mechanical connections). Circuit boards can be divided into insulated squares, and perf boards and pins can achieve the same goal as circuit boards. For integrated circuits, there are several brands of commercial breadboards, some of which have built-in power supplies. For extensive digital design work, these are a must. Breadboard circuits can be mounted on wood or almost any other material as long as you can easily work with the components. Even an old chassis can be pressed into service. It may save much time during your future design attempts to select the breadboarding method that suits your needs and style now.

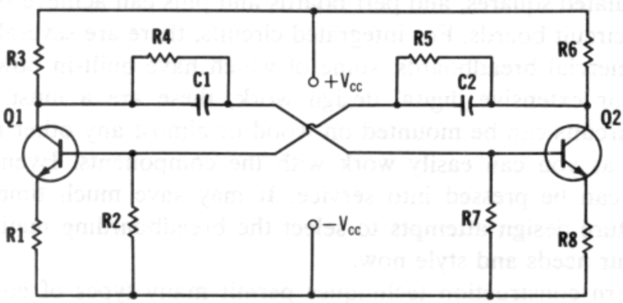
Modern construction techniques permit many types of equipment to be breadboarded and built simultaneously. If you use perf boards or circuit boards as the subchassis, and if you build each circuit or small collection of them one at a time, you may be able to install each finished subassembly into one cabinet or case. If the breadboarding method you use is also a sound building method, each experiment can contribute to the finished equipment.

CHOOSING BUILDING TECHNIQUES

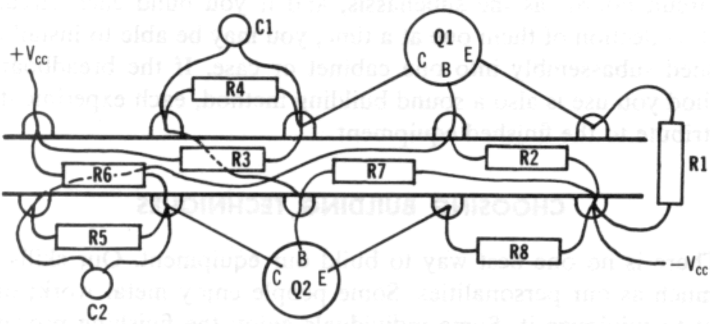
There is no one best way to build our equipment. Our skills vary as much as our personalities. Some people enjoy metal work; others want to minimize it. Some individuals enjoy the finishing process of painting and applying decals; others use blank panels and keep sketches to tell which knob is which. Some builders love to etch circuit boards; others prefer to use perf boards or employ tie-point strips for one-of-a-kind designs. Whatever the current commercial standard may be, it need not apply to us if the methods we choose as alternatives are mechanically and electrically sound. Fig. 8-1 illustrates three ways to construct identical circuits; in this case, a simple multivibrator.

In fact, we should consider methods which make use of skills we have but which manufacturers may not use. Manufacturers have gone to metal or plastic enclosures for good reasons. With due attention to proper shielding, there is no reason that the home designer cannot use wood for part or all of the enclosure. If we have skills with other materials, they are equally fit for use. At one hamfest that I attended, all eyes were turned on antenna tuners built into plexiglass boxes. Another builder used Morse code painted on his panel to identify switches.

The best building method for a given project may, in part, depend on the objectives of the project. If a unit is to be used as a permanent

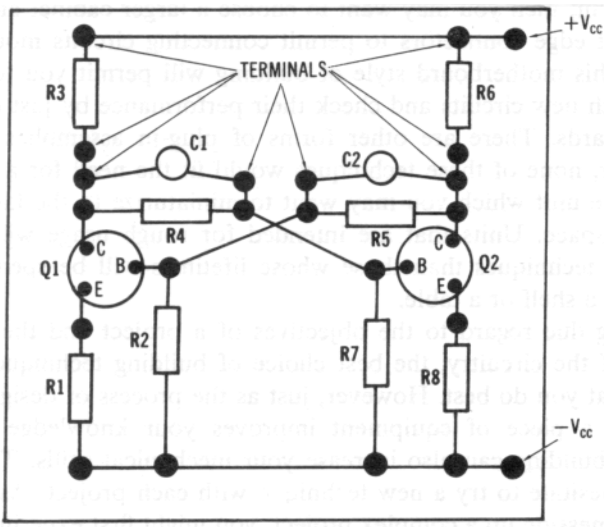


(A) The circuit.

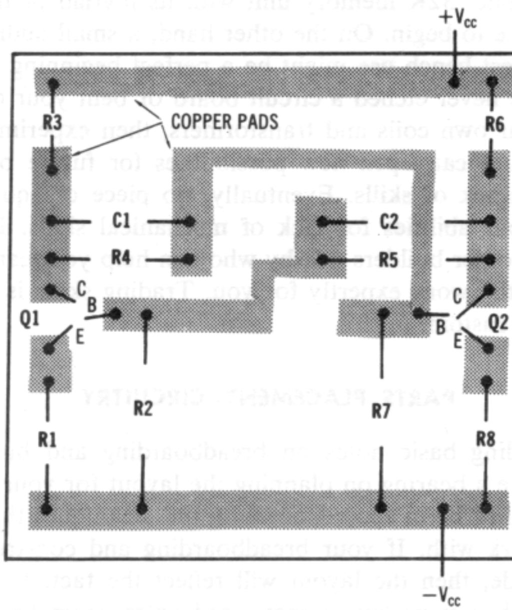


(B) Point-to-point construction using terminal strips.

Fig. 8-1. One circuit,



(C) Construction on a perfboard.



(D) Construction using an etched board.

three construction methods.

experiment, then you may want to choose a larger cabinet and install a rack of edge connectors to permit connecting circuits mounted on cards. This motherboard style of building will permit you to experiment with new circuits and check their performance by just changing circuit cards. There are other forms of plug-in assemblies as well. However, none of these techniques would fit the need for a portable or mobile unit which you may want to miniaturize to the last square inch of space. Units that are intended for rough usage will require different techniques than those whose lifetimes will be spent in one place on a shelf or a table.

Giving due regard to the objectives of a project and the requirements of the circuitry, the best choice of building techniques begins with what you do best. However, just as the process of designing and building a piece of equipment improves your knowledge of electronics, building can also increase your mechanical skills. Therefore, do not hesitate to try a new technique with each project. As a hedge against messing up a complex project, you might first experiment with the techniques on a small project, in order to learn the basic skills and discover the main pitfalls. If you have never etched a circuit board, a compact 32K memory unit with its myriad of minute lines is not the place to begin. On the other hand, a small audio oscillator designed for test-bench use might be a perfect beginning.

If you have never etched a circuit board or bent your own chassis or wound your own coils and transformers, then experimenting with these techniques can open new possibilities for future projects and add to your stock of skills. Eventually, no piece of equipment will be beyond your abilities for lack of mechanical skills. In addition, there may be other builders nearby who can help you learn a skill or who may do the work expertly for you. Trading skills is an old and honored ham custom.

PARTS PLACEMENT—CIRCUITRY

The preceding basic notes on breadboarding and building techniques all have a bearing on planning the layout for your equipment. That layout must be in accordance with the techniques that you have chosen to work with. If your breadboarding and construction techniques coincide, then the layout will reflect the fact. If you do not breadboard, then your layout may need extra room for adjustment or experimentation in case something does not work perfectly the first time.

The easiest way to plan layouts is to have all the parts on hand. Then, the sketches you make can reflect the true size of the components that will go into the equipment. In Part I, some suggestions were given regarding the sketching of layouts from articles. These sketches should have not only given you ideas to try out in your own equipment, but should have given you some practice in developing a layout for your own design as well. It is fairly obvious that complex circuit boards require complete and accurate sketches before the etching process can begin. Perf boards, tube sockets, and tie-point strips will require equal attention to prevent flaws in performance which may arise from unanticipated shorts, crossovers, coupling, and other problems.

The use of subassemblies is recommended wherever possible. Subassemblies permit the optimum placement of critical components within each circuit, the independent testing of the circuits involved, the replacement of only a small part of the project in case of a major snafu, and easier maintenance after the entire unit is completed.

In laying out the parts for the circuits, pay special attention to the following items:

1. *Signal paths*—Are they as short and as direct as possible? Are longer paths shielded and run at low impedance? Are input and output leads isolated as much as possible? Are there minimum crossovers?
2. *Components*—Will they be securely fastened? Will any component interact with any other in the circuit? (For example, are coils, except for toroids, at 90° angles to each other, or shielded?) Will all the components fit? Are any components strained by the mounting methods used?
3. *Dc paths*—Are they neatly routed? Are they isolated from possible capacitive pickup from rf and other signal leads? If wire paths, are they neatly cabled together? Are they bypassed for signal grounding at points where they enter or leave the circuit area?
4. *Switches and controls*—Are leads short? Do they carry only dc? Are they low impedance? Is necessary shielding well planned?
5. *Crossovers*—Do circuit paths cross over in ways that prevent undesired coupling? Are connecting cables between subassemblies isolated with respect to dc and signals? Are subassemblies isolated from each other either by position or shielding?

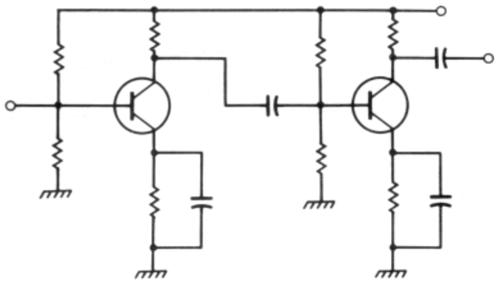
Figs. 8-2 through 8-4 illustrate some of the preceding points through the use of a series of sketches. These sketches make use of a variety of building techniques and try to show not only the most obvious errors but, also, some of the points we rarely think about when assembling a unit. They should be self-evident in their good/bad comparisons.

Not only must we use care in the placement of components and their interconnecting leads, we should also use some forethought in planning the mechanical connection points used for mounting parts, placing test points, and the like. Fig. 8-5 shows a terminal strip that is used to serve a tube socket. The sketch in Fig. 8-5A shows half a dozen things not to do, while the sketch in Fig. 8-5B shows the same components organized into a more orderly arrangement. The principles of neatness and directness that are displayed by the sketch are adaptable to nearly every situation. The sketches in Fig. 8-6A show a small subassembly that has no obvious faults with respect to circuitry. However, note where the test points and the input terminals are located—along the edge nearest the chassis and behind some components. If you mount this assembly close to another, there will be no room to insert a test probe for taking readings. The sketches shown in Fig. 8-6B illustrates a better way to handle the situation. These parts-layout considerations may be called the micro-layout arrangements. We must be equally careful of the macro-layout, the layout concerned with the placement and support of the major components and the entire unit.

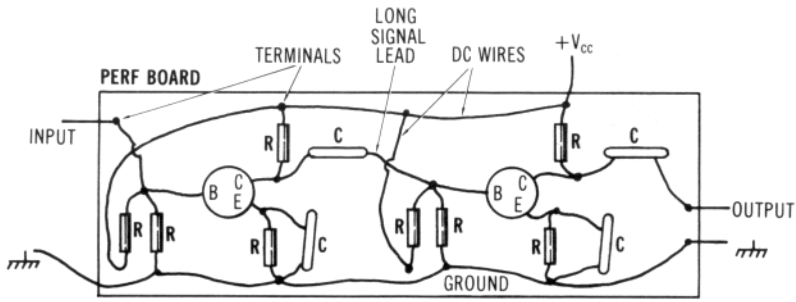
PARTS PLACEMENT—CABINETRY AND STRUCTURE

Cabinetry and structure decisions include not only the chassis and the case of the unit that we are building, they also include our thoughts and decisions on the methods that we will use to support the subassemblies, major components, panels, and controls. Some of the things you should think about are:

1. *Power supplies*—Are they positioned for adequate mechanical support of transformers and chokes? Is the ac isolated from lines into which hum might be coupled? Are high-voltage points insulated or isolated adequately?
2. *Major parts placement*—Is the size and weight distribution well balanced throughout the unit? Do all heavy components have adequate support? Will any component with moving parts inter-

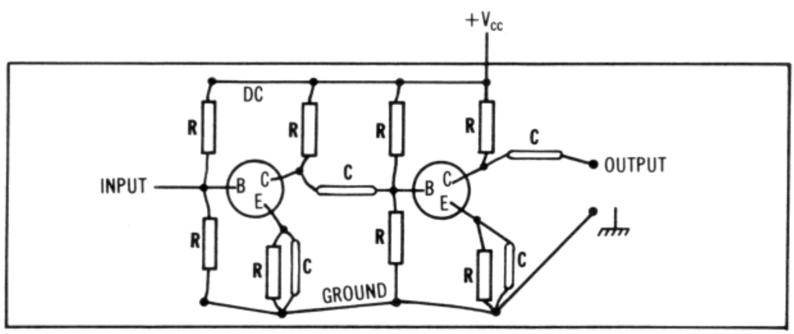


(A) Circuit example.



WORSE

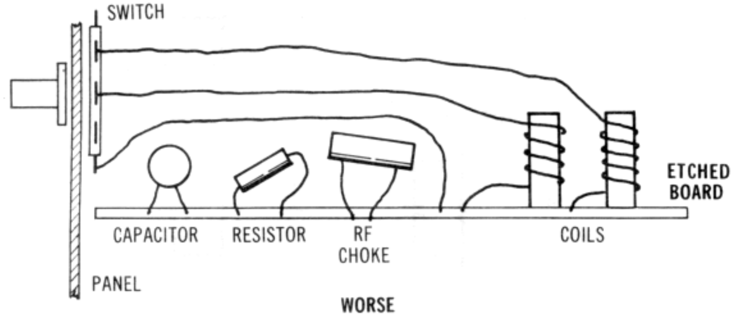
(B) Bad wiring arrangement.



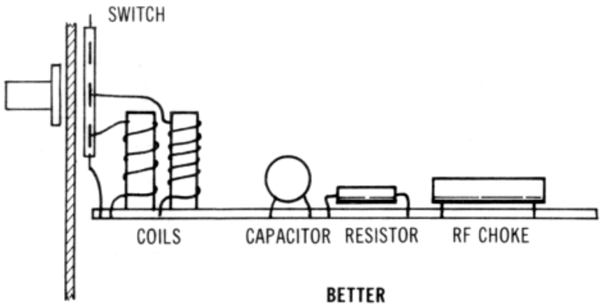
BETTER

(C) Better wiring arrangement.

Fig. 8-2. Comparison of signal paths and dc paths in perfboard construction.



(A) Bad arrangement of components.



(B) Better arrangement of components.

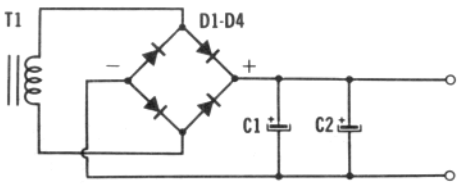
Fig. 8-3. Comparison of control leads and component mounting arrangement in etched-board construction.

fere with other components? Is there sufficient room around these major components for associated circuitry, shielding (where needed), and mechanical supports?

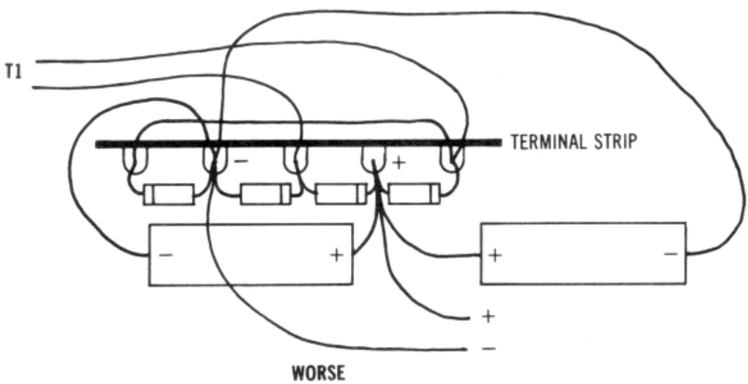
3. *Mechanical supports*—Are dials, vfo's, and other units with movable electronic or mechanical parts adequately supported for stable, unbreakable operation? Will the shafts or the mounting brackets of controls or subunits interfere with other subunits of the equipment?
4. *Maintenance*—Are subunits mounted so that they are easily removed for maintenance? Are test points accessible for metering? Are the parts mounted to the main frame or chassis easily accessible for replacement?
5. *Controls and jacks*—Are controls placed for ease of operation and minimum confusion? Are input and output jacks or ter-

minals conveniently placed? Are fuses and line cords accessible without causing interference in equipment operation?

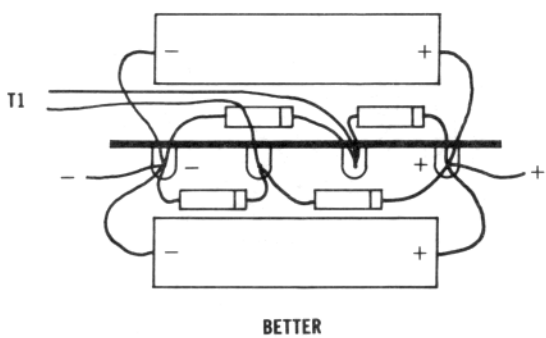
The questions asked in Item 5, above, open a new area of thought about design. In general, controls, jacks, and terminals should be



(A) Circuit example.

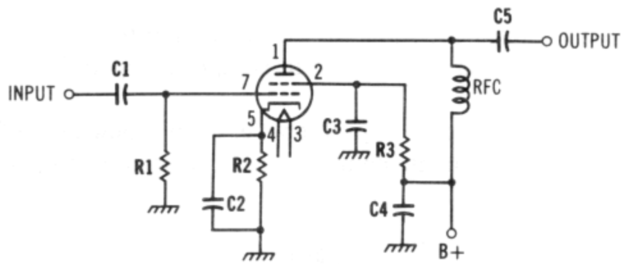


(B) Bad component layout.

