

CRYSTAL SETS TO SIDEBAND

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CHAPTER 5

GETTING ON THE AIR

Deciding what to do first

Earn an amateur license!

If you're going to build your own ham station, you will need a national government radio station license to transmit. In the US the Federal Communications Commission issues ham licenses. In this country committees of senior hams in our local areas give the tests rather than government officials. The simplest first step is to contact a ham in your area. He or she will tell you what to do. Failing that, if you are an American, contact the Amateur Radio Relay League, www.arrl.org. Most other countries have similar organizations of radio operators. They will fix you up with study guides and point you to the nearest ham radio club where you can meet other hams and take your test. Working on a license can be an interesting side project while you build your receiver and transmitter.

Learning Morse code

If you're going to build and operate a homebuilt transmitter, it will have to be a CW (Morse Code) transmitter. Building a single sideband (voice) transmitter is too difficult for beginners. Even for experienced guys that takes hundreds of hours of effort. Until recently, all nations required Morse code at least 5 words per minute (WPM) speed to earn a license for operating between 1.8 MHz and 30 MHz. That has changed and many countries including the US now issue licenses without Morse code skill. Fortunately Morse code is not hard to learn for most people - besides, it's fun! The average conversation on the air takes place at roughly 10 to 15 WPM, but there are usually a few beginners poking along at 5 WPM. The senior hams at the bottom of the CW bands zoom along at 25 or 30 WPM. Don't feel bad if you can't do that. I can't either.

To practice code, you can listen to it with a shortwave receiver and you will also need to practice sending with a key. During the evenings in the US the ARRL station W1AW broadcasts code practice sessions. These sessions start at 5 words a minute then gradually increase the speed. Scheduled times for the almost daily broadcasts can be found in the QST magazine. If I haven't been on the air for a while, I tune in the low ends of 40 meters or 20 meters and copy a few CW (code) stations to restore my speed and confidence before I start sending. I write down each letter as I receive it. The really good operators hear entire words and don't have to write down anything! I've never been that good. I spend too much time soldering.

Planning your station

Most hams are content to buy one of those marvelous commercial transceivers. They plug it into the wall, put up an antenna, and start talking. In contrast, a growing number of hams are building small, low power transmitters called *QRP transmitters*. QRP is an old Morse code abbreviation meaning "turn down the power." In modern usage QRP means a transmitter delivering less than 5 watts of RF power. QRP guys are usually fellows who have been using

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commercial rigs for years and want to try something more adventurous and primitive.

Most QRP enthusiasts buy tiny transmitter kits with pre-printed and pre-drilled circuit boards. The assembly procedure consists of following a picture, plugging components into the correct holes, and soldering the leads. These kits teach soldering technique and you learn what the components look like. Unfortunately, if the kit is well designed, it offers little chance to learn how the circuits work.

A few hams start with a circuit from the ARRL handbook or QST magazine. Following the circuit diagram, they build their own version of the circuit out of individual components. Their components are bought or scrounged one at a time and rarely exactly match the components used by the author of the article. A QRP like this usually doesn't work properly without sweat and rebuilding. This sounds like frustration, but the compensation is that now you're learning something! This kind of project is educational whether we planned to learn anything or not. Frustration, persistence, and triumph is what ham radio used to be.

Rules of the game

Scratch-building your own station is a kind of game. *Our chief opponents are the amount of free time we have and the modern frequency stability standards.* In my fantasy it would be neat to build all the components from raw materials and invent and design totally new circuits from scratch. Unfortunately, these tasks are too much for me. Rather, I use discrete parts I scrounge from junk and components I buy through catalogs or local stores. For circuit design I borrow circuit blocks from examples in the ARRL handbook and other sources. Then I assemble the circuit blocks into my project.

