CRYSTAL SETS TO SIDEBAND

CHAPTER 3A

SETTING UP AN AMATEUR WORKSHOP

Research and Development as Recreation

Building an amateur radio transmitter and receiver from the component level up is true research and development. That's why it's fun. Sure, it's easier than developing truly new inventions that have never existed before, but conquering the details will be hard and you'll find it plenty satisfying. When you're done, you can brag about your rig to your ham buddies. These days, if you have a 100% homebuilt station, you'll find you are extremely rare among other hams.

Reading this book you will notice that I have an aversion to modern digital electronics. Yes, I'm a Luddite. I am capable of building digital gizmos and there are some small examples in this book. I worked for 10 years programming embedded microcomputers in medical devices. It isn't that I can't do the work, it simply isn't fun any more. Modern circuits are arbitrary and endlessly detailed. Today electronics is like doing the income tax for a large corporation - zillions of random details.

In the 1970s, the early microprocessors were fun. The data sheets were 10 or 20 pages, not hundreds of pages. If you wrote down what you wanted the processor to do, the steps were easy to program and they (nearly) always worked. It was comparable to an entertaining Sudoku or cross-word puzzle. Programs were a couple thousand bytes, not hundreds of megabytes. Modern electronic design is endless, arbitrary details originally written down by some over-worked guy at 3 AM. You must clear the interrupt on pin 36 before re-initializing the subroutine variables on page 78. Oh, and pin 62 on IC-7 needs a pull-up resistor. Normally, it wouldn't matter, but if you read the footnote on page 226 ... and so on. Even if your design and software are perfect, truly modern electronics can't be built in a basement on homemade circuit boards.

Consequently, my projects are usually analog. Basic radios - communication systems - are plenty challenging for me. We can figure out how they work and how to make them better. A big surprise for me was that I often "invent" novel circuits, such as FM and AM detectors. I've never heard of these circuits before, but I'll bet a thousand other guys have "invented" them before me. Technically, they're probably not new, but ***it feels like I'm Edison, Marconi or Armstrong.*** My circuit actually works! Astounding! I did it! That is a true thrill and that's why I do this hobby. I describe my projects in this book and then you send me pictures and diagrams of ***YOUR*** "inventions." Your feedback and suggestions often launch me into more projects.

The masters' methods

We can learn how to do R & D by studying the methods of the master inventors. We Americans would probably nominate Thomas Edison as our single most famous inventor. Edison is not credited with the invention of radio, but he did develop many of the components used in 20th century radios. Also many of the techniques to build those components were first developed in Edison's laboratory. Edison fabricated the loudspeaker, the first vacuum tube diode and even an experimental triode vacuum tube. However, he never applied them to radio. Edison is best known for a handful of his most important inventions. However, ***Edison's greatest contribution may have been his <u>methods</u> of inventing.***

Persistence

A reporter asked Edison why he had often succeeded in perfecting inventions, while other experimenters who started down the same path were never able to build a practical device. Edison replied, "Most inventors will have a good idea and try out one or two versions of their concept. When it doesn't work, they declare it hopeless and give up. The difference is, I never give up."

Try everything and keep careful notes

The most well-known story about Edison's persistence was his legendary search for the ideal material to make light bulb filaments. Edison was asked if he was discouraged by his failure to find a suitable material after trying hundreds of substances. He replied that it hadn't been a failure. He now knew hundreds of materials that didn't work.

A corollary to Edison's method is that it's essential to write everything down in detail. It's not fun writing the details of experiments that failed. But a year later, any researcher can tell you they have had that "deja vu" sensation halfway through an experiment only to find in their notes that they had tried this before. At the moment when you discover "a pearl of wisdom," it seems so profound that you believe you will never forget it. Wrong! Unless your memory is much better than mine, a year later an old laboratory notebook can be re-read almost as if someone else had written it.

Lots of junk

Edison was asked what a fellow needed to become an inventor. He said, " First you need a large pile of junk. You can't afford the time and money to run down to the store every time you need something. Often the junk pile will supply the parts to try out an idea right away. If you order parts from hundreds of miles away, you may waste weeks just to find out that your idea didn't work."

Subdivide the problem

A complex invention like the incandescent light bulb consists of many parts. Light bulbs only ***look*** simple. What kind of glass can stand the heat of the filament? What kind of wire has the same coefficient of thermal expansion as that of glass? What kind of filament material is optimum? Will the filament leads bond to the glass and keep out the air? What should the resistance of the filament be in order to be compatible with the electric power source? How does the resistance change with temperature? What is the trade off between operating life and brightness? How good a vacuum is needed and how can it be produced? Once the air is pumped out of the glass, how can the bulb be sealed? Would an inert gas like argon be more practical than achieving a vacuum? Answers to all of these questions had to be found and tested one at a time before Edison could make a practical light bulb. A guy named Swan demonstrated a light bulb in 1864, but it was too crude and dim and hardly anyone has ever heard of his bulb.

Build for modification

Have you seen the movie <u>Gizmo</u>? <u>Gizmo</u> is a collection of film clips of early 20th century inventors showing off their inventions for the first time. The movie is hilarious because the inventors make the same mistake again and again. They start with ideas that are often fundamentally sound and then they build an entire, polished, beautiful prototype without ever testing the pieces. They make the first test run of their airplane, helicopter, jet boat, etc. in front of a movie camera. Sometimes they even call in news reporters just to make sure the test will be as humiliating as possible.

My favorite relatively recent invention was Paul MacCready's human-powered airplane. In 1959 an English sponsor named Henry Kremer offered a £50,000 prize to the first fellow who could fly over a 20 foot obstacle, fly over a half mile course, fly over a second 20 foot obstacle, then turn around and return to fly over the first obstacle again. The plane had to be 100% powered by muscle power. For 18 years many smart people tried to build the pedal-powered plane. Again and again they made the same error. They worked for months building handsome, handcrafted balsa wood airplanes. Then on the first flight the plane would crash and be smashed beyond repair. After two or three attempted flights, the inventors had spent months or years and were out of money and enthusiasm. In contrast, MacCready designed his aircraft out of aluminum poles, piano wire, adhesive tape and mylar. He designed his plane to be flown, crashed, repaired and modified. MacCready was able to crash and redesign his plane once or twice a day until he got it right. And he made sure there were no cameras around until it was tested and working.

Build for function, not beauty

First and foremost, your equipment should work well. It is natural to feel embarrassed by its crude, homemade appearance. Don't be! Commercial ham equipment has been designed and redesigned several times before you ever see it. Moreover, commercial equipment is packed with custom displays, custom heat sinks, custom cabinets and even unique integrated circuits. You can't compete with that, so don't try. Instead take pride in your crude prototype.

When you see designs for homebuilt equipment in the ARRL handbook or in ham magazines, the equipment is usually quite attractive. But if you read carefully, you will find that the unit in the picture is prototype number five or even number one hundred. You probably don't have the time to rebuild your station five times just to achieve beauty. Also, if you attempt to duplicate one of those units, you'll find you must use exactly the same parts and circuit board the author did. This means buying a custom circuit board and perhaps a complete parts kit from some manufacturer. If you try to substitute parts, I can almost guarantee it won't work.