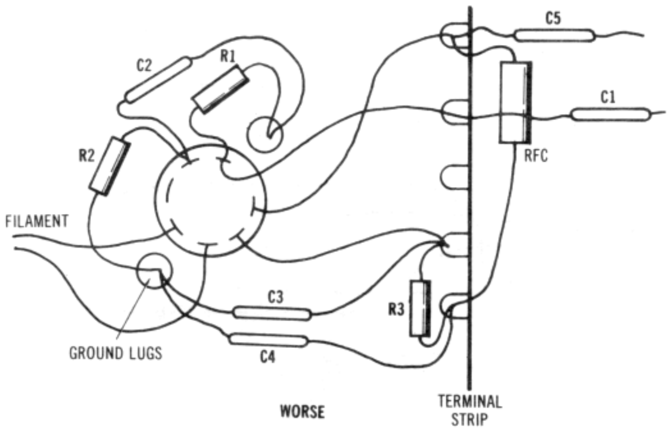


(C) Better component layout.

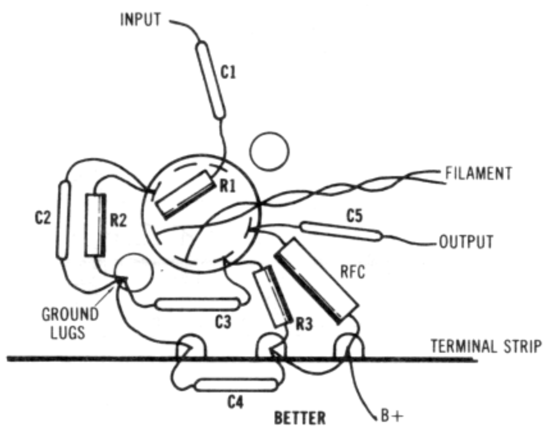
Fig. 8-4. Planning permits compactness and better component support.



(A) Circuit example.



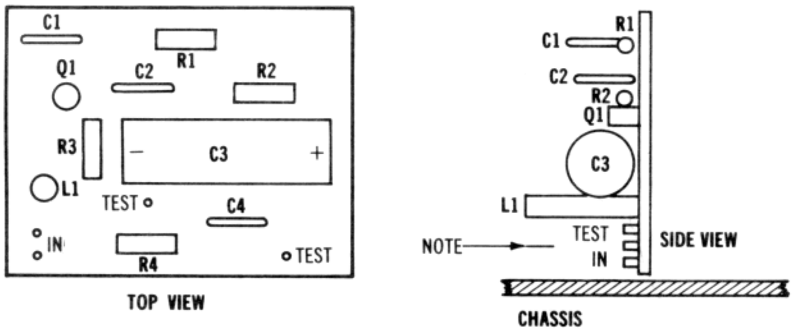
(B) Bad mounting arrangement.



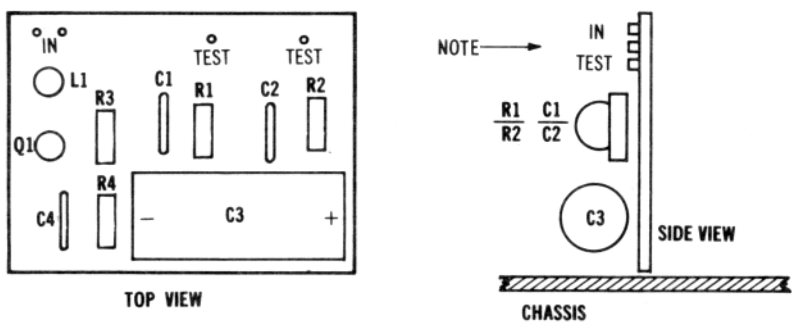
(C) Better mounting arrangement.

Fig. 8-5. Comparison of wiring and component placement for a tube and terminal strip construction technique.

placed wherever they are safe and yet convenient for the operator. However, most home designer-builders try to emulate commercial construction, even to the point of putting the same items on the front and rear panels. This policy may or may not be the best one with respect to the equipment that you are designing. Since you are custom building a piece of equipment for your own use, you are free to choose just where each control, jack, fuse, and cord will go. If you are building a cw transmitter, there is no rule that says you must put the key jack on the rear panel as most commercial manufacturers do. Where you put the jack depends on what position will give you the most operating ease and convenience. Design necessity will sometimes limit the placement of a terminal or control, but usually there are still several good choices. In principle, there is no good reason not to use the top and sides of a cabinet as well as the front panel. Again, the design of the cabinet may limit your choices, but too often we limit these choices even further by adhering to tradition rather than



(A) Test points crowded and inconvenient.



(B) Test points easy to use.

Fig. 8-6. Installing input/output and test terminals to permit convenience in use.

thinking through our true needs. The decision to use a surface should be limited only by your objectives, by circuit constraints (for example, high-impedance rf leads), by mechanical constraints (for example, a box having only independent front and rear panels), and by safety considerations.

Inside the cabinet, you have equal freedom and much the same limits. Except where a chassis is exactly right for the type of unit that you are building, the day of the large awkward metal chassis has passed. Smaller lightweight solid-state subassemblies open new ideas in construction. Subassemblies assembled on circuit boards or perfboards can be mounted vertically as well as horizontally. One method is to use plug-in boards and edge connectors. Another is shown in Fig. 8-7. Here, the boards are mounted on standoffs on either side of a

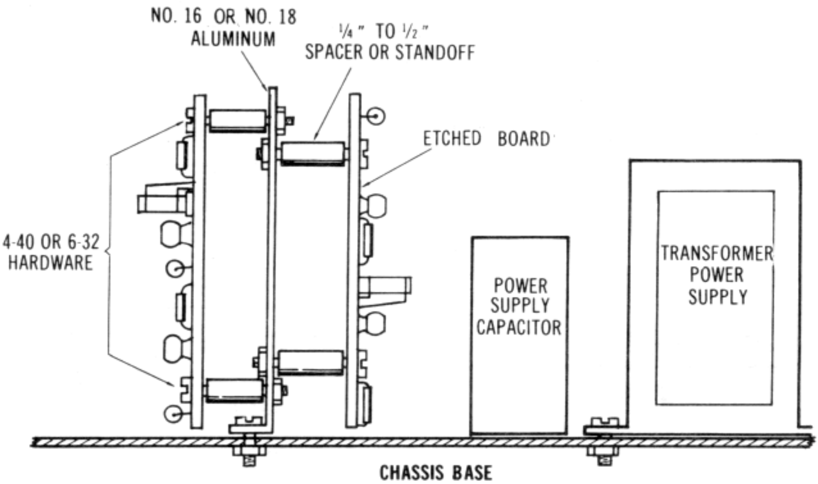


Fig. 8-7. One of the many simple methods for mounting etched boards to a chassis.

small sheet of aluminum which is mounted to a chassis. The vertical piece of aluminum provides shielding and support, all in one, while the main chassis directly supports only the power-supply components, as indicated by the transformer in the sketch. The variety of techniques are endless, and most of them require very little complex metal work.

Cabinets offer another area where there is a wide variety. Although equipment for rf usage should be well shielded, the shield need not be an expensive metal cabinet. Perforated aluminum underneath a plastic case will usually work just as well. Modern manufacturing techniques

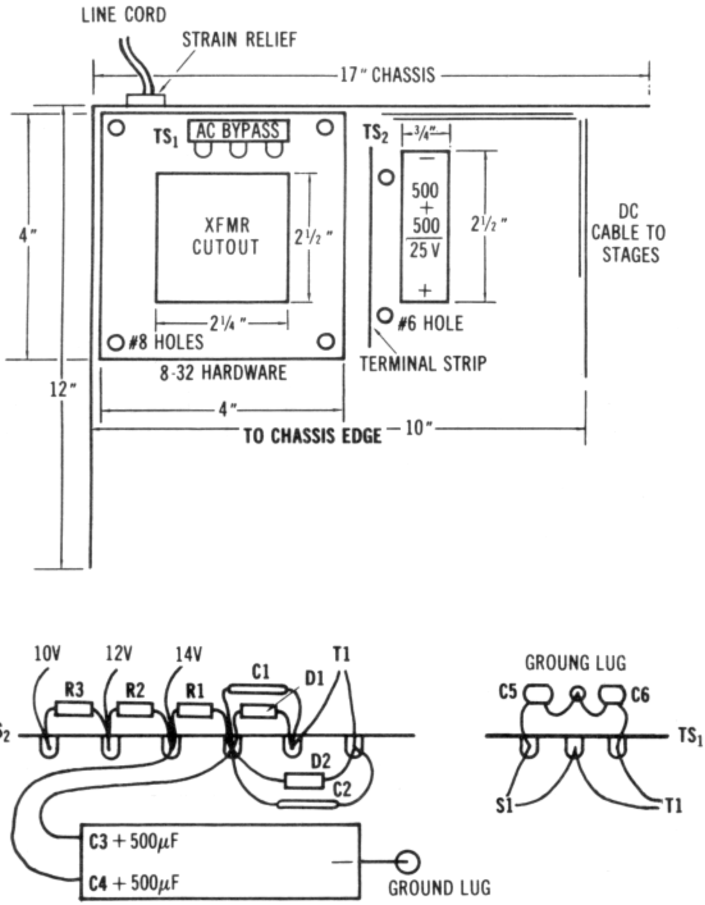


Fig. 8-8. Detailed sketch of the sample circuit.

are making plastic cabinets more readily available, and they are generally less expensive than metal ones. Perforated aluminum is also readily available. Some newer lines of metal cabinets are vinyl covered, and care must be taken where parts require a metal contact for grounding. However, many of these lines offer a new level of accessibility, since they come apart into more pieces. Which one of these cabinets will work best with your project will depend upon your design and your objectives.

The mechanical-planning part of the layout planning might, in fact, have produced some modifications in your objectives. Now, before you actually build the equipment, is a good time to perform a review

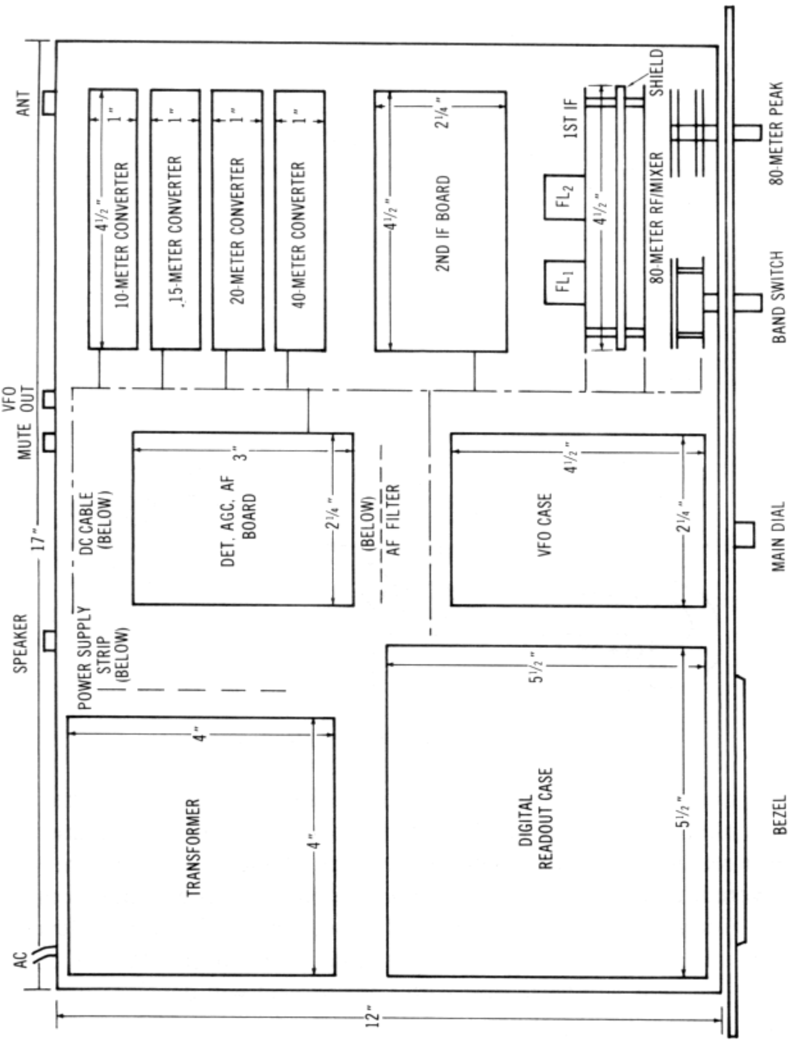


Fig. 8-9. Detailed sketch of the interior layout (top chassis) of the sample circuit of Fig. 8-8.

of your design objectives, since you might not have noticed the gradual shift of objectives or their relative importance. Operational ease and convenience are the kind of objectives that grow more important during this stage of planning. If they were not part of your original objectives, you should perhaps place them on the list now and evaluate their relative importance to other objectives (such as performance specifications). Remember that you can expect to operate this equipment for a much longer period of time than what you have spent in designing and building it.

The final product of all these considerations will be a set of sketches for the equipment we have designed. There should be a detailed drawing for every circuit, whether it is mounted on a circuit

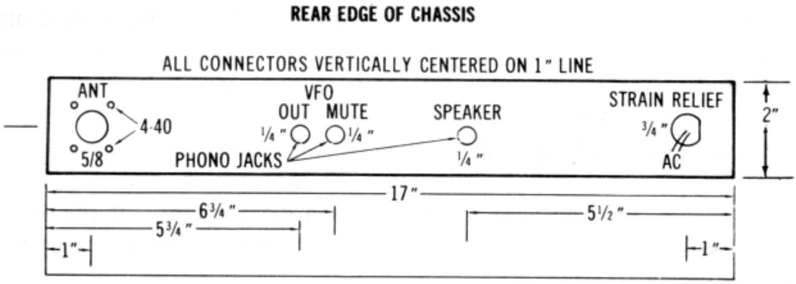


Fig. 8-10. Sketch showing layout of controls and terminals for sample circuit of Fig. 8-8.

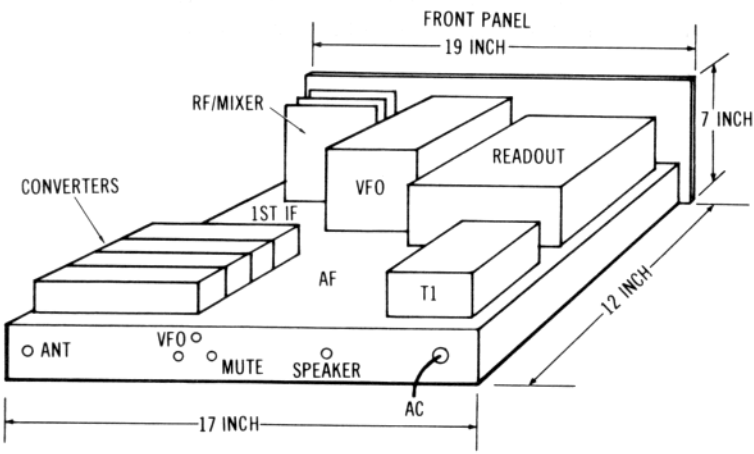


Fig. 8-11. A three-dimensional sketch of the component layout (rear view) of the sample circuit of Fig. 8-8.

board, perfboard, or main chassis. See Fig. 8-8 for an illustration of a typical sketch. There should also be one or more sketches of the overall layout of the interior of the equipment. See Fig. 8-9 for a sample sketch. A sketch of each panel that contains a control or a terminal is also needed, as illustrated in Fig. 8-10. Note that all of the sketches shown so far use two-dimensional techniques. To be sure that all the parts will fit together in the correct way, no matter what the angle of viewing, you should rough out some three-dimensional sketches, or at least some drawings from other angles, as shown in Fig. 8-11. All of the drawings should contain notes on dimensions, as well as remarks on the building work to be done, including screw-hole sizes, lead dress, and order of operations.

The end result is a set of plans that can be used for building the equipment. This set is every bit as important as the schematic diagram that we finished at the end of the last chapter. The practice that we acquired in making sketches for the idea book will help us to draw these sketches. Your work will not necessarily look like mine, since the angles of sketching and the style of work which makes something clear to you may not be the same as that which makes matters clear to me. But the goal is the same—a clear picture of the work that we have to do in order to turn our project into a real piece of equipment.

Before plugging in the drill and soldering iron, however, it might pay us to take one more look at circuit interaction. This time we will not be looking at how to get circuits together, as we did in Chapter 7. Instead, we will try to find ways to keep them apart.

Chapter 9

Circuit Interactions II—Shielding, Isolation

In Chapter 7, we looked at circuit interaction from the point of view of trying to get circuits to respond to each other in the desired ways. We asked questions about drive levels, impedance matching, and switching, as key considerations in circuit design, whenever we connected circuits together. The questions came up naturally at a point just after circuit selection, and that was the time to develop answers to them.

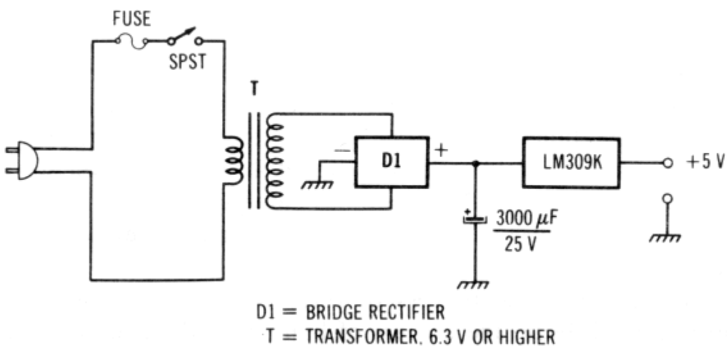
Now, we are in the process of reviewing our parts layout, and shortly, we will begin the process of building and testing our equipment. On paper, we have arranged the components in place, compiled a set of construction sketches, and drawn a complete schematic diagram of the equipment. This is a natural time to pause and examine another form of circuit interaction, namely, the kind we do not want. We shall review in this chapter some of the things we must think about to assure ourselves that the chances of any unintended circuit interactions are low to nil.

Many of the techniques for preventing unwanted interactions involve the mechanical aspects of construction. Thus, prior to this stage in the design process, we were not in a position to ask and answer all of the proper questions. Obviously, if we wait until we have built the unit that we designed, we might have a few unpleasant surprises. As in every step of the design process, we want to find the right place to ask our questions, and for questions about circuit shielding and isolation, this is it.