After I retired and had plenty of time, I got out my ARRL handbooks and studied plans for homebuilt receivers and transmitters. I quickly encountered my other nemesis, *integrated circuits*: Tracing the circuit diagram of a typical modern receiver, one finds that the antenna is connected to a chip marked "RF amplifier." Then the signal goes to another chip labeled "mixer." The mixer receives a local oscillator signal from a large chip called "frequency synthesizer." The output from the mixer goes to a "crystal filter" sealed in a tiny metal can. Well, you get the idea. *Modern radios are just block diagrams soldered onto printed circuit boards.*

I find that 1980 technology is usually a good compromise. Few integrated circuits appear in the parts lists from that era. And if you're a purist, most of the integrated circuits can be replaced with discrete components. In summary, I try to use individual transistors and passive components exclusively. This teaches me how the circuit works and I can still build equipment that's reasonably modern. One compromise I have had to make was integrated circuit voltage regulators. In order to hold the frequency constant, the voltage supplied to the oscillators must be more stable than I know how to build using discrete parts.

Another compromise I've made is the use of integrated circuit operational amplifiers. An operational amplifier is an array of transistors that functions as though it were a "perfect transistor." It is usually easy to substitute real transistors, but you need to use many more of them to get the same performance. After a while I became bored making the same complex circuit again and again using discrete transistors. So, my rule is that, if I have proved I can build the equivalent of an integrated circuit with discrete parts, I feel I have "earned the right" to use certain kinds of integrated circuit.

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My rules have taught me how the circuits work. I've learned plenty. And by golly, when I'm done, I really feel that I built it myself! Because I have struggled to understand it and make it work, I rarely have the feeling I am using "magic." You don't have to use my rules. Make up your own. If you're having fun, those are the right rules.

Planning your station

A simple receiver and a QRP transmitter are a great start on a homebuilt station. (See Chapters 6 and 7) However, before you can go on the air with your transmitter, you will also need:

- A ham radio license. Contact local hams in your area or, in the US, the American Radio Relay League in Newington, Connecticut. (888) 277-5289.
- A 12 volt DC power supply for the QRP. (Chapter 8.)
- An antenna (See end of this chapter, Chapter 5)
- An antenna tuner (Chapter 9)
- A telegraph key for Morse code. (Chapter 9)
- Basic test equipment to ensure that your transmitter is operating correctly. (Chapter 9).

Equipment for later on:

- A selective, sensitive, all-band hamband receiver (Chapter 13)
- A Class B or linear amplifier. (Chapter 12) Although QRP is fun, you will probably eventually wish your signal were more powerful. With a loud signal more stations will hear you without a struggle and your contacts won't say "73" (good bye) so quickly. There are two ways to achieve a bigger signal. Build a better, high gain (directional) antenna, higher above the ground. The other way is to build a linear (or Class B) amplifier to raise the QRP power from 5 watts up to 50 or more watts.
- **A lowpass filter.** (Chapter 9) If you have a high power Class B amplifier, it is a good idea to build a low pass filter to make sure that harmonics of your signal are not interfering with the neighbors' cellphones and television.
- **VFO.** As you'll soon learn, being restricted in frequency mobility by crystal control is awkward and you will eventually want to build a variable frequency oscillator to replace those clumsy and expensive crystals. (Chapters 10 and 11)
- **Single Side Band Generator.** (Chapter 15) After you have been a ham for a few years, you will sooner or later want to get on phone (voice) so you can talk to the majority of hams. Otherwise you'll be stuck just talking to funny old Morse code geezers like me. Almost no one ever builds their own SSB. So if you get that far, you will have joined an extremely exclusive club of homebuilding hams.

Divide and conquer

Building an entire ham radio station from discrete components is a huge project. The secret to having fun is to build it in carefully planned pieces that can be used and enjoyed right away. How big the challenge becomes depends on where you start. If you're a retired electrical

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engineer like me, the project begins by wandering down to the basement, dusting off the workbench and getting started. If you are still working for a living, your free time for this effort may be just a few hours a week. If you have never worked as an electronics technician or as an engineer and you have no formal electronics training, your road to homebuilt ham radio will be lengthy. If you have no electronic experience at all and little free time, then maybe buying a receiver and a QRP kit may be the best way for you to begin.