Get smart guys to help you

This piece of wisdom from Edison may be limited in usefulness to the basement ham, but it's still interesting. Edison was the first fellow to industrialize the process of research and development. Once he acquired financial backing, he hired a whole team to work on his projects. He didn't try to do everything himself. The quantity of Edison's inventions can be partly explained by the number of competent guys he had working for him. Edison and his lab were credited with inventions that represent the work of many lifetimes. Even for a guy who works day and night, there are limits to what one fellow can do. If you're a one-man show, it's important to limit yourself to projects you can complete. Be sure to use the Internet to find previous work in your area. A good source for ham radio circuit ideas is the QSL.NET website. The home page has a search engine that will look for topics in all the individual subordinate ham websites including this book, QSL.NET/KØIYE. Although real ham homebuilders are rare, homebuilding is the most fun if you can find someone in your area to share your triumphs and problems.

Assume as little as possible

Edison looked for guys who had the right attitude about R & D. Many job applicants have a knack for sounding good in an interview, but they turn out to be more glib than useful. Edison's interviews began by asking the applicant dozens of practical questions about ordinary objects such as, "What is asphalt made of?" Another of his tricks was to take potential employees out to lunch. If they put salt and pepper on their food without tasting it first, they were in big trouble with Edison. Edison's selection method is probably extreme, but it does illustrate a cardinal rule of research. ***Never assume anything about the project without good data to back up your starting assumption.***

For example, I had known for forty years that resistance in series with a transistor emitter was important for the thermal stability of an RF amplifier. However, I believed that any emitter resistance would inevitably reduce the signal output from that stage. In other words, I thought stability and gain were a tradeoff. Recently I took the time to try different values of emitter resistance over the entire range of possibilities. I was amazed to find that maximum output occurred not at zero ohms, but at a certain significant value, 300 ohms in my particular amplifier. When you do experiments like this, write down the details! You'll want them later.

Many inventions are frustrated by assumptions that turn out to be limiting. For example, weapons inventors were limited for centuries by the concept that firearms had to be ignited by flintlocks. When you consider the practical difficulties of inventing a waterproof, rapid-firing, breech-loading flintlock rifle, it's no wonder that firearms were essentially unchanged for 200 years. Millions of lives were probably saved by this fixation on flintlocks. Narrow-mindedness in inventors isn't always bad for society, but it certainly restricts innovation.

The genius of trying

Magic happens when you actually sit down at your workbench and try to do something. You may have thought about the problem in spare moments for weeks, but when you actually have the work in front of your face, ideas pop into your head as if by magic. For this reason, many people, like Edison for example, were well known for working non-stop all night. Once you get the momentum going, it can be wasteful to stop. Otherwise you may not remember all the details when you get back to work hours or days later.

I used to work with a patent attorney, Robert E. Harris, who always put everything off until the last minute. I kidded him about his procrastination. He answered me seriously with an explanation that went something like this: "I do it deliberately," Bob said. "I find that in order to write a patent application, I need complete concentration and nothing gives me that intensity like an approaching deadline. In order to write a good patent, I must have all of the prior inventions in my head at the same time. If I just put in just a few hours, by the next day I will have forgotten important details. For that reason, the day before the deadline I go into seclusion and work all night if necessary."

When you get stuck, do something else for a while

Unfortunately non-stop work slows to a crawl when you run out of significant new ideas to try. As long as you keep sitting in front of the problem, you will keep finding little variations to try, but as the hours go by, you will become more and more tired and your ideas will become less and less creative. To escape from this trap, get up from the workbench and do something else. Take a walk, take a shower or go to dinner. When you're not in front of the work, you can't do anything with your hands. Since you've been concentrating so many hours on the problem, your brain will continue to work on the problem long after you leave the workbench. Because you can no longer try out small, uninspired ideas, your mind must wander farther. You'll find you are suddenly seriously considering radically new concepts.

For instance, when Edison was searching for his light bulb filament material, he was stuck on the idea of using an inert metal filament. An inert metal would not react with oxygen or with residual gasses that might remain in the light bulb. If Edison had been able to carry through his "try everything" philosophy, he would have ultimately tested every metal. Therefore, he would have eventually tried tungsten and that eventually became the standard filament material. But I suspect tungsten wasn't available in 1879.

Actually, making tungsten filaments turns out to be amazingly difficult. It couldn't be extruded, pulled through an orifice, like most metals. Tungsten powder had to be "swaged," pressed together at very high temperature, in order to fuse it into wires. The process required years to develop and a few simple experiments wouldn't have succeeded.

Edison was particularly stuck on platinum as a filament material. Yes, it was expensive, but it seemed to work beautifully and gave a bright yellow-white light for a few hours. Unfortunately, after a while a segment of the platinum wire would become thin and abruptly melt, thereby ruining the bulb. A related problem was that the resistance of platinum was too low. This meant that a long, very thin platinum wire had to be used to make the filament compatible with his 100 volt DC power source.

Edison and his team realized that, if they could detect the sudden resistance rise of the filament as it started to fail, they could turn down the current and keep the filament intact. In theory, a temperature/ current regulator could allow the bulb to last indefinitely and would make it almost immune to power surges. The team expended a great deal of effort to invent the regulator, but it never worked well enough. Finally while away from work, Edison thought that the whole idea of a metal filament should be reconsidered. From metals he turned to carbon filaments. Carbon was cheap, had an inherently high resistance and it didn't melt. Carbon turned out to be a practical answer he could use. In the end carbonized cotton thread became the filaments in his first commercial bulbs.

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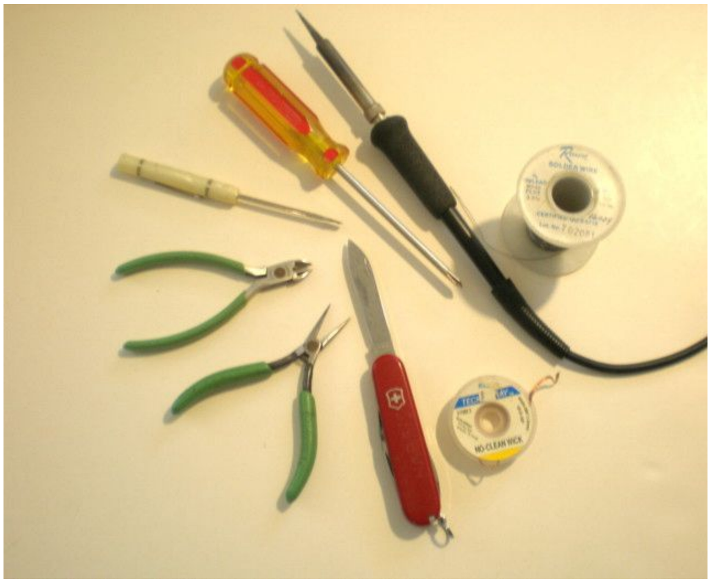
EQUIPPING YOUR OWN ELECTRONICS LABORATORY