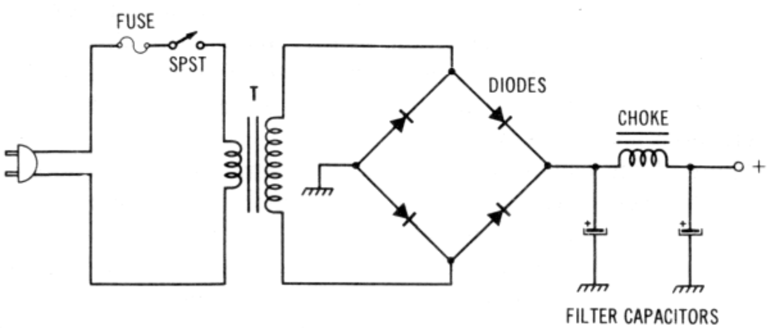
Preventing undesired circuit interaction is a subject that has three main parts—power circuits, signal circuits, and some special considerations for integrated circuits. The second part of the list is large enough to break into two subparts—mechanical and electrical means of isolation.

POWER CIRCUITS

Power circuits usually appear to be the easiest part of the equipment to build. Even regulated supplies do not create many problems, since we have a wide variety of simple devices which will handle most of our needs. Zener diodes, three-lead integrated-circuit regulators, and voltage-regulator tubes handle most of the work requirements and, thus, power-supply design is simple. Figs. 9-1A and 9-1B



(A) Low-voltage supply.



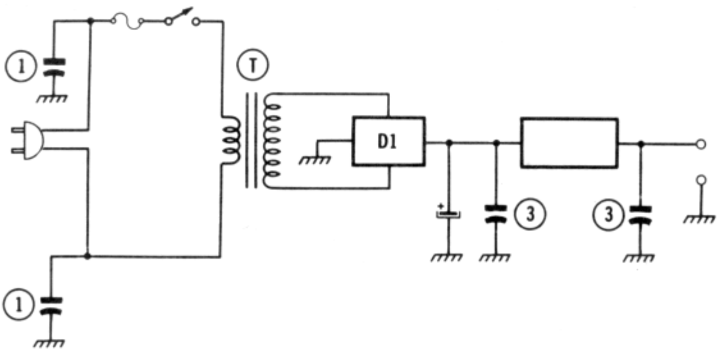
(B) High-voltage supply.

Fig. 9-1. Simple but usable low- and high-voltage power supplies.

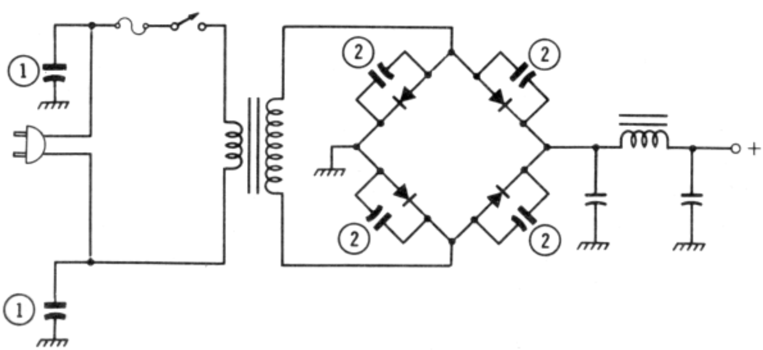
are examples of simple power-supply circuits for low and high voltage, respectively.

The problem with the circuits shown in Fig. 9-1 is that they are incomplete. Either circuit will work, and if the equipment they power is insensitive or noncritical, they might do a good job. However, they lack some features that we should have in our own equipment. Fig. 9-2 shows the same power supplies with some added features. The added components have been set out boldly and numbered. Looking at their functions in the power supplies may help us understand how a plain power supply might permit some circuit interactions that we do not want.

At the point of power entry, bypass capacitors appear in both lines of both power supplies (item 1). If the power supply feeds a transmitter, these capacitors can keep rf out of the power lines. If



(A) Low-voltage supply.



(B) High-voltage supply.

Fig. 9-2. The power supplies of Fig. 9-1 with additional components.

the device is a receiver, a piece of test equipment, or some other sort of sensitive equipment, the bypassing capacitors aid in keeping any signals on the power lines out of the equipment. Although the effect is small, these capacitors also tend to suppress any voltage spikes on the line.

The high-voltage power supply also has capacitors wired across each of the diodes in the bridge rectifier (item 2). The idea is also applicable to the low-voltage supply, but it is often less critical there. The capacitors aid further in the suppression of destructive voltage spikes, since the spikes are usually very short and the charging time of the capacitors is longer. This can save the solid-state diodes from exceeding their peak reverse-voltage rating. In addition, should a signal voltage enter the power supply, diodes without bypassing capacitors can introduce signal distortions as they feed dc to the signal stages. The bypass capacitors, at least for high-frequency rf, tend to suppress the effect.

Item 3 is located in the low-voltage supply. It is another set of capacitors connected on either side of the voltage regulator. These capacitors prevent the signal voltage, on either the filter side or the output side, from affecting the operation of the regulator. Very often, the dc lead from the power supply to the equipment it is serving is quite long. In its path through the equipment or outside it, numerous signal-voltage spikes can occur. Hence, it pays to bypass the output of the supply as a matter of course. Likewise, high-frequency voltages on the control line to the regulator will pass to ground, leaving only the load and the supply voltage to set the operation of the regulator.

Although there are no special numbers noted on the schematics for this item, be sure that the filtration of the power supply is adequate for the job at hand. Besides keeping signals out of the power supply, we also need to keep the hum inside the supply. With full-wave rectification, the hum frequency will be 120 Hz. The amount of hum or remaining ac voltage on the dc line will depend on the amount of filtering, as well as on the load. High-level high-voltage stages can stand a much higher percentage of ac ripple than low-voltage sensitive stages. In addition, low-voltage stages in many types of equipment draw large-current loads; this requires much higher values for the filter capacitors if they are to smooth the pulsating ac to the desired dc. Therefore, in a high-power rf amplifier running at high voltages, the effective capacitance of a filter may run between 25 and 50 μF. In solid-state designs, filtering may necessitate values of tens of thousands of microfarads. Such equipment may be sensitive to signal variations of only a thousandths of a volt, and the slightest ripple can be mistaken for a signal. The moral, here, is to tailor the filtration of your power supply to the application and to the load.

The power supply does not end at the edge of the board on which you mount the components. The dc lines to the individual circuits are also part of the supply. Extensive bypassing should be a matter of course. Fig. 9-3 shows the dc entry to a regulated oscillator. Note that the circuit contains a small electrolytic capacitor at the entry point, a small dropping and isolating resistor, and a ceramic disc capacitor, all before the zener regulator comes into play. The two capacitors play different roles. The electrolytic capacitor tends to hold the voltage to the resistor fairly constant, since its charge can partly compensate for sudden load surges in other parts of the circuit. The ceramic disc capacitor provides ordinary signal bypassing capability to keep the signal off the dc lines. If the application is critical enough to require shielding, the bypass capacitor might well be one of the feedthrough types.

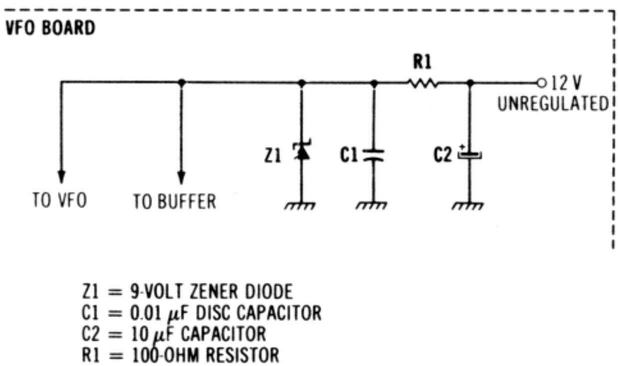
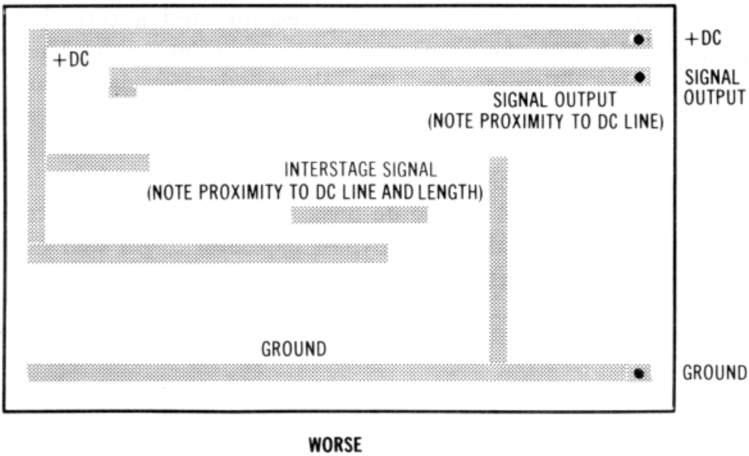


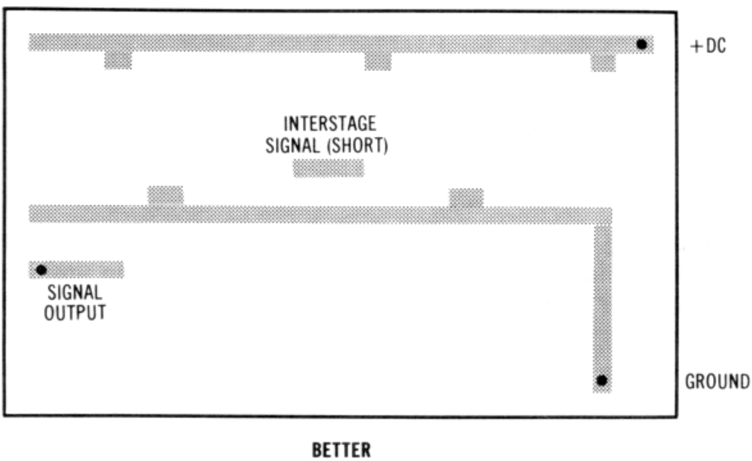
Fig. 9-3. A dc feedline path to a vfo.

The routing of the dc lead is another place to look for unwanted interactions. Placing the cables of the dc leads next to an unshielded ac transformer is asking for hum pickup. Also, running them past points of high levels of signal voltage is asking for a feedback loop to a preceding stage. This is why every stage should have adequate bypassing, no matter what kind of signal the equipment produces. It is even possible for digital pulses to latch onto dc lines and show up in the least expected and most damaging places. Correct lead placement and bypassing procedures can work together to keep signals where they belong.

Although there is some flexibility in running wire leads where we may want them, etched-circuit lines, once passed through the chemical baths, are permanent. Without good planning, we may have to redo an entire board. Because the copper plating on a circuit board is thin, the edge-to-edge coupling between a signal line and a power line is reduced. But it is not eliminated. Often, however, we can run a ground line between the power line and signal lines. An alternative is



(A) An arrangement that may permit interaction between lines.



(B) A better arrangement that may minimize circuit interaction.

Fig. 9-4. Some examples of etched-board patterns used for dc, signal, and ground lines.

to keep the signal points oriented on one side of a board and the power leads on the other side. Although some close conjunction will always be necessary, the interaction can be minimized with careful advance planning. Fig. 9-4 illustrates some "worse and better" techniques. Note that they are not strictly *bad* and *good* techniques, since the labels are not absolute values that are predictable for every case. In some equipment, the sketch labeled worse would cause no problem, while in other gear, even the better layout arrangement would present problems. However, the principles behind the illustrations are useful guides for our work.

There are many other ways to keep a power supply and its power leads isolated. A number of devices are available that can prevent surges, and there are, also, special filtration circuits. Handbooks can provide a variety of techniques and circuits for accomplishing what the simple steps given here are designed to do. But the simple steps of this section are the right ones to begin with. You should add them to your design notebook if they are not already there.

SHIELDING

Signal circuits can be isolated from each other by both mechanical and electrical means. Both techniques are good, and the reason for selecting one over the other in any given case is often a matter of ease of accomplishment, effectiveness in a given situation, and cost. Ideally, we might shield each circuit from every other one. In most cases, this drastic solution is not necessary. Certain critical circuits, such as oscillators, very-high-gain amplifiers, and circuits operating in environments filled with hostile interference are shielded as perfectly as possible. In other cases, we provide only as much shielding as is needed to prevent harmful interaction. This may mean lengthening the path for a feedback signal until its level can no longer produce oscillation in an amplifier, or it may mean providing enough cable shielding to prevent significant levels of coupling to other elements in a circuit. In general, then, we shield imperfectly because imperfect shielding is usually good enough. But then, there is no such thing as an absolutely perfect shield.

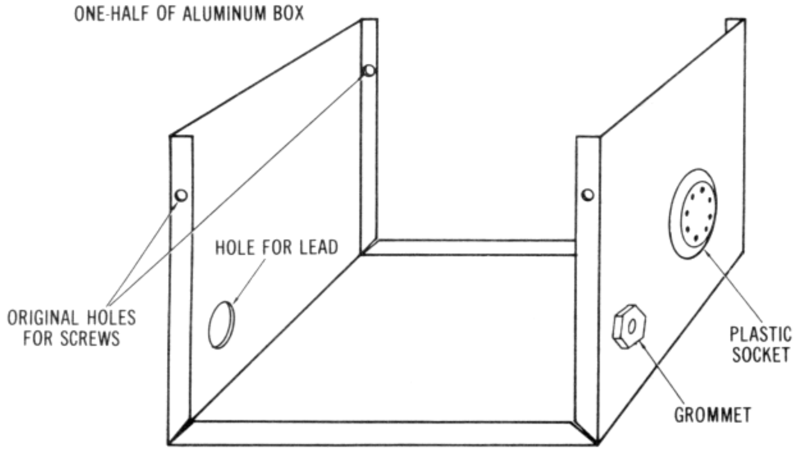
The most common form of shielding is a section of metal placed between two circuits. The metal should be conductive to signal currents. Copper is thus the best readily obtainable material. However, for most applications, aluminum will do adequately, as will steel. Therefore, the common chassis base and bottom plate, if they have no holes, make a good shield at high frequencies. There are four common techniques of shielding, depending on the material used.

A solid-metal shield is best for all signal frequencies. Unfortunately, solid-metal shields are heavy, sometimes costly, and often hard to build in the home shop. Commercially available aluminum boxes can be used to house critical circuits, and these range from light aluminum to heavy-cast metal housings. However, one common mistake that builders make with such boxes is to drill fair-sized holes in them in order to pass leads or to mount composition plugs and sockets. From about the middle of the high-frequency range upward, these holes will represent considerable leaks in the box. For applications at very high frequencies, there should be no holes that are not filled with either a feedthrough capacitor or a shielded cable jack. Fig. 9-5 illustrates the worse and better techniques of this point, as well as one other point. Small aluminum boxes usually come with holes for only four screws. The long edges of the box rely only on a metal-to-metal contact, despite the high skin resistance of aluminum. As is shown in the "better" illustration, adding more holes for sheet-metal screws can improve the shielding capability of the box.

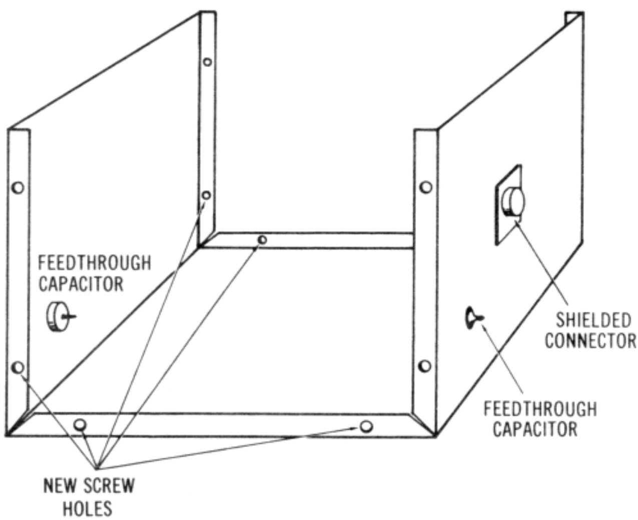
For applications that require an air flow in order to conduct heat away from the components, perforated metal is commonly used. Since the weight of a shield has nothing to do with its shielding ability, most builders use very light stock that is available from home-supply or building-supply stores. The material can be cut with tin snips. As Fig. 9-6 illustrates, a shell can be shaped from the material to cover an entire unit. Note the use of many sheet-metal screws and screw-nut combinations. Again, this is to prevent leakage. If surfaces larger than about 9 inches square are to be shielded, aluminum angle stock can be used to provide a frame and the perforated metal can be attached as panels.

Where heat is not a problem, copper-clad unetched circuit board can be soldered effectively into shielded chambers. Fig. 9-7 shows a typical application used to isolate solid-state circuitry. In this case, the dividers are soldered to a main board. Circuit paths may be etched on either the main board or the dividers prior to soldering them together. In short, with this method and some advanced planning, you can lay out the circuit and the shield lines at the same time. If your soldering is good, this technique makes a superior shield.

The final technique involves the use of foil. There are heavy-duty aluminum foils and some grades of copper sheet used for hobby purposes that are almost as thin. They are often the only means available for shielding the small plastic cases that are becoming more economical and more readily available. While foil can be easily shaped, making a good electrical connection to ground is often a problem. Holes must be punched rather than drilled, and washers then must be used to prevent the tearing of the thin metal. Even a lock washer will often twist enough to tear the metal. Nonetheless, it is often the only material that will work.

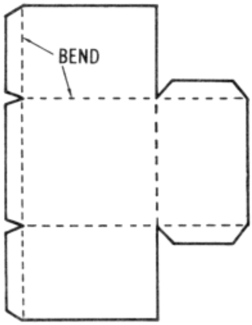


(A) As usually used.

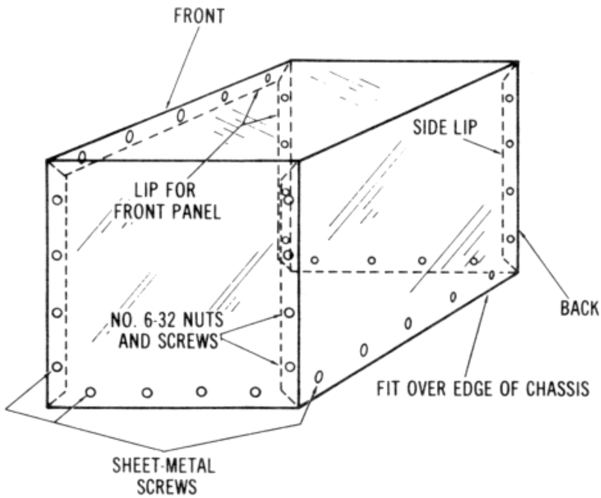


(B) A better method.