The author's 100% homebuilt station. It isn't flawless and it isn't the latest technology, but it talks around the world and sure has been fun. Oh, by the way, the oscilloscope and frequency counter are *NOT* homebuilt.

Many guys try to do too much too soon. This can easily result in many hours invested in useless junk that does nothing except get hot and generate acid smoke. A better plan is to focus on small projects that can make you proud as soon as possible. Try to decide what it is about ham radio that turns you on and then zero in on those aspects. Your ambitions will always be greater than the time you have to achieve your dreams. Plan carefully.

Pick an HF band

50 years ago it was practical to build simple ham transmitters that tuned several bands. Unfortunately today a ham transmitter must meet strict frequency stability standards. Actually, your government is only interested in having you stay inside the hamband and radiate a reasonably narrowband signal. However, other hams will almost always complain about your signal if you drift more than about 50 Hertz per minute. This degree of precision can be hard to achieve, but it's easiest if you start with crystal frequency control and just build for one hamband at a time. Later you may expand your capability as your time, knowledge, and enthusiasm permit.

There are ten different HF bands and seventeen VHF, UHF, and microwave ham bands.

In addition, a ham is free to operate anywhere he likes above 300,000 MHz, provided output power is limited. As the frequency goes up, the basic principles are the same, but the construction methods change radically and the precision and craftsmanship needed soar with the frequency. This book only considers the HF bands because scratch building equipment for VHF and higher frequencies needs expensive test equipment and a good understanding of HF building principles. In other words, walk before you run.

40, 30, and 20 meters

In my experience, the easiest and most versatile frequencies to build for are the 40, 30 and 20 meter hambands. (7 MHz, 10 MHz, and 14 MHz.) The signals on these bands are strong and these bands are usually “open” throughout the year. For Americans it’s easy to talk to hams all across North America on all three bands. Talking around the world is relatively easy on 30 and 20 meters. Optimal antennas are relatively small. On 40 meters (7 MHz) a dipole is 66 feet long while on 20 meters (14 MHz) a dipole is only 33 feet long. A vertical antenna on 20 meters is only 16.5 feet high. A typical suburban house is about 50 feet long so it’s usually possible to put up a 40 meter dipole somewhere on the property.

40 meters (7.000 to 7.300 MHz)

This is a great band for CW contacts within about 2,000 miles. However, for us Americans, often only the bottom 50 KHz is usable. Yes, we’re allowed to operate from 7.00 MHz to 7.30 MHz. Unfortunately, foreign broadcast stations often obliterate the upper half of the band. On the other side of the world most of this band is available for commercial shortwave broadcasts. Also, from 7.05 to 7.10 the band is filled with foreign hams talking on single side band phone (SSB, voice transmission). We Americans can’t use phone below 7.150 MHz, so we can’t join in. Consequently, most of the time American hams just use the bottom 50 KHz for CW. 40 meters can be useful for local sideband phone contacts during the daytime. For example, in my state there is a noon SSB net where guys around the state chat with each other. However at night most of 40 is unusable.

30 meters (10.10 to 10.15 MHz)

Thirty meters resembles the CW band on 40. It’s only 50 KHz wide and no phone is allowed. Typically there are only 4 or 5 CW stations on the air. It’s a terrific band for homebuilders. The power output on this band is limited to 200 watts worldwide, so it is a good band for talking to DX (foreign stations). Nearly everyone on 30 is using comparable equipment, so you won’t have to compete with kilowatt stations using giant, multi-element beam antennas. Another advantage is that contesting isn’t allowed on 30. Ham organizations often hold weekend contests to see how many stations one can talk to in a 24 hour period. All the bands except 30, 17, and 12 meters become packed with guys just exchanging call letters. It’s pretty boring if you aren’t competing in the contest.

20 meters (14.000 to 14.350 MHz)

Twenty meters is the single most popular band. It is large and, depending on the 11 year sunspot cycle, usually usable 24 hours a day and “open” year round. It normally has hundreds of stations. In fact, 20 meters is often so crowded, you will need a receiver with great selectivity to carry on a conversation. If you can copy fast Morse code, foreign CW stations are easily heard at the bottom of the band. Because of the crowds and high speed, talking to them isn’t so easy.