Before you can begin building ham equipment you'll need some basic tools and materials. The following list shows the tools I used to build the projects in the book. One of my readers complained that my equipment list is "too discouraging." I see his point. For a beginner with no tools, the entire list of equipment is overwhelming. How many resources you need depends on the complexity and sophistication of your project. Consequently I shall try to list the equipment arranged from the most basic to the more advanced equipment:



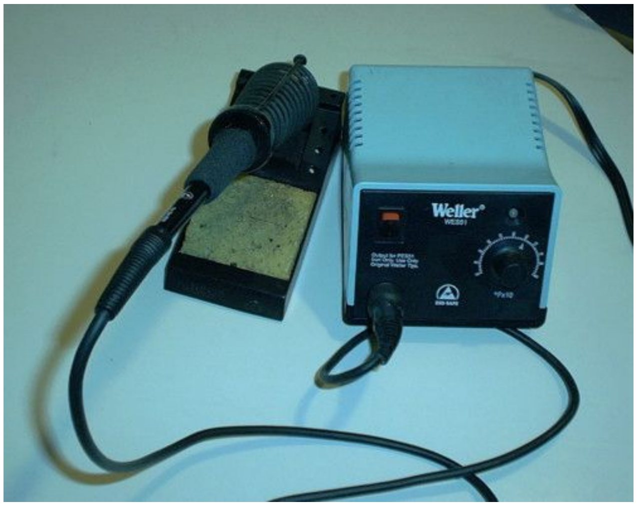
If you have **a table lamp, screw drivers, soldering iron, solder, solder wick, needle nose pliers, diagonal wire clippers and a Swiss Army knife**, you are ready to assemble a crystal set or a simple kit. As your projects become more complicated, you'll need more and more tools.

1. A bright light over your work bench

Dieter, DL2BQD, reminded me that the very first item you need is a bright desk lamp to illuminate your work. When exposed to bright light the pupils of our eyes narrow to tiny dots. This causes our eyes to become "pin hole cameras" and our visual acuity becomes as sharp as possible. The increased depth of field allows our eyes to focus much closer to the circuit. Also, bright light compensates for the light lost when you are viewing solder contacts through a jeweler's loupe or a hand-held microscope. Magnifying fluorescent lamps have a large, built-in magnifying lens which allows the circuit board to be viewed in comfort from above the lamp without bending down so far.

2. A fine, sharply pointed 25 watt pencil and a heavy duty, 100 watt soldering gun.

There are small soldering irons available that do not regulate the temperature. These are adequate for circuits that do not have sensitive, tiny semiconductors. I used irons like this for many years. A big 100 watt soldering iron is important for soldering antenna wires and heavy work. Trying to solder up on the roof with the wind blowing requires more heat than soldering tiny components indoors. Eventually you'll probably need both large and small irons.



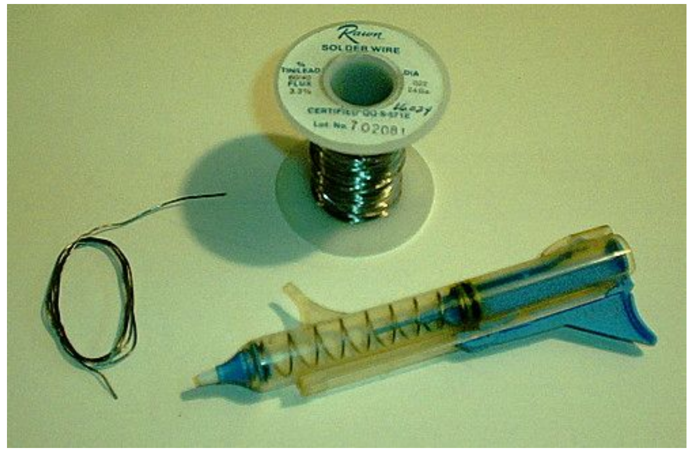
A sharply pointed soldering pencil is essential to connect the leads on fragile components like transistors and integrated circuits. A fine pointed pencil, like the Weller model WES51 shown above, has the advantage that the tip temperature is adjustable and calibrated. The useful range is about 500° F to 800° Fahrenheit.

Paradoxically, in some applications a high calibrated temperature is less likely to damage fragile components because the solder melts so quickly, that the heat doesn't have time to build up in the component. In contrast, at 500° F the solder barely melts and the entire component may be heated to 500° F before the solder flows properly. The sponge below the iron is kept damp and is used to wipe the oxidized, black solder slag off the tip and keep it clean.

3. 60/40 Rosin core solder, fine and coarse sizes

Rosin core solder (60% tin, 40% lead) is used for joining wires whenever reliable electrical conduction is the primary goal. The rosin flux is built into the wire-like solder, so you never have to apply solder flux. **Acid core** solder is used for structural purposes. It is not usually recommended for electrical use because the acid continues to corrode the metal for years afterwards. Eventually residual acid may result in a poor electrical connection. However, ***a roll of plumber's acid core solder is nice to have around.*** Sooner or later you will be building an antenna or other project that forces you to solder copper wires to steel. Since nothing else works, a bit of acid core solder or acid solder flux can be a lifesaver.

These days the classic 60/40 tin/lead solder is being replaced with lead-free solder alloys. These new solders replace the lead with more tin and small amounts of silver or copper. Personally, I haven't used any of the new alloys. All the electronic solders cost about the same, \$25 to \$40 per one pound roll, even the old lead based solder.



Rosin core solder and solder sucker

4. Solder Wick and Alcohol

You may also need some ***Solder Wick®*** for sopping up excess solder. Solder Wick® is just a small coil of fine, multi-strand copper wire specifically made for removing solder from circuit boards. The free end of the roll of wick is placed on top of the excess solder. The wick and solder are then heated with your soldering iron. The wick sucks up the excess solder. Before you can use it again, you must snip off the used end of the wick with your diagonal wire cutters. This sounds clumsy, but it works well.

In the above photo you can see a short length of silver colored, solder-soaked solder wick at the end of the braided copper wire. These short pieces of soldered wick are useful as patches on printed circuit board. If you need to cover or reconnect a trace, solder one on where needed.

There are also spring loaded, pneumatic pump-like devices called ***solder suckers*** that suck up surplus molten solder. They are especially useful for reworking printed circuit boards. When big components are removed, a large puddle of solder often remains on the board. This is too much solder to be easily removed with solder wick. For little droplets of solder, solder wick works best.

Isopropyl alcohol (rubbing alcohol) is useful for cleaning the excess rosin flux off circuit boards. I put a few drops of alcohol on the board, then use a small plastic brush (or old tooth brush) to scrub off the rosin deposits. Denatured ethyl alcohol also works, but not as well. There are also commercial flux cleaners, but the ones I have used are a bit harsh and tend to dissolve paint.

5. Fine needle nose pliers and diagonal cutters for bending and clipping tiny leads

These should be high quality and your best pairs should be almost small enough to fix watches. In fact, if you work with modern “surface mount” electronic components, you will also need fine pointed tweezers to manipulate the parts. Ideally, the tweezers should be free of iron or at least totally free of magnetism. Surface mount parts usually contain nickel in the tiny contacts and tend to stick to metal tweezers.