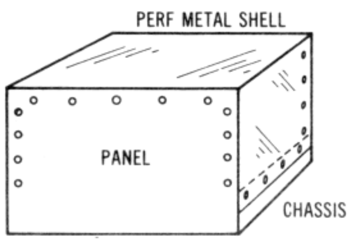
Fig. 9-5. Two ways to use aluminum cases.



(A) Shape before bending.

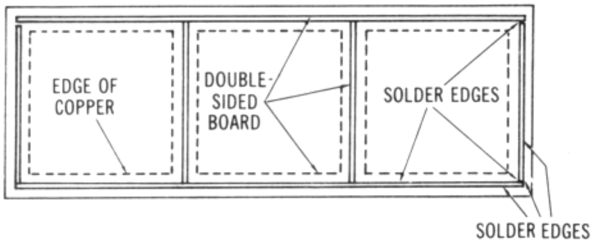


(B) Perf metal shell.

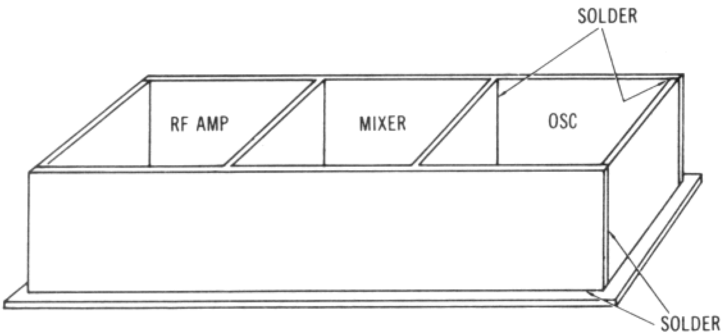


(C) Assembled unit.

Fig. 9-6. A simple perforated-aluminum shell used for cabinets.



(A) Top view.

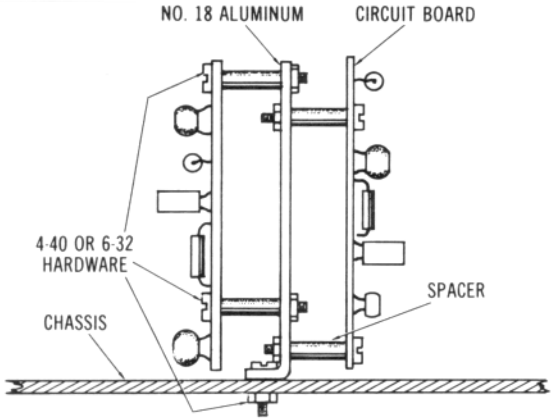


(B) Angular view.

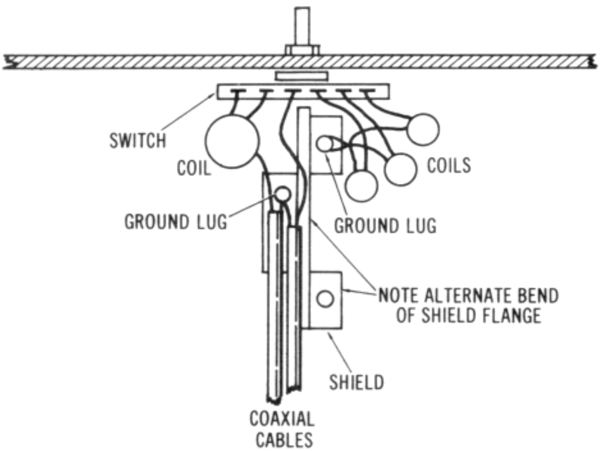
Fig. 9-7. Using double-sided copper-clad board to create shielded chambers.

For small interstage shields, a plate of 18- or 20-gauge aluminum will often work well. Fig. 9-8A illustrates a dual application. The two circuit boards are both supported and shielded from each other by the aluminum plate. The sketch in Fig. 9-8B shows a shield carefully fitted to a two-segment switch to minimize interaction between the components attached to the two segments. In addition, the cables running to the switch are also shielded. Note that they are run close to the shield so that the grounding braid has the shortest possible run to the ground connection.

The effectiveness of an interstage metal shield depends upon two main factors: first, whether there is shielding enough to prevent signal radiation or coupling to another circuit and, second, whether enough care has been used in the construction so that the shield can act as a shield. Often, we put a good basic shield in place and then fail to complete the job. The most common errors are an insufficient *good* metal-to-metal contact and an inattention to nearby leads and com-



(A) Shielding between stages.



(B) Shielding at switches.

Fig. 9-8. Interstage shielding.

ponents through which coupling may occur. The shield should extend well beyond the edges of all relevant components and should be fastened with many sheet-metal screws or screws with lock washers.

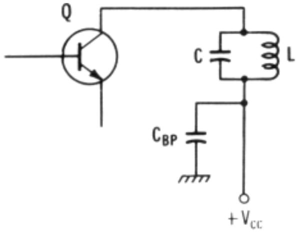
For low frequencies and cases where magnetic coupling may create problems, not all of the techniques given in this section will work. Oscilloscope cathode-ray tubes often have Mumetal shields around their necks, which house the beam-forming plates. Some scopes place the entire crt in a steel housing. Power-supply components are often isolated from the crt by a steel chassis or steel housing. The strong magnetic field set up by a power transformer can affect the operation of the oscilloscope tube. Steel, Mumetal, and other dense metals with magnetic potential effectively short circuit the magnetic field just as electrically conductive metals short circuit signal fields. Therefore, be sure to select the proper materials for the shielding you need, in accordance with the type of equipment that you are building.

ELECTRONIC ISOLATION

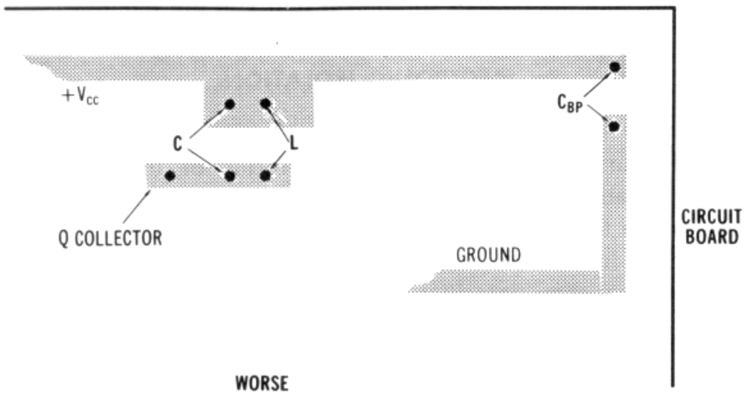
Not every form of circuit isolation depends on shields. In fact, a shield cannot ensure against many forms of unwanted signal coupling. If an oscillator has a harmonic content to its output, it will pass through the coupling cable as easily as the fundamental signal. If we bypass in solid-state circuits to compensate for high frequencies only, low-frequency parasitics may pass down the power lines and adversely affect other circuits. Let us, therefore, take a brief look at some of the design actions that we can take to control electronically undesired interactions.

The first action consists of the careful placement of all parts to minimize any potential coupling. Capacitive and inductive coupling should be suspected everywhere until you are satisfied that coupling is minimal. Capacitors whose plates are edge-to-edge rather than face-to-face couple less energy. Coils which are at 90° angles to each other couple least. Toroid coils with powdered-iron or ferrite cores are almost self-shielding. As noted earlier, separation of the signal and supply-voltage cables minimizes coupling, and wherever you can run a signal line at low impedance, you can use a section of coaxial cable. If you have a choice, transistors that have grounded metal cans reduce coupling to other components. Combining some of these ideas with judicious shielding can greatly prevent unwanted coupling.

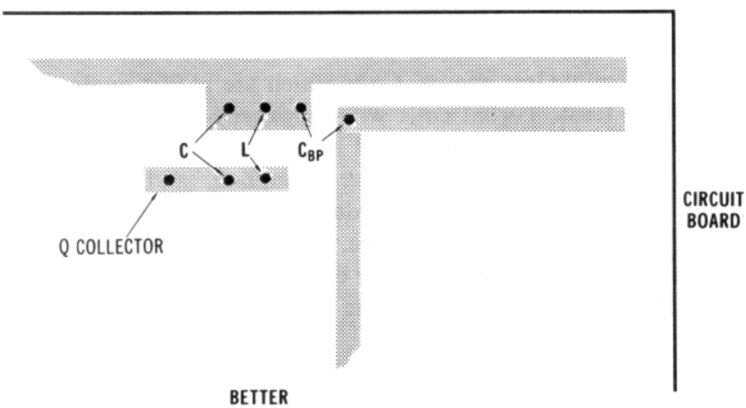
A second step that can be taken is to recheck all the filters. Every bypass capacitor and choke represents part of a filter circuit. A filter is simply a circuit which divides currents into two or more paths. We learn early that bypass capacitors pass ac and block dc. Thus, they can easily pass any audio or rf to ground while the dc goes on to the circuit. They can do this *if* they are of the right value and in the right place. Note Fig. 9-9A. The schematic shows a bypass capacitor in the dc lead between the voltage source and the



(A) The circuit.



(B) The bypass capacitor is near the power source.



(C) The bypass capacitor is near the tuned circuit.

Fig. 9-9. Effectively placing bypass capacitors in a circuit.

tuned circuit. The sketch in Fig. 9-9B shows the capacitor near the power source rather than at the cold end of the tuned circuit. The sketch in Fig. 9-9C shows a better position. At vhf frequencies, even lead length may adversely affect the ability of a bypass capacitor to do its job. And, of course, the capacitor must be of the correct value. A rule of thumb is that the capacitor should have less than one-tenth of the impedance of the alternate path for signal energy. An easier way to become familiar with values is to study circuits designed for various frequency ranges.

Similar considerations apply to chokes, which tend to oppose ac and pass dc. Since all choke coils have inter-turn capacitance, there is a self-resonant frequency, and the choke should be used only below that frequency. Again, a study of circuits that are designed for various frequency ranges will familiarize you with the proper values, as will some reading of detailed catalog listings. When using chokes, be sure that the current rating is adequate for the dc that is passing through.

Fig. 9-10 illustrates the idea that most elements in an active circuit work as part of one filter or another. In this output side of a power amplifier, there are at least six filter circuits. Circuits FL2, FL3, and FL4 are ordinary bypass circuits. Circuit FL1 consists of RFC 1, C3, and C4. As a whole, it separates the dc and rf components that are present together at the tube plate, forcing the rf component toward the antenna and the dc component through the power supply. Any rf making its way past the rf choke is bypassed to ground. Should the blocking/coupling capacitor, C4, break down to permit lethal dc to show up at the antenna terminal, circuit FL6, another rf choke,

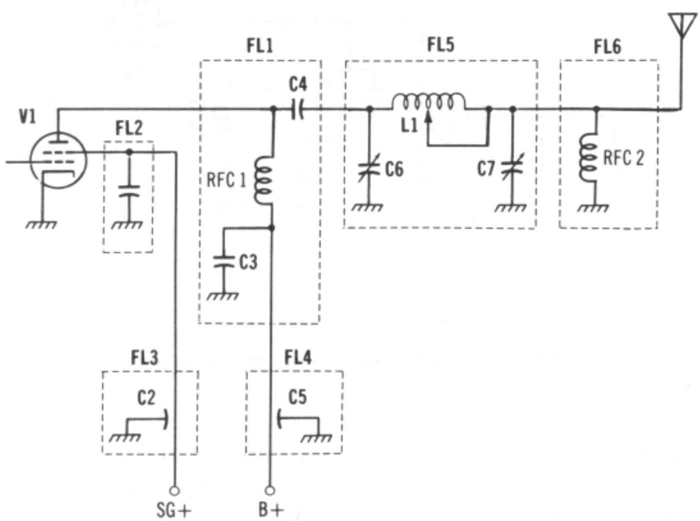
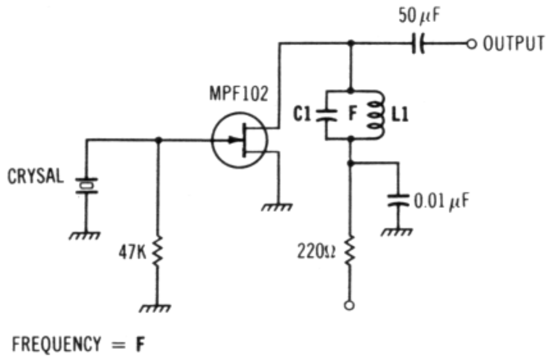
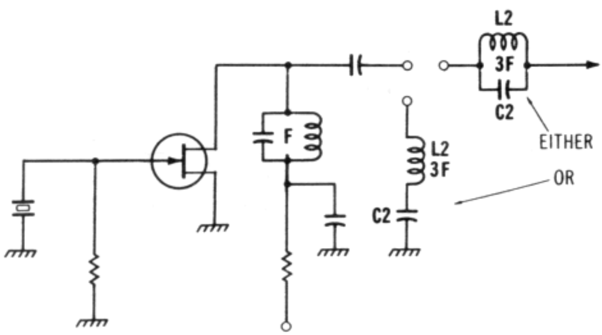


Fig. 9-10. A power-amplifier output circuit depicted as a series of filters.

would ground it and blow a fuse. Circuit FL5, consisting of C6, L1, and C7, is a typical pi-type network, which not only transforms the high-impedance signal from the tube to a lower impedance, but also suppresses most of the energy at frequencies other than the one to which the circuit is tuned. Thinking about the components of an active circuit in this way—that is, as a collection of filters—is useful in evaluating whether each type of energy is effectively moving in the proper direction and, thus, is not moving in a wrong direction.



(A) Oscillator . . .



(B) . . . with harmonic trap.

Fig. 9-11. Trapping harmonics before they cause problems.

Simple chokes and bypass capacitors may not solve all cases of unwanted coupling. Fig. 9-11A shows a simple oscillator. All proper filtering for usual circumstances has been done. However, let us suppose that the oscillator has some third harmonic output. Although much reduced from the level of the fundamental signal, the harmonic signal may be enough to mix in other stages of a piece of equipment to produce a spurious signal. In a transmitter, this might show up as an extra and, possibly, out-of-band output. In a receiver, it may be a birdie in the middle of the band. Shielding and bypassing may not cure the problem, since the harmonic may be passing through the output line. One measure that may adequately reduce the level of the harmonic is to add a tuned circuit to the output. As shown in Fig. 9-11B, it can be a series-tuned circuit to ground or a parallel-tuned circuit in the line. In either case, the circuit is resonated at the harmonic frequency. Such traps as these may cure many a problem, especially if combined with the other principles noted in this chapter.

It has been noted in several chapters that buffer amplifiers have a number of functions. They can be used to transform impedance and to control the signal level. In addition, they can help isolate stages. In Chapter 7, the isolation we mentioned concerned feedback which might create oscillation in amplifying stages. There are other reasons for isolating stages with buffers. One important use of buffers is to isolate oscillators from the pulling effect of the later amplifying stages. The load that an amplifier places on an oscillator can change the division of output power and feedback power in the oscillator. This effect shows up most strongly in keyed circuits. One way to minimize the effect of amplifier loading is to insert a buffer between the oscillator and amplifier. The buffer provides a nearly constant load to the oscillator. In solid-state equipment, where heat and the cost of buffer stages is minimal, their liberal and judicious use can prevent many problems.

The list of electronic techniques used to isolate circuits that we do not want to interact is far longer than any one chapter can list. Too, isolation methods become very specialized as we move from generalized to specific types of circuits. The exploration of handbooks and our idea books will provide additional techniques to the ones listed in this section. The key thought, however, is simple. In the evaluation of possible unwanted circuit interactions, be thorough. Every problem we anticipate at this stage is one problem that we will not have to face later and one circuit that we will not have to tear apart needlessly after we have built it.

INTEGRATED CIRCUITS

Digital integrated circuits share similar problems with linear devices when it comes to isolating circuits from each other. In Chapter

7, where we dealt with questions of load and fan-out, isolation proved to be one method of ensuring that the ICs would drive the other devices in our equipment. By using inverters or a transistor interface circuit, we could hold the load on any given IC to well within its ratings. The techniques noted in that chapter provided one kind of isolation from excessive loading.

Some unexpected forms of excessive loading may occur, especially with the TTL series of digital ICs. The regular TTL series draws comparatively large currents per device. It is possible to so design a circuit that when many devices change states simultaneously, the sudden load on the power supply will momentarily drop the supply voltage. In fact, the voltage drop need not be reflected all the way back to the supply. Load changes in parts of the circuitry may show up as supply-voltage drops in nearby segments of circuitry. This condition can create an erratic operation of the individual TTLs and produce an improper overall operation of the equipment.

These conditions show up mostly within equipment operating at higher speeds and in densely packed circuitry. Although a power supply with a large reserve current rating is necessary, it alone will not cure the condition. The cure is to have a reserve current capacity near the ICs that are likely to be affected. Fortunately, the form that this cure takes is simple and practicing the cure as preventive medicine is a good design habit. Fig. 9-12 illustrates what should be done. A series of 0.01-μF disc capacitors are placed in the supply lines close to the ICs and this solves all but the most stubborn cases. A capacitor for every three to four small ICs and an individual capacitor for each larger scale IC will keep load spikes from propagating to other devices. If the design uses multiple circuit boards, or if there are major subsections of an overall circuit, then each board or subcircuit should have a 100-μF electrolytic capacitor at the point of power entry. The key is that a single large capacitor will not solve the problem. What we need are many smaller capacitors distributed throughout the system.