Most of the band is filled with powerful stations on single side band phone. It is hard to build a homebuilt station that will compete on the 20 meter phone band.

17 meters (18.068 to 18.168 MHz)

Seventeen meters is a fine little CW and phone band. It's mostly inhabited by single side band phone stations. However, there are usually a couple CW stations at the bottom of the band. When conditions are good, many of these stations are DX on the other side of the world. It isn't my first choice for a QRP CW transmitter, but other than scarce CW stations, there's nothing wrong with 17 meters.

15 meters (21.000 to 21.450 MHz)

Fifteen meters is slightly harder to build for than 20 meters, but it's an excellent band for beginners. 15 meters is a large band, 450 KHz wide. It's not crowded but there are plenty of stations. 21.150 MHz is a great place to meet beginner CW operators. 21.040 to 21.060 MHz is where most of the QRP CW guys hang out. 15 meter QRP transmitters are crystal controlled and are usually locked into that frequency range. After your code speed gets up over 20 WPM, you can move down to the bottom of the band where the DX (foreign) stations and high-speed, old-time CW operators hang out. On the other hand, every now and then a station on the other side of the world will answer your slow speed CQ. Actually, these are usually the best DX QSOs because the other fellow obviously is no hurry to talk to anyone else.

Extra care in construction and antenna tuning are needed as the frequency goes up. You may find that your homemade receiver is slightly less sensitive than it was on 20 Meters and your transmitter probably won't produce as clean an output waveform as it did on 20 meters. On the other hand, a 15 meter vertical antenna is only 11 feet tall and a dipole is only 22 feet long. Another reason for selecting 15 meters is that *a 40 meter dipole (or 40 meter vertical) will work well on both 40 meters and 15 meters*. This simple antenna is ideally matched to both bands.

Some hams successfully string 15 meter antennas in their attics or along the ceiling of a large second story room. When I was in high school, a friend of mine, Al Beezer, KØKZL, had his 15 meter antenna strung across his second floor bedroom. He attached florescent light bulbs at each end of his dipole. The bulbs flashed every time he pushed the telegraph key. Great show biz! Yes, Al's signal would have been stronger if his antenna had been 10 feet higher outside in a tree, but his indoor antenna was adequate to make contacts all over the U.S.

Open bands and sunspots

The disadvantage of 17 meters and higher bands is that these bands are often not "open." When the sunspots are few, the Earth's upper atmosphere is minimally ionized. When the band is "dead" the radio signals are passing through the ionosphere right out into space. The sunspots occur in an 11-year cycle and 2008 happens to be one of those years when the upper bands are quiet. 15 meters is often closed for months at a time, especially in the summer. During these times all you'll hear is the hiss of static. On the other hand, 15 meters can still be used for local communications during these periods. The higher the frequency, the less often the bands are open. Ten and 12 meters are even more erratic.

10 and 12 meters

I found building receiver converters for 10 and 12 meters was as easy as it was for 15 meters. However, building the transmitters was more difficult. My final amplifiers and antennas

were hard to tune. It took me several attempts and many modifications before I got more than a few watts of power output on 10 meters. For example, my transmit-receive antenna relay had too much reflection (high SWR) to work properly on those bands. I had to bypass the relay and use a separate antenna for the receiver. However, once I was able to transmit just two watts on 10 meters, I could easily talk to other continents. In that sense, I believe 10 meters is the best QRP band. But as I said, sadly, months often go by when there is nothing to hear on 10 meters but static.

When I was in high school, several of my friends and I built handheld 10 meter walkie-talkies. They put out 1/4 watt into a 2-foot long antenna with a loading coil. One of my biggest thrills in ham radio was standing on my chimney in Colorado and talking to a guy in New Jersey - 3,000 kilometers away. That was nothing. My friend, Bob (KØIYF, now NØRN), was walking down the street and talked to a fellow in Morocco. Forty-eight years later he still remembers the call letters, CN8NN.