The larger yellow-handled tool in the collection is a wire stripper for removing plastic insulation from wires. A pocket knife is also nice to have for stripping insulation off the ends of enameled and Teflon insulated wire. These kinds of insulation cannot be removed gracefully with a wire stripper and must be scraped and carved off with a knife blade. A set of tiny jeweler's screwdrivers is also useful. A hemostat can be clamped onto a small component and hold it in place while you solder. Fingers are huge compared to the components we work with.

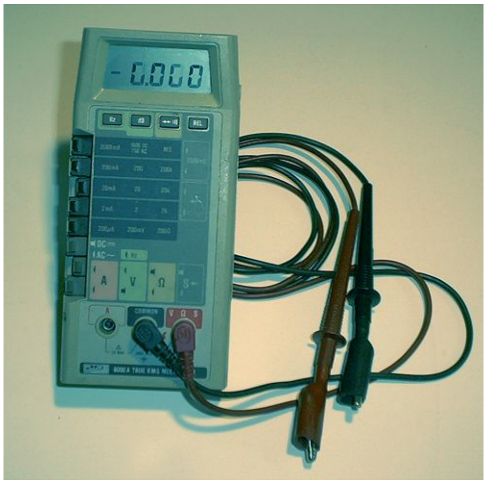
A cardinal rule about delicate tools is NEVER use them on large wires and parts. Be sure to keep them away from your wife and kids! They will use them to attack lawn mowers, chain link fences, huge bolts, etc. These fragile tools will be ruined instantly if you try to cut steel wire with the small diagonal cutters or use the needle nose pliers as a wrench. A non-conductive plastic screwdriver is helpful for adjusting trimmer capacitors in situations where the adjustment screw is floating above ground.

If you wish to construct your own heatsinks, modify aluminum enclosures or cut large PC boards into smaller pieces, you will also need a vise, a hacksaw, assorted files and hole reamers.

6. Microscopes & reading glasses

Back in the vacuum tube days, the wires and terminals were large and solder connections were easy to make and inspect. But these days, even the commercial ham kits have tiny leaded parts that you are supposed to mount on miniature circuit boards that are only a 3 or 4 inches wide. The cost of manufacturing the kit is minimized by literally reducing the size of all the parts, especially the printed circuit board. Even if your eyes are much better than mine, you'll need a strong magnifying glass to inspect your solder connections. Often tiny whiskers of solder or loose ends of multi-strand wire short out connections. Other times a solder joint looks OK from a distance, but under extreme magnification, the piece is not actually making contact with the desired terminal. These defects usually can't be seen with the naked eye and you might spend hours looking for a problem that you could have noticed immediately with a magnifier. ***I routinely examine each solder connection with my lens before moving on to solder the next component.*** I have used pocket microscopes, and over-the-counter, strong (+3.50) reading glasses for this purpose. My favorite is the large lens mounted in the gray plastic barrel.

7. A quality multimeter



Modern digital "multimeters" measure voltage, current and resistance. Fancy ones may also measure frequency, conductance, capacitance, decibels, temperature and other parameters. All multimeters are based on a high input impedance voltmeter. A quality modern meter has an input resistance (impedance) of 10 million ohms. High impedance is needed so that the measurement doesn't load down the circuit and change what you are trying to measure. Old-fashioned electro-mechanical multimeters have impedances as low as a few thousand ohms.

If you are totally new to electronics, you may want to run down to the hardware store and pick up a cheap multimeter for $10 or so. It will probably do most of the same measurements as the expensive meter, but will be less accurate. These are useful if you take the meter outdoors to work on the car or up onto the roof to do antenna work. A cheap multimeter will not be such a loss when it falls off the roof and shatters on the pavement. For this reason, I own both kinds of multimeter.

A quality meter justifies its much higher cost with extreme accuracy, stability and precision. It is the core of your electronic measurement capability, so accuracy is important. For example, if you build your own complex transmitters or receivers, they will include "VFOs." These are the **V**ariable **F**requency **O**scillators used to generate the operating frequency. The power supplies for VFOs should be stable to within millivolts. That means you need a voltmeter with 4 decimal places of precision plus a leading "one" like the meter illustrated above. If the power supply drifts several millivolts, your transmitted signal will drift tens of Hz. The fellow you are talking to is using a commercial receiver which has an extremely stable frequency standard and he will soon complain about your wandering frequency.

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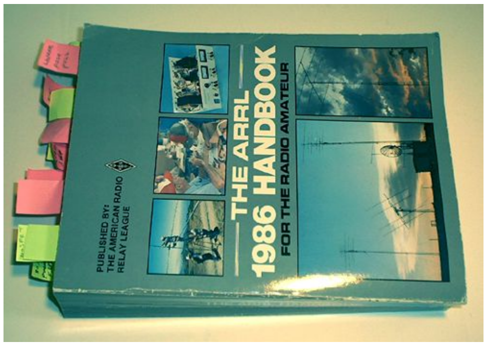
From here on, I shall assume that you are planning to build your own ham radios from scratch. You will need to make your own circuit boards, calibrate and align your circuit modules and troubleshoot your creations when they don't work. Another big challenge will be demonstrating the frequency stability of your transmitter and your receiver. This work will require far more in-depth electronic measurements and knowledge.

8. Buy or borrow an old ARRL Amateur Radio Handbook

An R&D hobbyist can't hire a staff of engineers and consultants, but he can get advice from guys who have done it all before. ***The first investment a new American ham should make is an old <u>ARRL Handbook for the Radio Amateur.</u>*** This handbook is as big as an old phone book and covers homebuilding and all the questions a beginner might ask about the hobby. Hopefully you can find an old edition at a ham swapfest or buy one from a local ham.



The ARRL Handbook, 1986 edition

Yes, the above handbook is way out of date. For actual homebuilding I recommend a handbook from the 1980s. I bought a 2013 handbook which was huge, but covers few topics in depth. I found that, whenever I had a specific question about some topic, such as looking up unusual Morse code Q-codes, FM modulator designs or a question about antennas, the answer wasn't in the 2013 handbook. I ended up consulting my good old 1986 edition. As the hobby has grown, the ARRL handbook was increasingly split up into numerous ARRL specialty books on operating techniques, digital signal processing, PIC microcomputers, RF design, antennas, software defined radio, and so on. There is even a new ARRL book devoted entirely to operating hand-held VHF/UHF transceivers! All the details of ham radio are now dispersed throughout the huge modern ARRL library. The actual "Handbook" had become a sort of introduction to the library.

As of 2018, they have expanded the Handbook into a 6 volume set. Hopefully this set is a good compromise between a single Handbook that covers nothing in depth, and an entire library of dozens of books that cover EVERYTHING.