Digital circuitry must be isolated not only from the effects of parts of itself, but also from external pulses and fields which can disrupt it. If digital equipment is to be operated in the presence of a radio transmitter, it should be well shielded. Careful bypassing of unwanted rf should be standard practice at every port of entry and exit. If rf is required to operate a digital unit, as with a frequency readout or counter, the initial signal should be isolated from the remainder of the counting circuitry by both shielded-signal processing and shaping

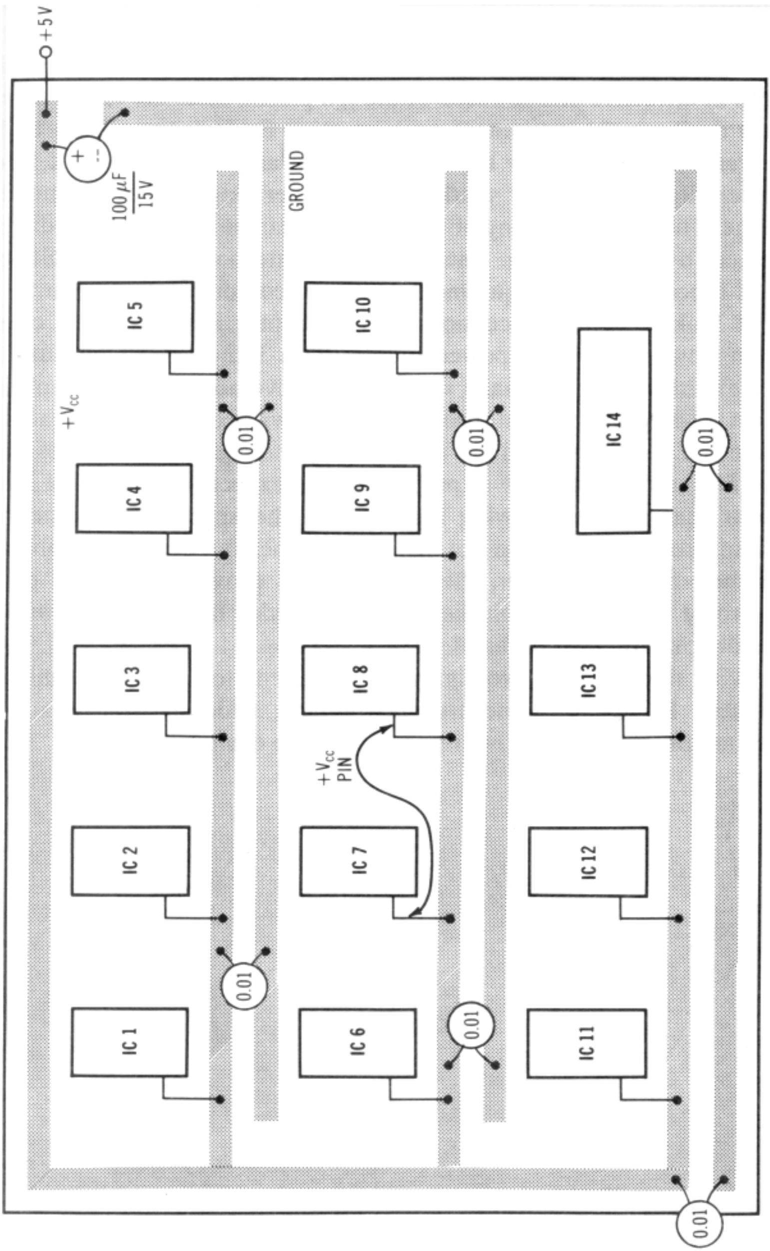


Fig. 9-12. Liberal bypassing of IC boards suppresses load interaction.

chambers and by means of signal limiting. Often, it is easier to shield the counting unit than it is to isolate all the rf sources.

Numerous pieces of commercial digital equipment are now packaged in attractive plastic cases. Although plastic cases are inexpensive, they do leave the equipment open to stray fields ranging from high-power amplifiers, power transformers, and antennas to motors, fluorescent lights, and other spark- or field-generating devices around the home. The effects of many of these devices can be carried to the digital devices by house wiring. Therefore, adequate power-supply isolation is as crucial to digital equipment as it is to communications gear.

It looks like the discussion in this chapter has come full circle from power supply to power supply. This is not at all unusual in design thinking. If we make sure that we have not omitted any of the most common potential problems of unwanted circuit interaction from our thoughts, then we have greatly increased our chances that the finished equipment will perform as we expect. Although we have spent many pages drawing attention to the specific techniques of circuit isolation, we have not exhausted either the potential problems or their cures. However, the chapter does provide a starting point for some work using both the notes in our idea book and the various handbooks we have on hand.

With this in mind, you may be impatient to begin the building process. Except for some breadboarding, a soldering iron or a drill has not been touched. The time has come to change all that.

Chapter 10

Building-Testing

The title of this chapter is not "building, then testing" nor "building and testing." The little hyphen between the words "building" and "testing" is the entire heart and soul of home building. We do the two processes together.

Up to this stage, your experience with building may consist of small one-circuit projects or of kits. For one-circuit projects, it is easy to think of the process as building first, and then testing. Similarly, with kits, the manufacturer has you work on all sorts of subunits in no good electronic order. He does this so that the unit will go together in a mechanical process which will also yield the proper electronic operation of the whole unit. He has spent weeks, months, or years of development time to ensure that little electronic ability is needed to make the unit work. The first test you perform (after visually inspecting your work) is the smoke test—plugging the unit in to see what happens. All further alignment usually follows this test. In many cases, these steps are easy because the manufacturer has provided prealigned stages or preset components.

Commercial manufacturing is much like kit building. Although some subassemblies may have test stations through which they pass on the way to the final assembly point, the general idea in most cases is to assemble, and then test and align the equipment. However, complex home design and building projects require a whole new way of thinking, one that is different from the thinking used to assemble the simple project, kit, or commercially manufactured equipment. Building a well-designed piece of equipment is not just a matter of following good construction practices. Although, you should certainly always adhere to the practices that the handbooks and various articles advise. Practice in the skills of mounting components, soldering, cabling dc leads, and etching circuit boards should be a part of every project. These skills will vary with the type of construction methods you choose and with the objectives of your design.

In fact, we will not review those practices in this chapter. The reason for this omission is that you should have thought them through in the preceding stages of the design process. The process should have started when you began to select circuits. By the time your circuit layout was fully planned, you should have given thought to and made notes on all aspects of the construction practices that your project would require.

In this chapter, we will concentrate on a way of thinking that concerns the construction of a one-of-a-kind piece of equipment that has been designed by the builder. This way of thinking will require us to combine the building and testing into a single operation. The combination also requires that we work one stage at a time. Actually, these ideas are pretty old and common. We just do not hear enough about them in the books and articles as we progress from building kits and easy projects to our more ambitious dreams of equipment design.

MAKING THINGS WORK

In Chapter 5, we listed the seven steps to designing and building your own ham equipment. The last two steps were listed in a funny way:

Step 6: *Building.* } One stage at a time, cumulatively.
Step 7: *Testing.* }

Hopefully, this way of listing the steps begins to make sense. The actual process of building is one of putting good construction practices to use in such a way that will best ensure that the equipment will function as designed and desired. This will happen only if we proceed one stage at a time, building and testing as we go.

The importance of having good layout sketches for both the details and the overall unit should be obvious. If we begin work on a small section of the total unit, we need to know in advance that it will fit together with the other stages. It will not do to reach the audio amplifier of a receiver only to discover that it no longer fits in the cabinet.

It is downright embarrassing to just about finish an oscilloscope and find out that there is no room for the cathode-ray tube. By working as hard on the layout design as we did on the electronic design, we can ensure that we will be able to proceed with the building-testing procedures, confident that we will not face such problems.

There are some exception to the rule of "doing all building one stage at a time." If we choose to build on a chassis base, it is usually best to perform all of the heavier metal work and the heavy component mounting before wiring the circuits. If the panels that will be attached to the chassis base require some metal work, this too should be done before wiring. Likewise, circuit-board etching must be completed before any wiring is done, no matter how simple or complex the board. However, to the greatest extent possible, you should follow the earlier suggestion "to do as much work as possible with subassemblies." Whether these subunits are circuit boards that plug into sockets on a mainframe or whether they are small boxes of circuits that are connected by power leads and shielded signal cables, the principle is the same. Each can be built, tested, or even replaced with minimal disruption to the overall unit. In this way, the "one stage at a time" principle can work for you.

Le us go a step further and change our whole idea of circuit construction. A good way to think about the building and testing procedure is to call it "circuit adjustment." Thus, we will be combining our circuit parts in order to *make a circuit work*. This thought may seem radical to the newcomer to the design process. Every experience so far with kits and simple projects has caused us to think of the process as:

We will build a circuit and see if it works.

Adjustment, therefore, is no more than a matter of setting a potentiometer, changing the plate position of a variable capacitor, or screwing a coil slug in or out. However, from the design perspective, nothing could be farther from the truth. Our work in adjusting circuits began in the early stages of design. Selecting circuits and circuit values were also early steps. Modifying the circuits involved adjustments, even if the adjustments existed only on paper. The directing of our attention to various forms of circuit interaction involved more adjustments and the planning of the parts layout took us a few more steps in the adjustment procedure. Now we are at the stage of adjustment that will involve handling components.

Every part of the construction and testing procedure is a matter of adjustment. This includes the mounting of components. Changing the value of a bias resistor, even if it means taking out a fixed-value part and putting in another, is also a circuit adjustment. Here are a few more examples of replacement adjustments that we might have to make at one time or another:

1. Replacing an active device with one having a higher/lower gain.
2. Rerouting leads.
3. Adding chokes or bypassing capacitors.
4. Rewinding coils.
5. Replacing capacitor-divider networks.
6. Changing resistor and/or capacitor values in timing circuits.
7. Altering supply voltages.
8. Revising ground paths.

The list could go on and on and never be complete. Every point of construction, whether it involves putting in a component or changing one, is an adjustment to a circuit, and every test we perform only tells us the effect of the adjustment that we have made. And, we do all this just to *make* the circuit work.

Of all the possibilities of circuit adjustment, we will have to think about only a few for any given stage—luckily. If we have worked through the earlier stages of design thoroughly, the number of actual adjustments we may have to make will be minimal. We will have made them on paper. Thus, they should work in practice.

TEST EQUIPMENT—RF GEAR

Before soldering that first connection, let us spend a moment thinking about test equipment. Most of us would love to have a completely equipped laboratory. However, the lack of space or lack of money makes us do with less than the best. Given that we must work with equipment that is far short of the ideal lab, what test equipment is most necessary? The answer to this question will vary with the type of project that we are building, but certain patterns of equipment apply to the two main types of projects that we may have in mind. Test equipment for rf and audio projects will differ a bit from the test gear that is most useful for digital projects.

The two most basic instruments for every project are the *vtvm* and the *vom*. The vtvm (vacuum-tube voltmeter), or its solid-state equivalent, permits us to accurately measure voltage and resistance. The high input impedance of the vtvm improves the accuracy of the reading over that of the vom (volt-ohm-milliammeter), especially in the lower voltage ranges, where the vom presents a load of just a few tens of thousands of ohms compared to the constant 11 megohms of the vtvm. Basically, the vom is for portable use for current readings.

Because current readings must be taken by placing the meter in series with the circuit, many beginning designer-builders simply ignore them. They just do not want to break a circuit that they have just soldered in place. This problem can be overcome by advanced planning. Also, current readings tell us so much about the health of individual circuits that we should never ignore them. Every amplifier, tube, or transistor will have a proper level of plate or collector current for a given application and set of bias conditions. Every digital device should draw a total current at the supply pin that will fall within a fairly narrow specified set of limits. If we plan in the layout stage to install a set of terminals or test points for taking current readings, we can check these readings during construction and adjustment. A short jumper, perhaps only a fraction of an inch long, can be installed for regular operation. Planning this measure into the design of our equipment can make tune-up and repair procedures much easier in the long run.

For rf work, the vtvm should have an rf probe. This will let us make measurements of the signal voltages along the train of amplifiers and oscillators. (For audio purposes, the ac probe of most vtvm's is good throughout the spectrum.) Some rf probes give the assembler a choice of two combinations of diodes inside the probe. (The diodes rectify the rf into pulsating dc.) With one diode, readings are more accurate, but the voltage is limited to less than 30 volts. With three diodes, the voltage rating climbs to about 90 volts, but the accuracy, especially in the low-voltage range, falls off due to the voltage drop across the diodes (about 0.4 volt per diode). Since rf probe kits are inexpensive, over the years I have built two probes, one of each type. After grabbing the wrong probe for work on a transmitter, I learned to label them with large letters.

Many of the recent *dmm's* (digital multimeters) are suitable to replace both the vtvm and the vom. They have a constant high-output impedance as well as having various current ranges. Their digital outputs are often easier to read (without confusion) than the scales of ordinary meters. However, many of these instruments are not apt for rf use and may be misread when in the presence of rf fields. In addition, many have no provision for connecting rf probes. Before converting your test bench to an all-digital set-up, be sure to read the specifications of the meters that you can afford and see if they will do all that you need them to do.

For building and design work, a *gdo* (grid-dip oscillator), or its solid-state equivalent, is more than handy; it is a life saver. Entire books have been written about all the possible applications of the gdo. Basically, the instrument is an rf oscillator with coils that permit the generating of signals over a wide frequency range. In addition, the coil is mounted externally to the case, and this fact permits the coupling of tuned circuits. The circuit under test should have no power applied to it. When the gdo is tuned to the resonant frequency of the test tuned circuit, some power will be coupled from the coil and the grid current will dip. If we know the value of either the coil or the capacitor in a test circuit, we can calculate the other. We can also pretune circuits, adjust coil spacing or capacitor settings, or make any number of other adjustments which depend upon frequency. In addition, the gdo can double as a signal generator for crude tests, and most gdo's will act as absorption wavemeters (with the power off) to sniff out spurious emissions. All this is available from one of the least expensive instruments on the market.

Beyond these instruments, recommendations for test equipment become more attuned to the type of project that we have and the type of other work that we want to do. For example, an *all-band receiver* can be useful for making checks on oscillators that do not work in the ham bands. With a *noise bridge,* it can be used in antenna measurement and adjustment. An *S-meter* can help us peak up a circuit. A *frequency counter* is useful for precise frequency adjustments that might be called, such as in setting a 2-meter fm rig. It is also handy for "tweaking" precise crystal oscillators. An *oscilloscope* will provide us with signal waveforms. For serious audio work, this instrument is very necessary; for rf work, it has some limitations. Oscilloscopes that work well at higher frequencies are very expensive. The cheaper scopes may require modification before they can be used to monitor transmitter signals. A tuning unit and direct connections to the vertical deflection plates will permit us to monitor a transmitted signal. A few scopes on the market, usually made for a specific line of equipment, will permit us to monitor both transmitted and received signals.

Rf generators and *function generators* are handy for numerous tests that require a signal source at low levels. Function generators usually operate through the audio range and will provide a variety of waveforms, in addition to substituting for the older audio oscillator. For receiver work, signals are needed for rf, i-f, and af testing. Unless our requirements are very precise in this area, equipment that is suitable and simple can often fill our needs until our experience indicates that we can justify the expense of multifeatured commerical units. A variety of *crystal oscillators* and simple *audio oscillators* can provide us with simple, almost foolproof, projects that will allow us to test a new building technique and provide a useful piece of equipment in the bargain.

Test bench *power supplies* are also candidates for the home-brewing process. For the low-voltage ranges, there are numerous integrated-circuit regulators (with up to several amperes of current capacity) that make construction simpler than ever before. For the higher-voltage ranges, handbooks contain numerous ideas for supplies that provide commonly used voltages at reasonable current levels. In home-brew test supplies, metering of the voltage and current is good practice, since these readings can often show a malfunction in the unit under test before any harm occurs.

We have come a long distance from the basic vtvm, vom, and gdo. All test gear is useful once we learn to use it effectively. Like everyone else, I dream of the perfect test shop. Then, I reach for my vtvm, vom, and gdo for over 75% of the work I do. The basic essentials will always be basic essentials.

TEST EQUIPMENT—DIGITAL WORK

For digital work, the vtvm and the vom are still basic equipment and they perform much the same function as they do with af and rf equipment. However, digital equipment operates largely on the basis of a series of pulses. If the pulse trains are correct throughout the equipment, then, ordinarily, the unit is operating properly. Beyond basic voltage and current checks, what we need most is a method to check the pulse trains of our equipment.

The least expensive way to check pulses is with a digital probe. The simplest probes take their power from the circuit under test and, therefore, are usually quite inexpensive. Most instruments will use LEDs (light-emitting diodes) to indicate a high, a low, or a pulse. There may be some limit to how useful such information is when checking out a complex piece of equipment, but as a first test, the digital probe earns its keep by its low price and ease of use.

More advanced circuit checks require a good oscilloscope. How expensive a scope we may need will depend on the speed of the digital circuitry. The instrument should have a dc input to register accurately the nearly square waveshape that digital ICs should put out. So far, most of the desired features appear in inexpensive scopes. More advanced checks of digital equipment require that we compare waveforms to check either their shape or timing. A good dual-trace scope is needed for this work, and now the price begins to climb. However, if our projects are going to be mostly digital types, then a good scope takes a much higher priority on our test equipment wish list. It just about joins the vtvm and vom as an essential item of needed test equipment.

Signal sources are as important in digital work as in af/rf work. Numerous subsystems can be checked by applying a set of pulses to them without requiring that the entire digital unit be in full operation. A reliable rf source of known frequency can check both a counter and some of the systems within it. A function generator, with its square-wave output, provides a handy signal source throughout the audio range and higher. The other waveforms can be useful in checking the effectiveness of signal-shaping circuits. As with rf test equipment, lab grade equipment may be more accurate, but it is also much more expensive than home-brew gear. For many projects, the cheap and easy way is often good enough to get a unit functioning fully and satisfactorily. For an adjustment that must be precisely perfect, there may be a well-equipped ham located nearby, or, perhaps, there is a friendly technical school or service shop in your neighborhood willing to assist you.

As with other types of equipment, digital designing and building benefits from the availability of a few power supplies on the test bench. For digital and other IC work, the requirements are more limited than for linear work. A 5-volt regulated supply for TTL devices is a must. CMOS devices operate well on 5 to 15 volts, so the TTL supply or the 12-volt supply used for transistors will work equally well. For op amps, a ±15-volt supply is handy. For other IC types, spec sheets will point the way to the right IC regulator. Some commercially available breadboards that are designed for IC use have built-in power supplies, and the breadboard, itself, may be a very useful piece of test equipment for circuit design.

Let us close this section with a rule and a warning. The rule is this: Except for the basic essential pieces of test equipment, simple home-brew substitutes for lab grade equipment should fill your workbench until you are sure that the added expense for better equipment will provide you with long term benefits.

The warning is as follows:

> What counts as a basic essential piece of test equipment contains a good bit of personal bias on the part of any writer. We all use best what we use most, and that what we grew up with is that what we are most used to, in obtaining meaningful information about the circuits under test.