6 meters

Six meters is a huge band, 50 to 54 MHz . It closely resembles 10 meters in that a few watts will talk around the world using high ionospheric propagation. Some years, on ham field day at least, (the last weekend in June) it is crowded with signals from all over the world. The catch is that 6 meter propagation is rarely “open.” You might have to listen for many months before you hear stations. With good craftsmanship, it’s possible to build homebrew equipment for 6 meters using the technology discussed in this book. However, I don’t recommend it until you have become bored with 10 meters.

80 and 160 meters

80 meters (3.5 to 4.0 MHz) and 160 meters (1.8 to 2.0 MHz) are large, lightly used bands. Of all the hambands, transmitters are most easily built for these bands. There are plenty of SSB phone stations on 80 meters at night, but relatively few CW stations on these bands. Good receivers are hard to build for these bands because the atmospheric noise is so heavy that it takes a sophisticated receiver to pull signals out of the static. Noise from lightning is especially bad in the summer. Also, if your homebuilt receiver isn’t well filtered, it may be overwhelmed by your local standard broadcast AM stations, which are located just below 160 meters. A modern commercial high-end transceiver can often hear dozens of stations while a simple homebuilt receiver might only hear a few. During the day, these bands buzz with noise and are usually only good for across town. Sometimes at night, if the thunderstorm noise isn’t too bad, there are lots of stations from all over the continent. It also helps to live out in the country far from power lines, plasma TVs, auto ignitions and heaven only knows what else is in city background static.

Another barrier to 80 and 160 meters is that large antennas are needed for good performance. On 80 meters a vertical antenna must be about 66 feet high and a dipole antenna is 135 feet long. For 160 meters, ideal antennas are twice those sizes. In my opinion 160 is the noisiest and least popular band. Yes, you can get on 80 and 160 with small antennas equipped with “loading coils” and antenna tuners. Unfortunately, in my experience, if you don't have a big antenna, you will rarely get out of town. On the other hand, once you have a full size antenna, I was surprised to discover that QRP transmitters can talk all across the continent on 80 meters.

60 meters

Since July 4, 2003 American hams have been allowed to transmit single sideband phone (USB SSB) on five discrete channels, 5.332, 5.348, 5.368, 5.372, and 5.405 MHz. This band is noisy and is shared by several services. Each channel is like an old time party-line phone on which everybody tries to talk at once. Moreover, at any one time, you will find that two or three of the channels are occupied by commercial teletype (RTTY) stations. It's interesting, but frankly it isn't worth the trouble for a beginning ham.

In summary, I recommend starting off with CW on 40 and/ or 15 meters. A 40 meter dipole works well on both bands and the equipment is relatively easy to build. Both bands will let you talk all over your local continent with ease. On 15 meters you will have the chance to work foreign stations even with simple equipment and minimal code skill.

Phone (voice) transmissions

For a homebrewer in the modern world, building an SSB phone transmitter is a difficult project. Actually, amplitude modulation (AM) voice transmitters, like those used on standard broadcast radio, are relatively easy to build and are still legal for ham radio. To convert a CW transmitter into an AM transmitter, all you have to do is impress an audio voice signal onto the power supply line of the transmitter's last stage of amplification. Occasionally you can still hear AM stations on 10 meters, 80 meters, and 160 meters. But in general, AM is rarely used today by hams.

The modern replacement for AM is *single sideband (SSB) phone*. SSB is similar in principle to AM phone, but it takes up about a third of the bandwidth of an AM signal. Sideband can be thought of as AM radio with half of the signal plus the carrier wave removed with precise filters. This allows more stations to share the band and makes your transmitted power three times more effective. The SSB signal must be generated at a fixed frequency then translated up or down to the desired frequency using mixer technology. To maintain the purity of the signal, all of the amplifiers along the chain must operate perfectly in linear mode so that the speech is not distorted.