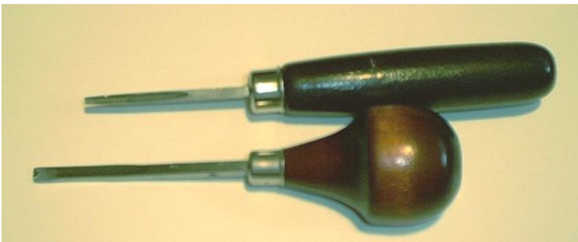
I want to emphasize that these ARRL specialty books are terrific references. Personally, I rarely need an inch-thick reference on each subject, but I do own some of the ones that interest me. Buying and reading the entire library at once is impractical. My 1986 handbook usually has the detailed answers I need. Another ARRL book I heartily recommend is Doug DeMaw's "**W1FB's QRP Notebook**." This book discusses many different designs for small homebuilt receivers and transmitters.

Years ago, while reading my 1998 handbook, I got the impression that building complex transmitters and receivers from the basic component level is impossible for amateurs. That’s not true and that’s why I wrote this book. During the 1980s hams were still building good equipment from discrete transistors. Handbooks from the 1970s and earlier usually describe projects that are unnecessarily primitive. Books from the 1990s and later use designs based on mysterious integrated circuits which teach me almost nothing about how the circuit works. If I didn't care how radio works, I'd just buy one of those wondrous modern commercial transceivers and forget about homebuilding.

9. One or two small wood carving gouges

Building your own circuit boards

Unfortunately, it's extremely difficult to build transistorized radios without printed circuit boards. The only alternative is to return to vacuum tubes, so we're stuck with building our own circuit boards. In my opinion, carving a circuit board is superior to any other method I have seen for homebuilt, one-of-a-kind HF radio frequency circuit boards. ***The main advantage is that you only have to commit to mounting one component or circuit block at a time.*** Wood carving gouges are a kind of delicate wood chisel with a cupped end. I use them for cutting traces on blank printed circuit boards. You will find they work well for making prototype printed circuit boards. I most recently bought gouges from www.TraditionalWoodworker.com. Most RF homebuilders who build from scratch, seem to prefer the Superglue and disk method of building circuit boards described in Chapter 6A. To each his own!



The gouges work best when they are kept sharp. When they become dull, they tend to skate across the board and make ugly marks on your beautiful unblemished copper. Sharpen the tips with an ordinary whetstone. When cutting traces, hold the blade nearly vertically and rotate your wrist back and forth carving a tiny, serrated trench through the copper surface. Pass the gouge down the channel a second time and the trench walls become smooth, like an etched board.

Some retired engineers I know simply build their boards just as they did when they were employed. They use a computer program to lay out the circuit board. Next they e-mail the project file to a commercial circuit board company which cranks out a professional quality board.

Yet another approach is to lay out a positive image of the board with a computer. The layout is printed onto clear celluloid with the traces shown in black. The celluloid is taped to a photosensitized circuit board material which is exposed to a bright light. Next it is soaked in a chemical bath to remove the unwanted copper areas. After drilling the appropriate tiny holes, the board is ready for use. It doesn't have the tin-plated feed-through holes, multiple layers, green solder mask and component labels of a commercial board. But for use with integrated circuits and surface mount components, it makes a much more compact and attractive board than my carving technique.

Notice that, whether you etch your own PC boards in your workshop or have a commercial manufacturer make them for you, you are making the assumption that the circuit design will work perfectly with no modifications. If you need to use a component that is larger than you expected or you must add an additional part or an amplifier stage, you're probably out of luck.

10. An electric drill

An electric drill is used to make holes in PC boards and heat sinks.

11. Male Thread taps

Rather than assemble your entire project with machine screws and nuts, you'll find it's often simpler and more professional to tap threads into the aluminum heat sinks and brackets. I find 4-40 and 6-32 threads to be the most useful sizes.

12. Your very own junk collection

As Edison said, it is important to collect junk so that you aren't continually waiting for parts to arrive in the mail. Considering that a capacitor or potentiometer costs a few dollars new, it is easy to spend hundreds of dollars on a project. If you are **not** getting most of your parts from old TVs and ham swap-fests, your project will cost a fortune and will proceed slowly. Organize your parts in bins, parts drawers and labeled boxes so you can find them when you need them. If you can't find a part when you need it, junk is just junk.

Never throw away an old radio, computer or printer without first cannibalizing it for useful parts. Besides, taking things apart is educational! You may be thinking that modern electronics are nothing but microscopic surface-mounted integrated circuits and strange little unlabeled modules. You're often right, but it's worthwhile to look. For example, I recently took apart a dead DVD player and found a small PC board stuffed with useless, micro-miniature, surface mount ICs. However, there was also a block of colored RCA connectors which I can probably use. The real gold was a hoard of 3 dozen tiny, through-hole, aluminum electrolytic capacitors of various sizes. I use capacitors like this in virtually every project. If I had bought a selection of capacitors like this at Radio Shack, they might have cost $60 or more. They went into my capacitor drawer and are immediately available the next time I need any of those capacitor values.

13. Catalogs of electronics parts suppliers

These days paper catalogs have become rare. So find your own favorite on-line companies that will send you parts quickly. I like RF Parts Company, Jameco, Digi-Key, and Mouser. We used to have a Radio Shack and a surplus electronics store in my area that allowed me to get ordinary parts the same day. Sadly, the world has changed. A difficulty with the Internet world is that companies like Digi-Key and Mouser have become so huge and efficient that their catalogs are now thousands of pages of surface mount components suitable for building cell phones, but rarely appropriate for basement homebuilders.

For example, I looked up ordinary 2N3904 transistors on-line and found pages and pages of varieties of this simple transistor. They are listed from different manufacturers, different packages and different shipping packaging. Would you like them in tape, tube or bulk? Leaded or

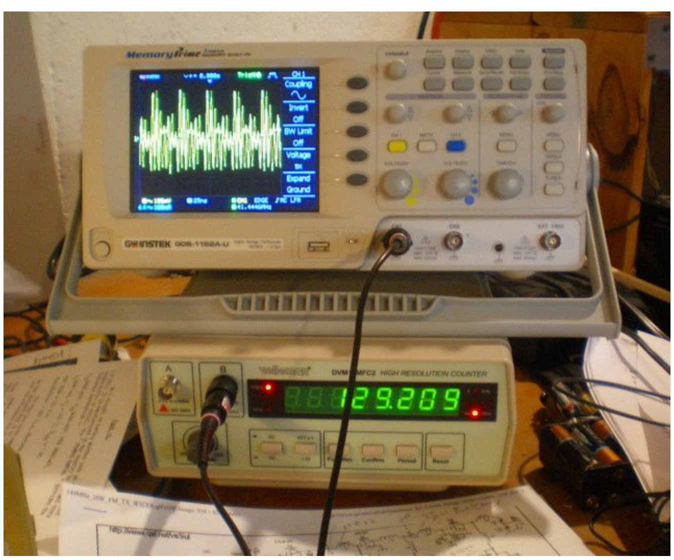
Surface Mount? Which SM package? Will you be ordering 2,000 or more? I imagine that if the entire catalog were printed, it would fill tens of thousands of pages. There are so many new microscopic surface mount parts available for machine placement, it is hard to find parts usable by humans with fingers.