This section and the last have given you my biases as well as some of the good reasons for having biases like mine. Do not be afraid to have different biases, according to your own experiences, just as long as you have a good vtvm and vom, with a gdo for rf work and a scope for digital projects.

START WITH THE POWER SUPPLY

Building-testing begins with the power supply. This beginning holds several advantages for us. First, power becomes available to all the stages that must be added for signal processing. Second, the power supply usually contains the most weighty components of the entire unit, as well as the ones requiring the greatest amount of mechanical work. Third, we can run the dc cabling around the chassis or case before adding other parts which might interface with the cable runs. Fourth, we can assure ourselves that the power supply will meet all the requirements of regulation, ripple, and load capability before the supply interacts with the signal stages.

With the exception of high-power amplifiers, some hf transceivers, and mobile vhf or uhf transceivers, commercial manufacturers usually try to include power supplies inside the same cabinet as the main unit. The chief advantage is compactness. Thus, we can carry a single unit to wherever we wish to use it. For the home designer-builder, this advantage may or may not override all other design factors. There are some considerations, however, which, in some cases, suggest the use of separate packaging for the power supply. Here are a few:

1. Will the transformer or other components create fields which might interfere with the proper operation of the equipment? If so, a separate power supply or special attention to shielding is in order. Home-brew oscilloscopes are ready candidates for a

separate supply that is housed in steel, with the scope itself housed in lighter materials.

2. Will the equipment be used regularly? If not, and if the power needed is typical of what other projects might require, then we have another good reason for a separate supply. In fact, it is good practice to standardize power-supply plugs so that external supplies can be used from project to project.
3. Will the power-supply components create a serious imbalance of weight distribution in the unit, or will they require more room in the operating position that what we desire? Size and weight are important properties of electronic equipment. This is not to say that large and heavy is bad. Rather, if something is to be large, there should be some good reasons for the size and we should have a good place to put the gear. Heavy is sometimes useful, but badly distributed weight can cause problems when we try to carry a unit or turn it on the wrong side to service it.
4. Will the power supply be affected by fields from the rest of the equipment? Rf fields can induce extra currents into power-supply components. Unshielded power supplies that use zener diodes to control regulator transistors can lose their bearings in the presence of rf to the point of blowing some components. A well-shielded and bypassed power supply housed in a separate case can prevent such problems.

On the other hand, a power supply housed in the same cabinet as the equipment gives us a self-contained unit that is without any need for special lines to control the ac source indirectly. It also eliminates the need for building special shelves under the work table. In short, no one way is best for all projects, but we should think the problem through and not just blindly follow the lead of the commercial manufacturers.

The finished supply should also include termination points for all the cables that become hot when we apply an alternating current. These termination points may be tie points, test points for current measurements, etched circuit-card sockets, or any variety of other means depending upon the construction technique. The key is to ensure a safe building-testing of other circuits.

Measurements that are taken to ensure that the power supply meets the desired specifications require loads approximating those that the finished equipment will draw. For most purposes, a series of resistors of proper values and dissipation ratings will do the job.

Measurements that are taken with no load on the supply other than that of the safety bleeders may not accurately reflect the conditions under load. Therefore, it is wise to provide for substitute loads in the design process. This may require the addition of extra test points or other means so that the substitute loads can be connected safely. By prethinking this part of the job, we can often add some tie points for the loads and then remove them before moving on to the next phase of construction.

Measuring the circuit regulation is for most purposes an easy task. Using alternately high and low resistances to simulate light and heavy loads, we can note the supply voltages. It should be noted that unregulated 12-volt power supplies for small transceivers may vary as much as 2 to 4 volts between the receive and transmit conditions. Regulator circuits should cut that variance to a few tenths of a volt. The requirements for larger equipment at different voltages will vary, but the notes in our idea book that are taken from handbooks and articles will give a good idea of what counts as good and bad performance. The following is one check that is often overlooked and should be performed. If more than one voltage is drawn from a single transformer, check the effect that the drawing of the expected load variations in the heavy load line causes on other windings. If the other voltages vary, evaluate the acceptability of the variation and determine whether the voltages may require a need for additional regulation circuits or separate transformers. Unless we take corrective measures now, such voltage drops in these unexpected places might cause frequency shifts in oscillators or erratic operation of digital circuits, among other hard to trace problems.

We can check load capability by operating the supply for some time under the heaviest average load anticipated for the equipment. If transformers get unacceptably warm, if regulator ICs become too hot, or if something blows out, we know we have some deficiencies to correct. Likewise, the ac ripple is relatively easy to measure, if we have an ac voltmeter. (This will be available in the vtvm and possibly the vom.) Some ac-meter circuits use only a single diode to rectify the alternating current into the direct current which the meter scale reflects. Therefore, measure the ac component by beginning with a scale that is higher than the dc voltage. If the reading is very low, then proceed to decrease the scale until a reasonably accurate reading is available. If the reading is the dc value, reverse the leads and try again. Since many specifications show an allowable ripple as a percentage of the total voltage, convert the reading to a percentage of the dc-voltage reading. Once the power supply meets all specifications, we can move on to building-testing other stages.

PROCEEDING WITH SIGNAL DECODERS

The next stage to be built depends upon the type of unit under construction. In general, there are only receivers and transmitters. In the most general terms, we can call them signal decoders and signal generators. All signal generators initiate signals, whether it involves the electronic generation of electronic signals, or whether it involves a conversion of human intelligence into another form, such as audio or radio-frequency electronic signals. Function generators, audio oscillators, and computer typing terminals are in a class with transmitters. In contrast, signal decoders convert an electronic signal form into a different form that will provide information or intelligence to humans. Frequency counters, vtvm's, and oscilloscopes are simply special types of decoders and, generically, fall in a class with receivers. So, too, does the output terminal of a computer.

From the double reference just given to computers, we can see that many pieces of equipment can house both signal generators and signal decoders. Amateur and commercial hf and vhf transceivers are another example of double-duty equipment contained in one case. Often, some of the signal-processing circuits will serve both functions. Wherever these double-duty circuits may occur, we should build and test them with the first set of circuits.

Let us begin with signal decoders. For decoders or receivers, this means beginning with the output stage, and in an ordinary receiver, this will usually be the audio stages. In a counter, we would start with the visual readout. The crt voltages and controls of an oscilloscope, the video output of a television or computer crt, and the alarm sounder of a protection system all correspond to the audio output of a receiver. For most devices, it will usually be easy to provide test inputs to check proper operation, and all other stages work progressively into this one. If we are not sure whether or not this stage functions properly, then when we build the next stage, we will have only doubled our uncertainty. However, if we test the first stage and verify its proper performance, then we will have cut our potential problems in half.

The principle is simple. For all decoders, we start with the output stage and work progressively back toward the input stage, checking each stage as we go. This principle does not prevent us from making a change in the output stage after we have added stages closer to the input. In fact, the modifications of gain levels and other features may well be dictated by the best performance that we achieve at points closer to the input. What the principle does ensure is an orderly sequence of building and testing which allows us to catch problems and locate them precisely for easy correction. It also ensures the best chance of an overall success in getting the unit to work as designed.

There are many designs which may call for building and testing subunits as a whole before adding them to the main signal-processing scheme. A typical example of this is the converter which may function as the front end of a hf receiver. In this and cases like it, the internal construction of the subunit can be treated in the same way as the overall project. Fig. 10-1 shows a typical progression for building a converter. Since this device required the use of a signal generator, the crystal oscillator (Step 1), we began there. Without it, no conversion would have been possible. Next we added a mixer (Step 2) and tested the combination by applying power and an rf test source, using the receiver mainframe to check the output (Step 3). Since the output of the mixer was lower than needed, we added a low-gain buffer and rechecked the circuit (Step 4). Finally, we added the input amplifier and retested the entire unit with a very low-level signal source (Step 5). Finally, the tested converter was mounted into the receiver and the combination tested once more to verify both the previous checks and the effects of the switches in the receiver on the converter signal (Step 6). Only then did we move on.

Whatever the subunit, and whatever the overall project, similar principles apply to the building-testing of all decoders. The only variation in the idea of moving from back to front occurs where we need an internal signal to mix with the processed signal. In that subsection, we begin with the oscillator. An oscillator is, of course, a signal generator and that, in turn, means that it is time to change sections.

PROCEEDING WITH SIGNAL GENERATORS

When testing transmitters and other signal generators, begin at the other end of the circuit, or at the end that is farthest away from the output. Whatever the starting point, follow the same rule of proceeding one stage at a time, testing as you go. An audio system may start with the microphone amplifier. A cw transmitter begins at the crystal or variable oscillator. In both cases, the output amplifiers are the last items built and tested.

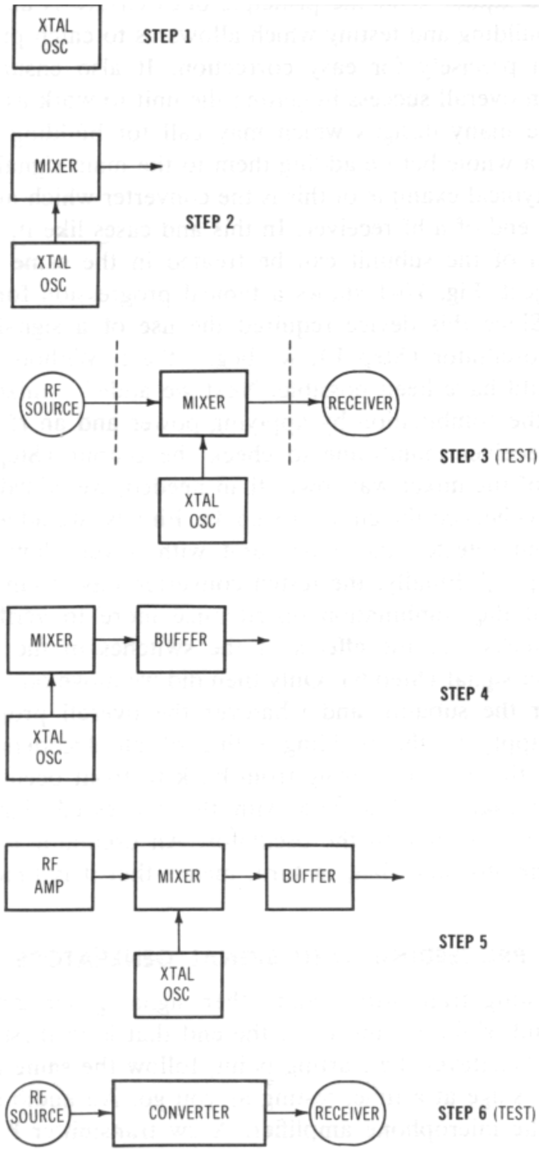


Fig. 10-1. Steps in building a converter using a signal decoder as an example.

Fig. 10-2 illustrates the general process for building and testing signal generators by referring to the block diagram for a low-power solid-state 7-MHz cw transmitter. The first step was the power supply, which in this case was a 1-ampere 12-volt supply of common design. Next came the vfo and buffer, all on one small board (Step 2). Successful testing of this circuitry allowed the next step, the addition of a driver stage (Step 3). Since this stage is tuned, testing included checks for feedback and loading of the vfo. A keying transistor that controls the emitters of the buffer and the amplifier was added next (Step 4), and checks were made for both the waveshape of the keyed signal and the effect, if any, of the keyer on the operation of the buffer and amplifier. The final amplifier and half-wave filters for the output were then added (Step 5). Checks, here, included the power output, efficiency, signal purity, and feedback. Since the vfo runs all the time during the transmit period, a "CWX" unit was added to provide power to the entire transmitter with the first key-down condition, along with a built-in delay to hold the vfo on for one second after the last key-down condition (Step 6). The circuit acts as a T-R switch. Timing, clean application of power to all circuits, and reliable operation were the vital checks on this system. The job was completed.

The preceding order of operation might well vary with equipment having more than one starting point. An ssb transmitter might begin with either the vfo, carrier oscillators, or with the audio-input stage. A second variation on the basic principle (for either decoders or generators) might occur whenever there is preliminary metal, etching, or other mechanical work to be done prior to the wiring of specific circuits. However, when wiring, the principle should still be followed. The major exception, which is common to digital work, occurs when certain feedback or control signals that are generated late in the processing procedure control the vital functions of earlier stages. Keying control circuits, such as those in the transmitter diagrammed in Fig. 10-2, can be added later; however, in many digital circuits, such control signals are a part of the functioning of the unit. Hence, an entire group of circuits must be wired and tested as a unit. Like all principles, then, the idea of working one stage at a time provides us with a good rule of thumb; however, all such rules can be violated judiciously depending upon the nature of our design.

In general, accessories should be added last. Side-tone monitors, electronic T-R switches, and vox are all accessory to proper transmitter operation and, therefore, should be deferred until we are sure

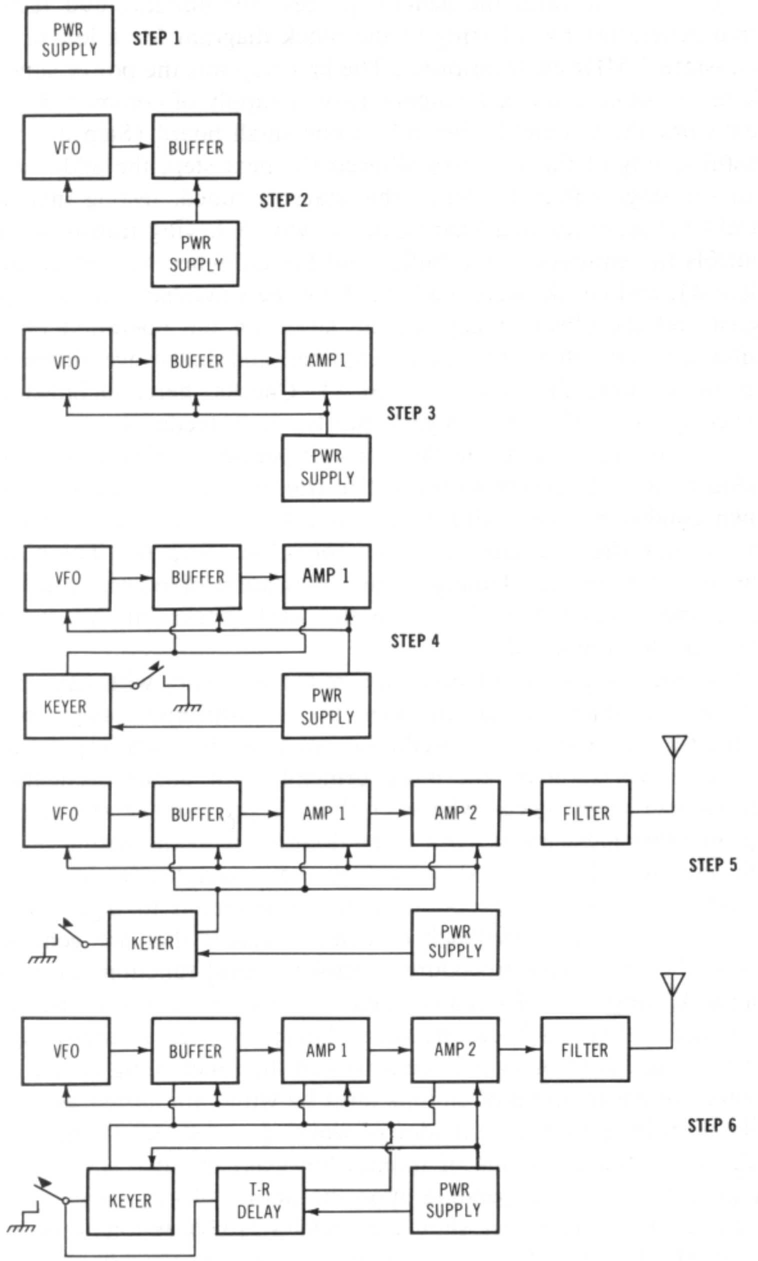


Fig. 10-2. Steps in building a signal generator using a 7-MHz transmitter as an example.

that the basic unit is functioning properly. However, what may be an accessory to one design can be a central item to another, and only careful analysis of the overall design will reveal the difference. Unlike the separate keying transistor in Fig. 10-2, blocked-grid keying, in most tube-type transmitters, has a direct affect on the design of grid-bias circuits. Thus, it should be developed with the main part of the equipment and wired in early. Likewise, agc may be essential to a given receiver design and it should be wired in as soon as the stage from which the control voltage is derived is reached. In other cases, agc may be treated as an accessory item and wired in after the completion of the rest of the receiver.

Some types of design work treat certain subunits as central items of the entire building process. They may be so improtant that nothing else in the project makes sense until we get them working. The CPU of a small computer has this status. However, once wired, the CPU cannot be checked unless we do one of two things—either we wire some of the input and output devices to check for proper operation or we develop substitute tests for proper operation. The latter option often involves constructing temporary or test inputs and outputs. These can include small keypads for inputs and LEDs for outputs, or other variations on this theme. The key idea is that if we *must* start in the middle, we will have to provide temporary beginnings and endings (inputs and outputs) to check what we have done so far. But, in no case, should we proceed without the checks. Isolating a problem after several dozen ICs are fastened in place on the board is much tougher than finding the trouble when only a few ICs are on the boards. Few things are more discouraging than wiring an entire complex circuit only to get bad results. By proceeding one stage at a time, to the fullest extent possible, our equipment grows cumulatively. We can maintain our ability and our confidence to make the equipment work as planned. This is circuit adjustment in action.

At this point, we feel ready to close the lid on the project and to start operating it on the air, on the test bench, or wherever the project may be used. However, we should pause to check once more for circuit interactions. What comes out of our equipment should be only what we intended. When something else comes out, we have work to do. So let us take a quick look at some improper outputs. Then, we can close the lid.

Chapter 11

Circuit Interactions III—Spurious Emissions, Oscillations

During every building-testing operation, we should be aware that no physical component, such as a capacitor, coil, transistor, or resistor, works as perfectly as the schematic diagram would make it appear. The size and shape of components can create unexpected problems. Some of these problems occur in the components themselves. For example, every capacitor and every rf choke has a self-resonant frequency at which the component acts as a tuned circuit rather than as a simple unit. Some problems occur because components cannot be placed in one tiny spot, but have to be spread out. The length of the leads alone can create new circuits to surprise us. The very materials out of which the components are made can produce problems. We must be prepared for all of these kinds of problems during the building process. If problems do arise, we should be ready to take some curative actions. Harmonics, parasitics, and other spurious emissions can occur in any type of signal encoder or decoder. They are most famous in the output of transmitters. However, receivers also have an output which can be filled with unwanted signals.