A sideband generator is described in chapter 15 of this book. Scratch-built sideband phone is definitely an advanced project. To be honest, I found mine hard to get working and spent many months on the project. I rebuilt some stages of the transmitter several times. Perhaps homebuilt single sideband should be something to look forward to when you have loads of free time. After you have worked on an SSB transmitter for a while, you may decide that good old Morse code isn't so bad after all!

On the other hand, receiving single sideband is easy. A filter made from a single, off-the-shelf, microprocessor crystal is all you need to receive clear, interference-free speech. The homemade receiver described in chapter 13 works great for SSB.

Instant high quality communications

Perhaps you have read all of the above and decided that your primary goal is to talk to people by radio as soon as possible. For you, building equipment is a secondary interest. If that describes you, you should probably buy a modern high frequency (HF) transceiver then begin work on your ham license as soon as possible. Modern commercial ham stations are usually "transceivers" that combine the transmitter and receiver in one unit. Many of the circuit blocks

in transmitters and receivers are almost identical. Logically enough, the transceivers use the same circuits for both send and receive.



A modern, top-of-the-line HF transceiver – the Yaesu Mark V Field, FT1000MP

I recommend buying a transceiver that can tune all ten high frequency bands. If you buy a modern, quality **used** transceiver, the price can be well under \$1,000. This will give you a (nearly) complete station that is more sophisticated than you or I could build with years of effort. Even if you don't have your license yet and can't transmit legally, you should buy or borrow some kind of receiver as soon as you can. That way, you can at least listen to shortwave radio. Really, listening is more than half the fun. Many commercial transceivers or receivers can receive the entire shortwave spectrum from 1.8 to 30 MHz. This includes all the commercial broadcast, foreign stations, and time and weather stations. Listening will make studying for your ham license much less theoretical. If you want to experiment with the built-in transmitter, you may not transmit on the air without a license. However, you can practice loading a "dummy load" instead of an antenna. If you have an antenna tuner, it's fun to load up an ordinary filament lightbulb as a dummy antenna and watch the light pulsate as you talk or send Morse code. See Chapter 9.

Occasionally I consider buying a modern transceiver like the one above. These transceivers are "easy" in the sense that they can instantly perform virtually every feature and communication method you have ever heard of. For example, when the new 60 meter band opened, it was possible to reprogram the Yaesu FT1000MP to cover 60 meters just by pushing the right combination of buttons. And, as you might expect, practically everyone on 60 meters was using an FT1000MP. The bad news is that the instruction manuals make operating your VCR look like child's play. All those buttons, menus, and operating modes are enough to drive you to drink.

Yes, I occasionally think about buying one, but for me, it wouldn't be satisfying. As soon as I had read the manual and tried out the features I was interested in, the transceiver would become boring. I can name several hams who have superb transceivers gathering dust in their home stations. They haven't turned them on in months or even years. On the other hand, if your ham radio bliss is working all the 335 odd call signs in the world, then you will need the best possible equipment. Building your rig yourself is going to slow you down for many years or decades. Maybe that's a good thing. You decide!

Pursuing a dream

When I was in high school 48 years ago, television was "exotic." Although black and white TV receivers were common in our living rooms, almost no one could afford a TV camera.

Because I couldn't afford a camera, their unavailability made them fascinating. I spent hundreds of hours building and experimenting with TV cameras. Only one of my five camera projects actually worked properly. (See chapter 16.) Later when I was grown, my wife bought me a fantastic TV camcorder which today is a big yawn. Because camcorders are routine today, to me the camcorder was just another way to take baby pictures. I have hardly done a thing with it. *Familiarity and ease of acquisition produce boredom.*

VHF/ UHF Hand-helds

The simplest and cheapest kinds of commercial ham transceivers are VHF hand-held walkie-talkies for 2 meters (144 MHz) and/or 70 centimeters (420 MHz .) These walkie-talkies are slightly more adventurous than a cellphone, but in my opinion they aren't as useful or interesting unless you are using IRLP, described below. Hand-helds also require a ham license, but in the US at least, a VHF "technician" ham license has the easiest test. Another limitation of hand-helds is that the communication is basically line-of-sight. In other words, if you are behind a mountain and want to talk to the other side of the mountain, you need a relay station (a repeater) that just happens to be on top of the mountain or in some location that is visible to both you and the guy you're talking to.