One way to avoid getting lost in these on-line catalogs is to shop with companies such as Jameco and RF Parts Company that have small, manageable catalogs and specialize in relatively old-fashioned parts usable by experimenters. Another approach to is look for companies that still manufacture old fashioned parts, such as J.W. Miller inductors. Specialty items such as custom ground crystals and powdered iron cores you will have to buy from on-line catalogs such as Bomar and Coil Winding Specialists (CWS) respectively. In general, I have found the mail order service to be excellent from all these companies.

14. A high frequency oscilloscope

The oscilloscope is another foundation of your laboratory. Many homebuilders manage to build working equipment without one. Back when I was an impoverished high school student, I was sometimes able to build working radios. Unfortunately, when my circuits didn't work, I had few ways of finding out what was wrong. The traces on an oscilloscope screen tell you whether your device is working and how well. Without a scope, you are almost blind.

Perhaps the most amazing achievement of engineers like Edwin Armstrong was that they were able to do their work by inferring the function of circuits from secondary measurements. For example, the DC plate current of an RF amplifier tube dips when resonance is achieved. Unfortunately, there is often more than one resonance. The other resonances are off frequency or they are unwanted self-oscillations. It's so much easier to just look at the signal with a scope and *WATCH* the actual sinewave while the circuit is tuned. For example, your transmitter amplifier stage may be "motor-boating," turning on and off hundreds or thousands of times a second. The oscilloscope below displays a motor-boating amplifier stage of a 145 MHz transmitter. The frequency counter displays a low, erroneous frequency.



Recently I've been trying to build VHF 2 meter ham gear. I soon realized that my old 50 MHz rated scope and insensitive frequency counter were not adequate. Yes, I could see traces, but they were faint and 1/10 the amplitude they should have been. My old frequency counter rarely responded to VHF signals unless they were half a volt peak or more. I looked at on-line catalogs and found the above scope and counter at Jameco.com. When new 40+ years ago, my old scope and counter were the best quality available. Together they cost nearly as much as a car. In comparison and considering currency inflation, the new equipment seems almost free - $450 for the scope and $150 for the counter, all brand new. The performance is excellent. The scope is plagued by the usual modern software nightmares. It has way, way too many operating modes and submenus with no instruction manual. However, once I was able to set it up as a simple oscilloscope, it's great!

Another feature of these digital scopes is that they can freeze and store waveforms and send them to a printer. The frequency counter is no more complicated than it looks. Connect it to the signal, and presto - there's the dominant frequency.

Oscilloscope probes

The oscilloscope is connected to your project by a ***probe***. A probe is a 3 to 6 foot long coaxial cable with a ground wire clip and a little "grabber" at the end that hooks onto the wires carrying the voltage waveforms you want to look at. Probes usually have a 10:1 voltage divider that protects the oscilloscope from high voltages you may be measuring. Not all probes are created equal. ***For high frequency radio work you need a short probe cable with minimum capacitance***. If you buy a probe, look at the specifications to see what kind of capacitive load you are putting on your circuit. The probes are universally equipped with BNC RF connectors and may also be used with frequency counters.

Suppose your probe has 25 pF of capacitance. If your circuit is tuned by a variable capacitor that ranges from 5 to 60 pF capacitance, your probe will totally dominate the circuit tuning. In general, a good RF probe has a short cable and a short ground lead. Of course even 5 pF is a significant load. Therefore when I'm tuning one stage of an amplifier, if possible, I use the scope to monitor the signal in the following stage. That way, the tuning of the first stage will not be affected by the probe. If you must look at the shape of the waveform of the stage you're tuning, put a 1 picofarad capacitor in series with the probe. 1 pF will only change the tuning by ... 1 picofarad! Unfortunately, it will also decrease the amplitude of the trace on the screen, so the calibrated voltage level on the oscilloscope will no longer be valid.

15. A frequency counter

As soon as you as you build your first ham transmitter, you will need to prove that your transmitter is operating inside the ham band. Also, we hams are supposed to limit our transmissions to one frequency and not splatter all over the band. By definition, a pure sinewave is a single frequency. My solution is to routinely monitor the frequency and shape of my RF sinewave right at the base of the antenna. If it looks like a pure sinewave on the scope, the signal is almost certainly clean.

It is possible to check out a QRP transmitter and tune it to an antenna using just a calibrated receiver and a home-built Wheatstone Bridge style antenna tuning indicator. There is an indicator like this is presented in Chapter 9. An elderly frequency counter is shown below.

You can estimate the frequency of the sinewave by using the horizontal marks on the oscilloscope screen to measure how long it takes to complete a complete sinewave. If you count grid squares on the screen, you can measure the frequency of a sinewave to about 10 or 20% accuracy. Unfortunately, that isn't nearly good enough. For example, if your transmitter frequency is 7.05 MHz, one complete sine wave will take 0.142 microseconds. You won't be able to read it closely enough be sure it isn't really 0.143 microseconds and just outside the 40 meter band. You really need a frequency counter.

Some modern oscilloscopes, like the scope pictured earlier, have built-in frequency counters to measure the exact frequency of a signal. The frequency reading of my new counter is more stable and reliable than the one on the scope, but the scope counter works OK. If you are building a VFO to control your transmitter, you'll need a frequency counter accurate to the nearest Hz to measure the rate of frequency drift. If you buy an old scope or counter at a ham fest, be sure that, when new, it was the best quality available and don't pay too much. The old guy who is selling it believes his old gear is worth hundreds because it originally cost many thousands. But today brand-new test gear is superior and astoundingly inexpensive.

16. A quality short wave receiver

Aside from using it to hear other hams, a good quality, commercially manufactured shortwave receiver can serve as a laboratory instrument. A modern receiver is so well calibrated that it may be used as a substitute for a frequency counter. Also, it's important to be able to listen to your own signal in a receiver to be sure that it doesn't have subtle defects that may be hard to see on an oscilloscope. Ideally, it is helpful have both a counter and a calibrated receiver.

17. A laboratory power supply

A laboratory power supply allows you to apply voltage to a circuit cautiously. This will usually prevent component damage due to wiring errors or other problems. Meters tell you how much current is being drawn and the voltage applied. The voltage is adjusted with a control pot. You can start at zero volts and then gradually turn it up if the current flow isn't excessive. Also, lab supplies are current limited to prevent damage to your supply and project. If you short the supply during a test, the current will be limited to some specific value. Some supplies even allow you to set your own limits. This particular old power supply is actually three separate supplies. For example, you might use the 5 volt supply to power a microprocessor, while the other two variable supplies can be set up to deliver +12 volts and –12 volts for operational amplifier circuits. The three supplies can also be wired in series to provide as much as 45 volts. As you will see in Chapter 8, building your own lab power supply would not be difficult.

18. An RF frequency generator

This is a tool you will eventually want. But if you have everything above, it isn't essential. The RF frequency generator allows you to inject a sinewave of known amplitude and frequency into an amplifier so that you can align it. When aligning a homebuilt receiver, it is convenient to have a known test signal you can listen to any time you want.