At the same time, as we look at a few of the major sources of building frustration, we should also be thinking ahead to operating the equipment that we have designed. The unit must connect to the outside world somewhere. There are right and wrong ways to think about that connection and, in its own way, it amounts to a circuit interaction. Thus, some consideration of the post-construction stage of our work can help prevent a number of problems from surprising us.

What we shall do in this chapter, then, is consider the final collection of potential problems. Before we close the case on our design, we shall try to anticipate a number of things that might interfere with the long and satisfying operation of our equipment.

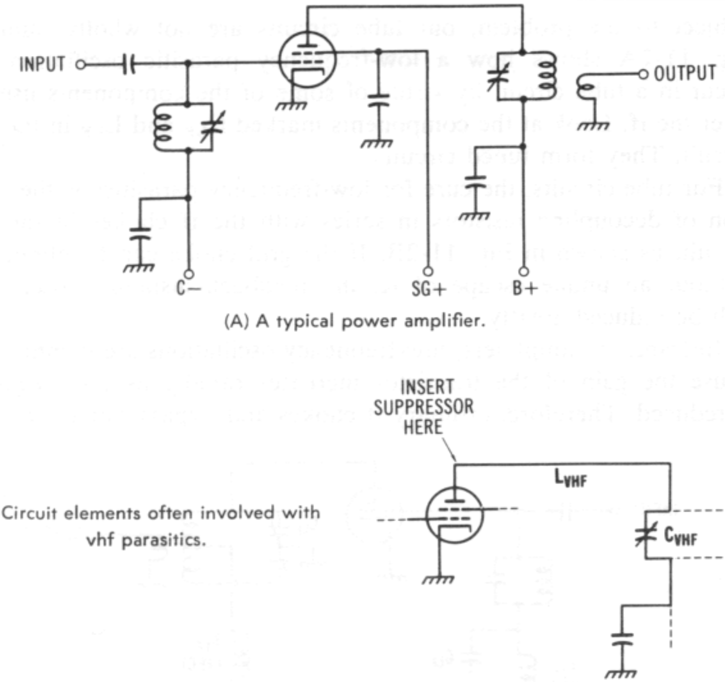
INSIDE PROBLEMS GETTING OUT

In any piece of electronic equipment, numerous spurious signals are generated. If they escape, that is, if they get into the output of our device, they can interfere with proper operation. Some of these spurious signals can get us into trouble with the FCC (Federal Communications Commission), as, for example, an out-of-band harmonic. Others can destroy the purity of the signal we want, for example, a squealing audio amplifier. Still others destroy the function of the unit, for example, extra outputs from a generator on the test bench.

Not all of the spurious signals emerge from a single stage. Therefore, we usually do not think about the possibilities until we have several stages built and the problem actually arises. The best we can do is to cure each problem as it happens. We can take some precautions to minimize the chances of encountering any problems, but we should also be prepared with some cures. Here is a starter list of potential circuit upsets:

1. Parasitic oscillations in high-frequency amplifiers.
2. Parasitic oscillations in low-frequency amplifiers.
3. Spurious mixing.
4. Harmonics.

In *high-frequency amplifiers,* the wire leads and the components associated with an amplifier can produce oscillations at some unpredictable very high frequency. This is true of both tube and transistor amplifiers. Usually we run into the problem in higher power circuits. The components are so large that we are forced to use longer leads, and these produce tuned circuits for very short wavelengths. Fig. 11-1 shows a potential case of vhf oscillation in a high-frequency amplifier, as indicated by the components marked L_{VHF} and C_{VHF}. Note that the elements do not have to be "real" coils and capacitors to act that way.



(A) A typical power amplifier.

(B) Circuit elements often involved with vhf parasitics.

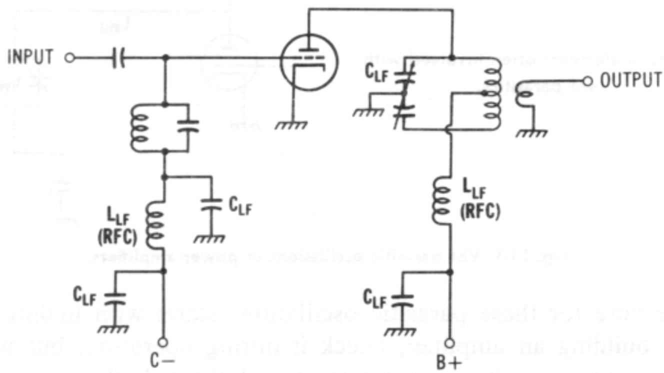
Fig. 11-1. Vhf parasitic oscillations in power amplifiers.

The cure for these parasitic oscillations starts with finding them. When building an amplifier, check it during operation, but without drive, using a sensitive wavemeter tuned through the range of 50 to 200 MHz. If you find any signals, corrective measures are in order. For tube circuits, the usual cure is a parasitic suppressor. A suppressor consists of a few turns of heavy wire often wound around a low value 1- or 2-watt composition resistor. For transistor amplifiers, where the current load is heavy and even the length of wire in a suppressor would create a voltage drop, parasitics can be controlled by slipping a carefully selected ferrite bead onto the collector lead. Representative values can be found in handbooks and articles. For this most common problem, it pays to plan a corrective measure into the basic design. You may have to change values to get good suppression, but the forethought will keep you from being completely surprised by the parasitic oscillation.

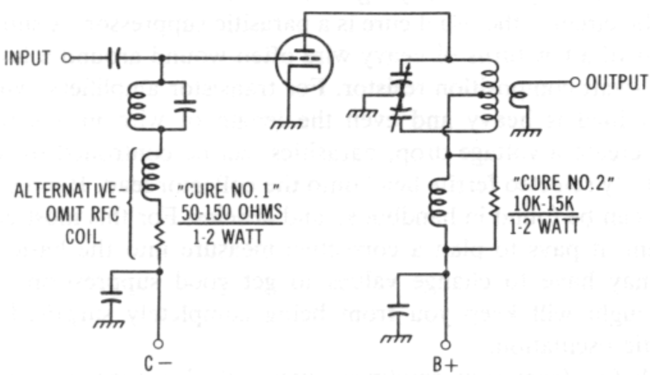
With *low-frequency amplifiers,* you will also encounter problems since not all parasitic oscillations occur above the signal frequency. Some occur at lower frequencies. Transistor amplifiers are commonly subject to the problem, but tube circuits are not wholly immune. Fig. 11-2A shows how a low-frequency parasitic oscillation can occur in a tube circuit by virtue of some of the components used to filter the rf. Look at the components marked C_{LF} and L_{LF} in the grid circuit. They form tuned circuits.

For tube circuits, the cure for low-frequency parasitics is the addition of decoupling resistors in series with the rf chokes in the grid circuit, as shown in Fig. 11-2B. If the grid choke can be eliminated without an undue escape of rf, the feedback-sustaining oscillation will be reduced greatly.

In transistor amplifiers, low-frequency oscillations are common because the gain of the transistor increases rapidly as the frequency is reduced. Therefore, ordinary rf chokes and bypass capacitors form



(A) An LF parasitic-problem circuit.



(B) The "cures."

Fig. 11-2. Low-frequency parasitic oscillation in power amplifiers.

effective low-frequency tuned circuits. Fig. 11-3 illustrates some ways to cure low-frequency parasitics. Capacitor C_{LF} can be a 1- to 10-μF capacitor, which forms a low-frequency bypass element, in addition to the regular bypass capacitor. The rf choke shown without a value is a ferrite bead slipped over the power leads. This type of choke has a very low Q and, thus, rarely can sustain oscillation. Another way to lower the Q of chokes is to place a small-value resistor in parallel with the regular choke. In troublesome cases, combinations of both of these techniques can be used.

Before turning away from parasitics, we need to remember that they infect not only rf amplifiers; audio amplifiers are also susceptible. Therefore, no amplifying circuit should be considered immune. Audio parasitics that are connected either to other audio circuits or to rf circuits can create unacceptable distortions in the output signal. Thus, the time to work cures is as soon as a stage is built.

Spurious mixing can sometimes cause problems because modern equipment, especially that designed for rf usage, usually contains several oscillators. Often, signals from various oscillators may mix in unsuspected portions of the overall circuitry and, until enough circuitry has been built, the problem will not show itself. As noted in the case of receiver "birdies," the mixing may not be a simple case of a fundamental plus or minus a fundamental. Stray harmonics of the oscillators may get into the act. In signal decoders, the effects will show up as a false signal, usually of a constant amplitude. In a transmitter, the effect may be a signal, other than the desired one, that falls inside or outside of a legal amateur band. For other types of signal generators, we may get false outputs.

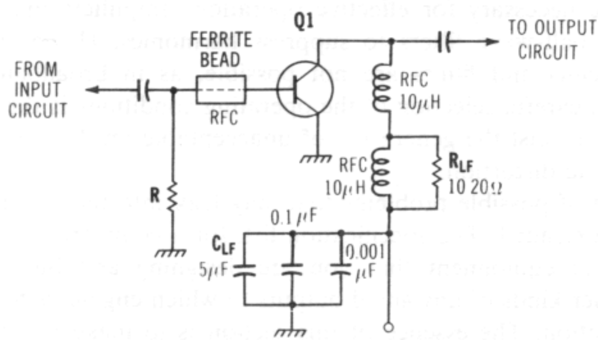


Fig. 11-3. Some LF parasitic-suppression measures that can be used for transistor circuits.

The cure for spurious mixing requires careful attention to a number of elements mentioned along the design path. Careful shielding of the circuitry and rf leads will help ensure that signals go only where we want them to go. Proper lead dress and well-placed dc-line filtering can prevent unwanted signal pickup and transmission. The addition of traps can reduce the harmonic output of oscillators. If worse comes to worse, we can always redesign the entire frequency-mixing scheme of the equipment. In fact, design arguments in favor of direct- or single-conversion receivers and for if frequencies above the signal frequency are based in part on the reduced susceptibility of such designs to undesired mixing.

Next, you will be bothered by *harmonics*. If amplifiers and oscillators were perfectly linear, there would never be problems with harmonics. However, the very design of oscillators and of many types of amplifiers require them to operate under conditions that produce many orders of harmonic energy. We noted some problems that harmonics can cause during the discussion of spurious mixing. Let us briefly note the production of harmonics in amplifiers.

Any condition which squares the wave of a signal that is passing through an amplifier produces harmonic energy and also signal distortion. Thus, anything other than pure class-A operation for single-ended amplifiers creates the right conditions for harmonics. Excessive drive causes the amplifier output to reach a limit before the input signal peaks. A large value of negative grid bias (taking an amplifier beyond cut-off) acts to square the wave as the amplifier cuts on and off. This particular condition is natural to class-C amplifiers; therefore, protection from harmonics must take the form of high-Q tuned circuits to suppress harmonic energy. In transistor circuits, where low Q may be necessary for effective operation, amplifiers may be followed by half-wave filters to suppress harmonics. However, where tuned circuits and filters are not possible, as in broadband audio amplifiers, careful selection of the operating conditions is the primary safeguard against the generation of unacceptable levels of harmonics or harmonic distortion.

The list of possible problems that may leak into the outside world could be extended. The specification list, for a commercial version of the type of equipiment that you are designing and building, will reveal other kinds of unwanted outputs to which engineers have given their attention. The essence of this section is to make you aware of some of the more basic problems and some of the simpler cures. If you attempt to clean up each stage as you proceed and if you think through potential problems as you begin to accumulate stages, the chances are that you can catch most problems in the beginning. The simple cures will take care of about 90% of the difficulties that you will encounter. The procedure of building-testing one stage at a time will make their detection and cure even easier. The remaining 10% of the difficulties that you will encounter, however, will cause anyone to go back to the handbooks and idea book for a thorough review of the circuits.

OUTSIDE PROBLEMS GETTING IN

Problems created by our equipment will leak into the outside world, and just as often, unwanted factors in the outside world get into our equipment. One major way that the outside world gets in the set is through the shell of the equipment. The principles of shielding and terminal protection were outlined in Chapter 7 and should provide guidance from this most obvious source of trouble. Mere shielding of the equipment, however, does not protect it from all the gremlins of the world. Some can sneak into the input or output terminals and not be dashed to the ground through the bypass capacitors.

Signal decoders, for example, are subjected to many problems through inputs that are too strong or too weak. In Chapter 5, we spoke of setting the drive levels between stages of our equipment neither too high nor too low. We need to take similar precautions at the input terminal. Lack of sensitivity can prevent us from being able to process an incoming signal. If the decoder is a receiver, we just do not hear the incoming station. In test equipment, we do not get any reliable readings of frequency, deviation, or whatever the parameter it is that we may be measuring.

The cure for low input is not always simply the addition of a stage of preamplification. A preamplifier can, in some cases, overload the main receiving device and create more problems than it solves. If the receiving device has some form of agc, it should, if possible, be applied to the preamplifier. This will control the amount of signal fed to the main receiver from the preamplifier. In the absence of agc, an attenuator at the front end of the preamplifier or the receiver may provide protection from a strong signal overload.

Overload at the input terminal of any signal decoder can present a number of direct and indirect problems. In some cases, excessive signal input can prevent the proper operation of a decoder. Among the most common problems are these:

1. Distortion.
2. Spurious outputs.
3. Blanking.
4. Device destruction.

Distortion is due to an excessive signal input that overdrives the first stage of the equipment, often taking it out of the linear range. In some cases, this may overload each succeeding stage, thus compounding the problem. The consequent signal distortions will show up in different ways, depending upon the exact type of decoder. In a receiver, the output audio is distorted. In an oscilloscope, the waveshape shown will not be true to the signal under test. In a television receiver, the picture may show the effects of distortion as much as the audio does.

Spurious outputs are the product of overloads. Overloads which take any stage out of the linear range may create harmonic signals. In and of themselves, these spurious signals may create no problem while circulating in the decoder, but when mixed with the outputs of oscillators, the result may be spurious signals at unpredictable frequencies.

Blanking is the effect when, under the most severe overload conditions, an expected output may not occur. Instead, the device may simply blank out or put out no output for the period of overload. When this is combined, in complex waveshape conditions, with periods of normal operation and with periods of moderate overload, the result is a garbled output that is unintelligible.

Device destruction is due to various factors including extreme overload which can destroy sensitive active devices such as transistors. This, of course, prevents the equipment from operating as desired. Overload can also be a problem even when the signal decoder is not set to the frequency of the overloading signal. This phenomenon is common with television receivers. When tuned to one of the lower channels, strong signals in the 10-meter Amateur band or the 11-meter Citizens Band can show up as distortions to the video signal. The problem results from the fact that the input amplifier of the television set is broadband; thus, its discrimination among signals well outside the desired range of reception is poor.

To a lesser extent, but with equal agony, similar phenomena occur in other types of reception. A strong signal just outside the narrow passband of a well-filtered receiver can still cause enough voltage to pass to interfere with proper operation. In some cases, the agc system may be controlled by the signal that is outside of the passband frequency. In other cases, spurious signals may be heard across the tuning range of the receiver. In test equipment, spurious reading may also result.

The cures for overload have already been noted. Basically, there are four of them.

1. *Signal limiting*—The addition of back-to-back diodes across the signal input can limit signals to less than one-half a volt and act as a safety valve for destructive overloading. More sophisticated limiting is needed to prevent distortion of high-level signals.
2. *Attenuation*—A signal attenuator in the antenna lead can provide manual control of the level of the entering signals. Such attenuators often operate in conjunction with manual-system gain controls (often called an rf gain control in receivers) which reduce the gain of selected stages in the decoder.
3. *Improved agc action*—Much of the problem caused by overloading signals within the passband of a decoder can be solved by improving the agc system to reduce system gain automatically when in the presence of high-level signals. This cure works best in designs where the agc can be applied to the very first stage of the device.
4. *Front-end passband filtering*—In severe cases, where signals outside the normal passband of the device create undesired effects, additional passive filtering may be needed at the input terminals. Such filters may be tunable or fixed and they may be ganged with the regular tuning system of the device or they may be tuned separately.

Fig. 11-4 illustrates simple applications of each of these cures. Other versions appear in many articles and handbooks.

Just as signal levels are important, both inside a device and in connecting a device to the outside world, so too is impedance matching. Much has been written about matching the output of transmitters to antennas. Much less has been written about other terminals that are used to connect the world to a piece of electronic equipment. In earlier days, when tubes were required for the front end of receivers, high-impedance inputs for maximum voltage were the design standard. Now, low-impedance current-driven devices that require power transfer, even though in the milli- and microwatt ranges, are common. So, too, is the use of low-impedance transmission lines for the signal

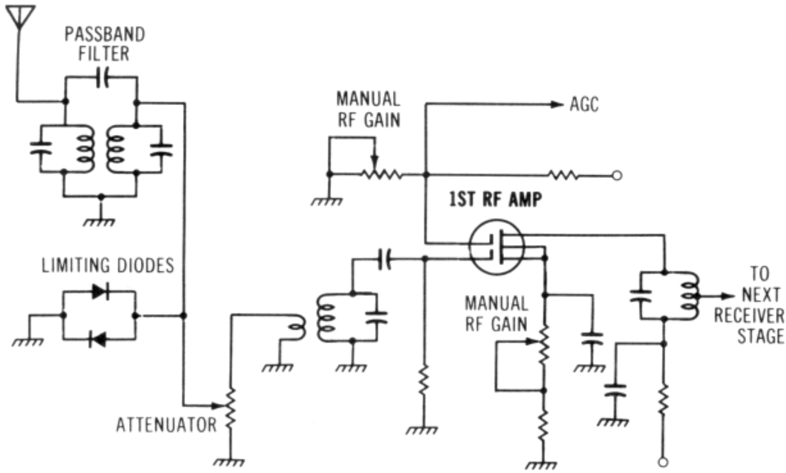


Fig. 11-4. Ways to protect receiver front ends from overload.

transfer from the input antennas to the receiver terminals, even when a voltage-driven amplifier fills the front end. Test equipment, too, makes great use of 75-ohm transmission line in both decoding and generating equipment. And, of course, the interconnection of audio amplifiers to the speakers is also impedance sensitive.

All of the notes given in Chapter 5 on impedance matching take on new importance. They apply to the input and output terminals of our equipment as well as to the internal transfer of signals. Thus, you should review your idea book and handbooks to get ideas so that you may effect proper matching for every possible entry port and exit port on the equipment that you build. Matching equipment to the world is not just a matter of getting the right signal level. It also involves getting the right level in the right way.

MONITORING EQUIPMENT PERFORMANCE

Part of the work of interconnecting a piece of equipment with the outside world consists of monitoring the performance of the equipment. A wide variety of instrumentation exists for monitoring purposes. However, we can easily spend more money and design time on peripheral checks than we do on the device itself. We have to draw a line somewhere between what is most useful and helpful and what we can do without. In the process, we should avoid the temptation of using mere window-dressing monitors.

Window-dressing monitoring is a large part of consumer-oriented equipment. Miniature Citizens Band transceivers that are designed for mobile use often contain miniscule signal-strength meters. If the operator attempts to read the meter while driving, I hope to be on a different road. His ears will tell him what he needs to know better than the meter can. Similar metering occurs in window-dress fashion on many pieces of home audio equipment. Sales may improve, but the amount of useful monitoring that is accomplished is dubious.

On the other hand, some monitoring is essential with many types of equipment. For other equipment, some forms of monitoring can be helpful, even though it is not absolutely essential. A third type of monitoring is that which is required by law or regulation, as for example, frequency and high-power determination in amateur transmitters. Let us take a brief look at monitoring from a design perspective. For convenience, we can divide monitors into an internal and an external group of instruments.

Internal monitors usually consist of meters that display levels of voltage or current, or both. The levels indicated may be either supply or signal values. Thus, on a transmitter, we may find a meter for the plate or collector current of the final amplifier. In high-power amplifiers, we also find a meter to monitor the plate voltage and, sometimes, the grid current. In most other forms of equipment, we do not find such meters. The reason is simple. In other types of equipment, we expect the values of voltage and current to remain reasonably constant, and no ordinary adjustment of the equipment will make any material difference in their values. In transmitters, however, critical adjustments affect the indicated values, and misadjustment can cause them to reach dangerous values. On the other hand, monitoring these values can assist in our adjustments and tell us when they are correct.

More common, in all forms of equipment, are the meters that are related to signals which are either generated or received by the equipment. Receivers contain S-meters to display the strength of the signal. Transmitters often have a relative output meter to show the level of transmitted signal. Audio amplifiers often contain VU meters which show signal strength on a decibel scale, and some power amplifiers have transferred this function to output power readings. In all these cases, the monitors show us at least one of two things—either the level of the signal being processed is of interest in itself or the level of the signal is an indication of the proper operation of the equipment.

External monitors are often used for similar purposes. Power meters, oscilloscope-type monitors, and SWR meters function with transmitters to indicate proper system operation. The power meter shows performance to be at a proper level; a bad reading may indicate either misadjustment or a malfunction. An oscilloscope signal monitor, in showing the quality of a waveform, can indicate both proper and improper functioning of the transmitter. The SWR indicator reveals the state of match between the antenna and the feedline connected to the transmitter and it can, indirectly, indicate proper and improper transmitter function.

Some types of monitors may not at first appear to be monitors. We have become too used to them to take them seriously until something goes wrong. A cw sidetone monitor is typical. If it does not key properly, then either the monitor is defective or our keying is faulty. Even less likely to be thought of as a monitor is the output of a signal decoding device. For example, the audio from a speaker of a stereo system or a receiver furnishes us with a continuous monitor on the functioning of the system. A no-signal or faulty-signal condition puts us instantly on the repair trail. An oscilloscope that has either a bad trace or no trace will also cause us to start repair operations. If the digital readout of a frequency counter, timer, or capacitance meter does not make sense, we will try a few reliable sources and then start attempting to fix the machine. In short, the output of signal decoders substitutes, in many cases, for the metering of a transmitter. To look at it differently, the meters in a transmitter substitute for the direct monitoring that we do of decoders.

The point of reviewing these typical cases of internal and external monitoring equipment is to call your attention to the possibilities. The crucial question for the designer-builder is what monitoring systems will be built into or added externally to the equipment under construction. The general answer is easy. Add any monitors that will provide information that is useful to you. Some information is vital, as with transmitter adjustments while other information will be of greater or lesser interest to different builders. Some builders require only basic information, and may rely upon output monitoring in decoders and signal reports in transmitters until the time for servicing is at hand. Others take great interest in keeping a close check on every facet of operation of their equipment. For one builder, the frequency counter and the oscilloscope belong on the test bench; for the other, they belong on the operating position, if not within the equipment itself.

There are no clear rules for making the decision as to whether to place a monitor inside or outside of a piece of equipment. A few questions, however, may help us decide which is best in a particular piece of equipment.

1. Will the monitor increase the size of the equipment too much from our original design aims? There is a limit to what one case will physically hold.
2. Will inclusion of a monitor significantly increase the complexity of circuitry or switching? Some internal monitors involve activation circuits which may interact with other circuits in the unit. Others may require more switches, or more positions or wafers on existing switches. If the consequent complexity of circuitry or switching is too great, we may want to use an external monitor.
3. Will the monitor be useful for other pieces of equipment as well as the one under construction? If so, then an external unit may be most useful.
4. Will the monitor provide important as well as interesting information? If the information is important enough, then internal mounting may be in order.
5. Will the monitor detract from any intended use of the equipment? Ruggedness, portability, and other such factors may be reduced by some monitors. We can also turn the question around. Will the inclusion of the monitor add to any intended use of the equipment?

These questions give you a starter list to which you can add others as they may be important to your designing and building desires.

Of course, you must plan the internal monitors of your equipment during the design phase of your work so that they will have their place in the acquisition of parts, the planning of the layout, and the building and testing of the equipment. External monitors also require planning, because if you are to get maximum benefit out of them, you must set up their operating position carefully. If the operating equipment takes up all of the prime space, the monitors may never get the use that you intended for them. However, they may also turn a good operating position into a rat's nest of connecting wires and cables, thus disrupting both pleasant operations and family relations. In fact, we should spend a moment examining the question of operation.

OPERATING THE EQUIPMENT

In Chapter 8, we examined some ideas connected with operating your equipment. Most of these ideas had to do with the device itself. However, few, if any, pieces of equipment are ever operated in isolation. They take their places in an environment consisting of people, other equipment, connections to other devices, etc. Test equipment has its bench, test cables, ac outlets, and the things that it will test. Transmitters have their keys, microphones, transmission lines, and antennas. Audio systems have signal-source equipment and connections, speakers, and the room in which they are used. Very often, the room has people, such as members of the family. The family may also include neighborhood children and pets.

An enterprising author could write an entire book on the considerations that must go into effective and pleasant operation of various types of equipment. Let us, here, start a thinking process by listing a few considerations of interest to the home designer-builder.

1. Will the operating position permit us to use the equipment as it was designed? If a shelf, table, or desk blocks access to certain controls or terminals, then, perhaps, we should rethink either the equipment design or the position design.
2. Is the operating position safe? Can anyone, big or small, hurt themselves through carelessness or accident?
3. Will other people, especially those not knowledgeable about the equipment, be a part of the operating environment? If so, then we need to think about neatness, safety, locks, or enclosures from a new perspective. The equipment must not only satisfy our design, building, and operating desires, it must also satisfy the living habits and aesthetic tastes of other people, not to mention safety again.
4. Is there a properly designed space in the operating position for all accessories, including the external monitors? Notice that this question does not ask only if there is *enough* space. It also asks if the space is properly designed for effective use of the accessories.
5. Will operation of the equipment interfere with other activities in the same room or environment? Is there a better place to put the equipment?
6. How does the operation of this equipment interact with the operation of other equipment in the same area? Placing a

number of test units neatly on shelves behind the service area may not be enough. We need to think through factors, such as how test leads may intertwine, how units located side-by-side may interfere with each other, and how we can patch from unit to unit without getting in the way of equipment situated in the middle. Good operating space, whether for servicing, communication, computing, or audio, is not merely neat. It is also well arranged from a functional viewpoint.

7. Can accidents in the home damage your equipment? Accidents can include anything from spilling dinner on the equipment to having it serve as dinner for a pet alligator. What has taken us a good amount of time and effort to design and build needs protection.

These thoughts are only the beginning of a self-evaluation process. Also to be questioned are our desires for the equipment after the design and building process is completed. We should also look into the circumstances of our homes for methods of using the equipment in an effective and satisfying way. Such a checklist for ourselves will not be easy to construct the first time around. We take too much about ourselves and our lifestyles for granted. After a few projects, or after just one accident that destroys our labor of love, we will get pretty good in compiling lists.

Hopefully, these thoughts will add to the process of "building-testing, one stage at a time." Design is not finished until we close the lid on the equipment, label all the switches and controls, clean the handling smudges from the case, place our equipment carefully into position for all to admire, and then begin to use it. The only question left is about satisfaction—will it be greater the first time we use the equipment or a year later when we realize that the device still works and that it works as well or better than many commercially built pieces of equipment?

Oh, there is *one* other question. What do you want to design and build as your next project?

Chapter 12

Summing Up

In the last 11 chapters, we have covered a lot of ground. Part I put us in a position to design our own equipment by showing some ways to gather information effectively. From both the text and schematic diagrams of articles and handbooks, we gleaned specific information about the function, design, construction, operation, and maintenance of equipment and the circuits within pieces of equipment. With this information, we found ourselves in a position to design our own equipment, even if we could not do everything a graduate engineer could do.

Part II introduced an orderly process of thinking through the design and construction of equipment. We learned to establish our objectives for a piece of equipment and learned to block out circuit functions to achieve these objectives. Circuit selection, parts acquisition, and layout planning set the stage for building and testing our equipment, one stage at a time. Along the way we paused to look at crucial elements of circuit interaction to ensure that the unit as a whole would do what we wanted it to do. Just as important, we also took steps to keep it from doing what we did not want it to do. These have been the seven steps to designing and building our own equipment.

All that is left is a bit of clean up. Computer programmers like to speak of completing the documentation. This is the last step in the process of developing a program. A similar step applies to every project that is worth doing. For our design and construction work, completing the documentation consists of working with the project notebook so that it contains all the information that we will ever need in the future.

THE PROJECT NOTEBOOK—SOME FINAL TOUCHES

Up to this point, the project notebook has been accumulating a large body of material. Every design note or sketch is in it. Among the specific items we should find are these:

1. A list of objectives that were set for the project.
2. Block diagrams setting out the circuit functions designed to achieve the stated objectives.
3. Circuit diagrams selected to fill in the block functions of the preceding step.
4. Notes on circuit elements and their interactions.
5. Parts lists and copies of orders.
6. Sketches and notes on the physical layout of the equipment to be built.
7. Special notes on construction, including shielding and isolation measures.
8. Notes taken while adjusting circuits, that is, while building and testing each stage of the equipment.

The list of materials, plus other notes that we may have found useful in our work, contains a wealth of information. In our haste to finish and use the equipment that we have built, we may leave it in this form. However, we should take time to be sure the material is organized in some logical way. What counts as a logical organization will be any arrangement that makes sense now and which permits us to find what we may look for in the future.

To supplement what we have already accumulated, we should add in a systematic way the following items:

1. *A clean schematic of the final unit,* just as we have completed it. Earlier drawings may be a bit messy from the work we have done with them. Some parts values may be only small notes reflecting what we tried while building and testing. Some values may be missing altogether because we could not put down the soldering iron long enough to make a notation. Now, before we forget all the things that we did while building the unit, we should prepare a complete schematic.

Our drawing can be broken into sections according to the subunits we built, or it can be one large single drawing. If we break down the drawing into parts, we should add a block diagram to show the overall design and how the parts interconnect as a whole. The subunit system of drawing schematics has the advantage, in complex equipment, of telling us where every part is located. This information can be very helpful later when our present clear memory of the building process has dimmed because we have been working on other projects. If repair ever becomes necessary, parts-location information will ease our work by many hours.

2. *Clear drawings of the front panel, the rear panel, and the chassis or subunit layouts,* just as we finally built them. Working with real materials may have altered some of the precise dimensions from earlier plans. Some parts may have required last minute substitutes. Better ideas might have struck us at the last minute. The new drawings will record all these changes of plans so that we will have a record of the mechanical portions of our labors.

   Good sketches of the mechanical portion of the equipment are as important to future maintenance work as good electrical sketches. They can keep us from needlessly breaking mechanical assemblies, stressing cables, or marring the cabinet. They, combined with the schematic diagram, will make the work of locating parts easier. Finally, they also make good reference points for future projects.

3. *Notes on the typical operation of the equipment.* These notes should be as complete as possible. I suppose that a unit with only an on-off switch might be exempt from this advice, but most of what we build is a bit more complex. Transmitters require notes on tune-up procedures, neutralization, alignment, as well as a set of dial readings for proper adjustment on each band. Receivers also need alignment procedures, plus useful notes on the effects of each control and their interaction, the most useful ways to employ filters for enhancing or nulling out signals, methods of calibration, and other matters. Test equipment should include notes on the occasional internal adjustments and on the proper methods of connecting test set-ups.

   These samples should provide some ideas about what type of notes might be most usual. In personally designed and built equipment, there may also be idiosyncracies which deserve note. One-of-a-kind equipment usually has a few hitches and glitches which we live with rather than change. Many times, these notes have the sense of "do not do this." Well, no one is perfect. Even commercially built gear contains certain warnings.

4. *Notes or charts of signal and dc voltages, device currents, and circuit resistances.* Signal voltages and dc voltages can be entered on the schematic diagram or arranged as a chart. Most tube-type equipment has traditionally referenced the voltage readings of the tube pins. Solid-state equipment, in all its diversity and integration, does not make these reference points easily accessible or even desirable in all cases. Readings taken at interstage points, such as coils, transformers, and coupling capacitors, can be just as useful from a maintenance perspective. If values appear on a chart, a clear reference indicating the point of the reading is essential. Similar rules apply for taking the current readings of active devices and, also, for resistance readings. As a note of caution, around solid-state devices, reversing ohmmeter probes can yield a change in the resistance reading.

   Taking all these readings will provide a record of the normal operation of the equipment that you have built. If you ever have to troubleshoot your unit, they can help you locate a problem source speedily.

All of these notes can be placed at the beginning of your project notebook, since they are the first matters that you will need for any future reference. You can expect three major occasions for looking at these notes, besides showing them to friends out of pride. The first is for servicing and routine maintenance. As a side note, the more regularly you make routine checks, the less you will have to make service and repair tests. The second occasion will come up if you sell or give away the unit. Your notes will provide a complete operating and service manual for the new owner. If this happens, save a copy of the notes for your records and keep them with the design and construction notes, which the new owner will not need. Then, there is a third possible use. If you ever have the urge to write up your project for one of the amateur radio or electronics magazines, you will have all the information you need at your fingertips. Some day, you may even want to write a book making your project ideas available to others.

WHEN TO REUSE THIS BOOK

The main purpose of this book has been to develop a step-by-step thinking process so that the relatively new electronics builder can move from soldering circuits to designing his own equipment. The new builder may be a ham who has recently upgraded his license and his interests, or a service technician who wants to create in addition to repairing, or, perhaps, a hobbyist or computer enthusiast who wishes to build what others buy. This book is based on the premise that clear thinking is nine-tenths of the battle to successful design and construction at any level of skill and electronics knowledge.

The seven steps to design and building are nothing more than aids to clear thinking. As such, they have no magic. As you progress in the art of design, you will begin to alter them to suit your own individual way of going about things. More and more of the work will become natural to you. You will discover that you need fewer checklists about the procedure and more of your notes will deal directly with the design itself.

Having a workable system to begin with can make the process of growth more rapid and more successful. Experience has shown the system described in these pages to be very workable. Although we have stressed the steps to design, another element worked closely with these steps. The element was evaluation. In fact, we have been learning to evaluate two things at the same time. First, by asking the right questions at the right time, we have sharpened our abilities to evaluate situations in electronics. This skill should carry over into other electronic endeavors, which may range from servicing a piece of equipment to teaching others to master the skills we are acquiring.

The second item of evaluation has been ourselves. One of the hardest tasks we can ever be assigned is to set down objectively what we desire, what we have as goals, what we want to get out of an activity. By being able to set all of these things down on paper, in the form of design objectives that cover the field from operation to appearance, from circuit function to construction technique, we have gained a skill that transfers into every part of our lives. A quick mental inventory of all the things we own and of all of the activities that we engage in will show the profit of working on this skill.

The thought processes described in these pages even have application to the amateur or the electronics enthusiast who does not plan to build. The stages of design thinking can help in the evaluation of commercially available equipment. By thinking through our objectives in having a piece of equipment, we can determine what features are important and what features we can do without. By examining the manufacturer's literature, we can learn how he has designed the equipment to meet his objectives and what circuits he has chosen to satisfy each block function. Examining the parts layout and the construction techniques can tell us what advantages he wanted to gain and what potential problems he wanted to overcome. The examination can also tell us something about what difficulties he could not overcome and what potential problems we may have to face as a purchaser of his equipment. In a more general vein, the close look we take of commercial circuitry and construction can teach us much about the interaction of the physical and electronic dimensions of equipment. All of this will not only make us more intelligent buyers, it will also add to our understanding which will make operating and servicing equipment more satisfying.

Ideally, then, you should glance through this volume each time you begin a project or each time you contemplate an equipment purchase until you have mastered all of the basic principles involved. Mastery of the principles does not mean memorization. Precisely the opposite. Mastery means using these principles as a starting point for the development of your own unique system of design.

One good way to proceed is to make notes in the margins or on pages you insert in your idea/project book. These notes may contain your set of questions or steps for each stage of the design problems that you usually work through. The type of equipment you design, the type of construction you prefer, and your own special uniqueness will eventually yield lists that vary from mine. I have no doubt that your lists can be better than mine. Design thinking needs progress as much as design does itself. One day, I may read your book on design with much appreciation.

In the meantime, apply two tests to the design system that you develop for yourself. First, does it produce a design procedure that is satisfying to you? In other words, are you comfortable going through its stages on the way to constructing the equipment you want? Second, does it produce success? To put this in other words, is the end result a piece of electronic equipment that meets your design objectives and leaves you proud of your work? If your system meets these two tests, whatever the level of electronic sophistication, it is the right system for you.

Other Publications

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