My RF generator is a old vacuum tube instrument that I bought at a ham swapfest for $10. It was considered cheap test gear when it was new, so I didn't expect much. To my amazement it produces a clean, stable sinewave that scarcely varies its amplitude into a 500 ohm load from 120 KHz up to 260 MHz. I modified it by adding a small bandspread capacitor for fine tuning frequency while testing crystals for filters. For that application, 10s of Hertz are often important.

20. A capacitance meter

While not essential, you can use a battery-powered capacitance meter to sort out your junk drawer and give a reliable indication of capacitor sizes. I find it extremely useful for determining the maximum and minimum set points on trimmer capacitors. You can also identify stray capacitances in your circuits or measure the capacitance of your scope and counter probes. Finally, many modern capacitors are so tiny, the labels are either missing or confusing. Does "470" mean 47 pF or 470 pF?

The capacitance meter can also help you measure inductance. First you use the meter to determine the capacitance of your oscilloscope probe with respect to ground. For example, it might say "15 pF." You connect the unknown inductance between the probe and ground creating a parallel LC circuit. Next connect your RF generator across the inductor and sweep the frequency over the likely range of its resonance, say 3 to 15 MHz. Typically, somewhere in that range the RF voltage will peak as seen on the scope. Now, using the formula

$$\omega^2 = 1/LC$$

where ω^2 = (2 x π x frequency) squared = 1/(L in microhenries x C = 15 picofarads).

[where π or pi = 3.1416]

Solve for L, the inductance.

20. Freeze spray

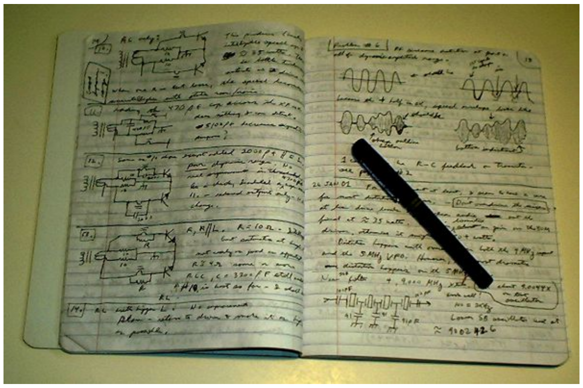
One of the frustrations of electronics is finding intermittent connections. One minute your device works, the next it doesn't. You open up the cover, expose the circuitry and … it starts working again. It's hard to fix something that's working! Spraying refrigerant on suspicious solder joints can often reveal which connection is at fault. Sometimes a heat gun (or hair dryer) can be used the same way, but they are not so focused.

In Chapter 13A I describe designs for receiver IF and audio amplifiers. What I didn't mention in that chapter was that I had a devil of a time trouble shooting the module that contained the audio and IF amplifier. The symptom was weak signals that were better some days and worse on other days. I was convinced that there was a loose connection in the audio amplifier. I discovered that I could reliably fix the weak signals by slapping the top of the module - very scientific. I removed the audio module and examined every connection with a hand microscope. Not finding any faults, I re-soldered every connection - No change. Next I got out the freeze spray and squirted freon on every connection - No change. Since the audio amplifier is fed by the

IF amplifier and product detector, I sprayed those circuits. Voila! All signals vanished entirely when I sprayed a particular connection in the IF amplifier. When it warmed up again, the IF returned to working intermittently. Using the spray I was able to find the cold solder joint. I re-soldered the connection and lived happily ever after.

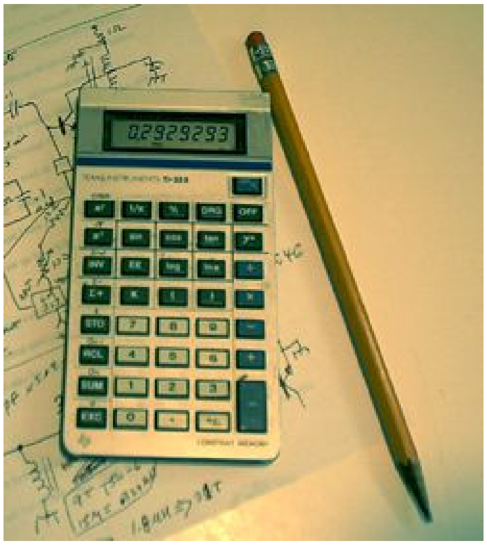
21. A laboratory notebook

Your memory isn't half as good as you think. Write down all your experiments, your triumphs and ***especially your failures***. The experiment that doesn't work is just as important as the experiment that did.



22. A simple calculator

You probably already own a calculator that will be adequate for the simple component value calculations you must do. Square roots may be the most complex calculation you'll perform on your way to your first two-way ham radio contact.



When I was in engineering school, the calculator age had not yet arrived. We young engineers swaggered about carrying big sliderules that hung from our belts like swords. We were very cool. When I sat down in class to take a test, I would ceremoniously draw my sliderule from its scabbard and check to see that the upper scale was perfectly aligned with the lower scale. If it wasn't lined up perfectly, I used the blade of my pocketknife as a screwdriver to adjust it. For me this ritual was something like a parachutist checking his harness and D-ring one more time before leaping from the airplane.

For you whippersnappers who haven't used sliderules, those antiques do logarithms, calculate trigonometric functions, take squares and square roots and do almost everything you can do on a simple "scientific" calculator. The reason for this archaic story is that sliderules don't do decimal points. Therefore, to get the right answer, ***we had to have a FEEL for the math***. We had to be able to estimate the answer so that we would know what order of magnitude it would be and where to put the decimal point. In other words, we had to know what we were doing.

The sliderule expanded our skills. It did not replace them.

When calculators came out, engineering students suddenly began to fill their test papers with random numbers. Beginners think that, if they push the buttons, the calculator is doing the thinking for them. Wrong. It turns out that calculators really aren't different from sliderules. The students must estimate the answer in their heads so that they will know if they have pushed the right buttons. Once the students mastered the ability to estimate, calculators became a boon to engineering.

23. Simulation software for experimenters

I hesitate to mention circuit simulation software. I object to the modern age of smug engineers who have never soldered a wire. I don't like the trend of increasing specialization and generalized ignorance that is spreading through the technical industry. For example, I met a recent (and very bright) graduate electrical/computer engineer who didn't know what inductor hysteresis was. Yes, half of his electronics education was devoted to computing, but even so.

Once you get very far into building ham gear, you will probably get tired to doing everything the hard old way. There are many different simulation programs available that allow you to emulate a circuit on your personal computer before you build a real circuit. Like most modern conveniences, this one is truly marvelous.

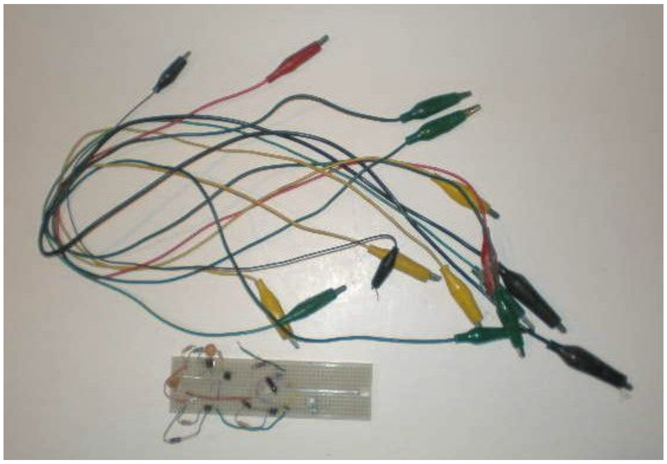
I formerly used an old **Electronics Workbench** "Spice" program, but there are many newer ones that work as well or better. If I need to build a filter with a certain cutoff frequency, but I don't have the right parts, I can simulate substituting parts and find out how critical the values are.

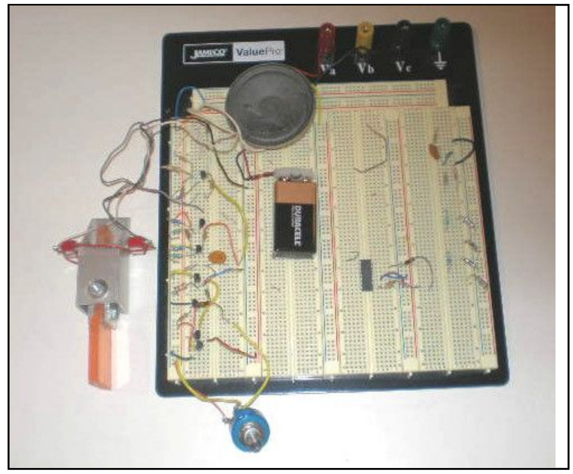
Actually, it's so much fun trying out circuits with so little work, that it's almost addictive. Also, other problems in my design become obvious that I had never thought of. For example, I built a filter for a ham transmitter that was designed to eliminate interference to the neighbors' TV reception. (See Chapter 9.) Every transmitter signal has minor "impurities" in its frequency spectrum. This means that it can easily be radiating weak signals on the TV channels. A filter will reduce these harmonics. Before I built my filter, I took the time to model it on the Spice and found that, as I had planned, it severely reduced interference on channels 2, 3 and 4. Above those channels, the attenuation of possible harmonics was not nearly as great. For the upper UHF channels, there was hardly any attenuation. Once I saw the problem, it was easy to add a couple more stages of filtering to insure that *all* TV channels were protected.

When my old computer died, I was forced to "upgrade" to the *&^%$# Windows7 operating system. In spite of a menu that supposedly simulates older operating systems, my old Spice no longer worked. I found a free Spice program on-line called "5Spice" which works well for the R-L-C filters I often design. Be patient while guessing how to make the program work. There are no instructions. It took me a day or two to discover why even simple circuits crashed.

I almost gave up on it, but eventually figured out how to make it work. Now it's an old friend.

24. Test leads and experimental "plug-in" circuit boards





Every electronics lab has handfuls of test leads and a few temporary plug-in circuit boards. Although I routinely use these, I hesitate to recommend them. ***ANY ELECTRICAL CONNECTION THAT ISN'T SOLDERED CAN'T BE TRUSTED!*** Yes, it's true that these gizmos usually work, but many times I have been led to believe that parts were bad or that circuits didn't work when they actually worked well.

Let me illustrate: When I was in the Air Force I once had to wire some explosive squibs onto a 1,500 pound cargo parachute load. The squibs - electric detonators - were supposed to explode and deploy the 64 foot diameter parachute. I passed the bare, scraped copper wires into two tinned metal eyelets, then wound the wire through the eyelets again and again until the eyelet holes were stuffed with clean, bare wire. Then I wrapped the remainder of the bare copper wires tightly around the outside of the metal eyelets and wrapped the whole thing securely in tape. I believed there was no way that the copper wires weren't in good contact with the eyelets! The huge box fell 3,000 feet and crashed into the dirt at a couple hundred miles an hour. The squibs never fired. I checked the firing circuit with my meter and found the proper 3 volts across the squibs. I unwrapped the tape from the eyelets. The squibs exploded as soon as I tugged on the bare wire. After that day I soldered my squib wires and never had another failure.

If you buy an experimenter's socket board like the ones shown above, be aware that the contacts are easily damaged by stuffing component leads into the board that are too big. For example, ½ watt resistors are usually OK, but one watt resistor leads will permanently expand the spring contacts.

25. Pliers for crimping connectors and eyelets

What about those special pliers used to crimp connectors and eyelets? Some metal eyelets and lugs are designed to be installed onto wires using special crimping pliers. Yes, crimped connections can be fairly *reliable in the short run*. However, in my experience crimped wires pull out easily and after several years they often become open circuit. I have seen dozens of failures in old equipment. I still use eyelets on leads, but after I crimp them, I solder them as well. Surprisingly, eyelets that are screwed down to tapped aluminum metal seem to make a reliable contact with the aluminum, even on outdoor antennas. However, I still solder the copper wires onto the tinned eyelets.

26. Heat guns and heat shrink tubing

Heat shrink tubing and heat guns are not essential. Your methods of construction may never need shrink tubing. I find it most useful for splicing wires and restoring insulation. First I slide a short length of heat shrink tubing onto one of the wires. Next I solder the bare ends of the two wires together. Then I slide the loosely fitting heat shrink tubing over the splice. I set the gun to "high temperature" and blow hot air on the tubing. The sleeve of tubing shrinks tightly around the solder connection and it will not slide off to expose the bare metal.

Heat shrink is especially helpful when I don't have access to both ends of a cut wire. A few years ago my pick-up truck wouldn't start. I opened the hood and discovered a half-built squirrel nest packed into the corner of the engine compartment. To make more room for the nest, the squirrel had chewed through the entire main wire bundle connecting the dashboard instruments with the engine compartment. Fortunately the wires were color-coded so it wasn't difficult to solder them all back together. It was just extremely time consuming. I insulated each wire connection from its neighbors with heat shrink and then wrapped the entire bundle with electrical tape. I filled the squirrel-tempting nest site with an empty coffee can. The squirrel rebuilt her nest 25 feet up a tree and raised 3 children whom I named Otto, Julius and Margaret.

In another application, I often need a tiny connector to join a single wire to a printed circuit board or to another wire. I make the connection with bare Molex male and female pins and then insulate and strengthen the pins with shrink tube.

In another application, I had three old oscilloscope probes that had their skinny plastic "beaks" broken. The probes were unusable with loose tips. Otherwise, they were in good shape. I was able to put shrink tubing on the beaks to secure the tips in place and they became functional again.

You are now reasonably well equipped

The equipment described above should allow you to build everything in this book. However, everyone has different ideas about what works best and what is essential. For what it's worth, the above list pretty well describes my workshop. Sure, I'd love to have more test equipment, such as a spectrum analyzer, a calibrated UHF signal generator and a one gigahertz oscilloscope. But like you, my budget and workshop are limited in size. For what I do, the above equipment is enough.

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