The best feature of hand-helds is *IRLP*. This is an Internet-connected network of VHF and UHF repeater relay stations or "nodes." The idea is that you use your handheld transceiver to key in codes into your local repeater node. The repeater uses the codes to connect you via the Internet with other nodes anywhere in the world. The repeater node in Boston, Australia, or Berlin then rebroadcasts your VHF signal as if it were local. Guys in those distant cities hear you and reply as if you were located in their own town. This system is mostly used for rag-chewing and isn't burdened with contests and guys who are just interested in collecting call letters and QSL cards.



A 2 meter hand held transceiver (walkie-talkie) with a spare battery pack.

Personally, I use my 2 meter walkie-talkie as an emergency radio for hiking. Honestly, I think a cellphone would probably serve me better in an emergency, but I've been too cheap to buy one. Most owners of VHF walkie-talkies use them like citizens band radios to talk around town. In general, the quality and range of the commercial amateur radio hand-helds is far

superior to citizens band radios. On the other hand, citizens band and the "Family Radio Service" (FRS) are other "quick and dirty" ways to get on the air without a license.

If you buy a hand-held, be sure to buy an extra battery pack or two. To make mine reliable in an emergency, I replaced the rechargeable batteries inside the battery packs with alkaline batteries. Although they aren't rechargeable, alkalines store several times more energy and tolerate cold temperature much better than rechargeables. I found that the original NiCads went dead almost immediately when I was out skiing.

HF versus VHF and UHF ham radio

Among serious hams, the spectrum is generally divided into two halves, "High Frequency" (HF = 1.8 to 30 MHz) and "Very High Frequency" (VHF = 50 MHz) extending up to Ultra High Frequency (UHF = 220 MHz and above). Above UHF are the microwave bands with frequencies measured in gigahertz and wavelengths in centimeters. Most HF hams like long distance communication with either CW or voice. There are also HF packet-radio modes and slow speed picture transmission which resembles e-mail with a very slow modem. RTTY and PSK-31 are modes that resemble instant e-mail messaging on the Internet.

There are two kinds of VHF/UHF guys. The vast majority of them just own hand-helds, but a few UHF hams are extremely technical and do high tech experimentation. This can be ham-television, exotic voice modulation like spread-spectrum and transmissions using satellites. One way the microwave guys have fun is trying to see how far they can communicate between mountain tops.

Much like my effort to build a TV camera, what you do with great effort is more rewarding than buying a gadget and copying the crowd. So it shouldn't be a surprise that, for the technical UHF guys, a lot of the fun is organized around trying to talk to distant stations using ionosphere substitutes like satellites, or bouncing radio waves off the moon or even the aurora and falling meteors. Instead of using repeater relay stations, these guys get their kicks by using these exotic substitutes.

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BUILDING AN ANTENNA

Every shortwave radio station needs an antenna and building one should be your first project. Shortwave reception with a modern receiver can be adequate with as little as a few feet of wire dangling off the antenna connector. Many commercial short wave receivers built for non-hams have coil antennas (magnetic antennas) built inside the receiver case. Tiny antennas like this are adequate for hearing powerful stations such as Voice of America, Deutsche Welle, (Radio Germany), Radio Moscow, or the BBC (British Broadcasting Corporation).

Amateur radio stations, by law, are limited to 1,500 watts Peak Envelope Power (PEP) and most of them run 100 watts or less. This means that hams are hundreds of times weaker than the commercial stations mentioned above and a big antenna is important to hear them. The lower the frequency, the bigger the antenna you will need. A good transmitting antenna needs to be at least ¼ wavelength long. A good transmitting antenna for shortwave radio signals must be high enough to send signals toward the horizon with as few obstructions as possible. Although an adequate receiving antenna can often be small and close to the ground, a large, high wire

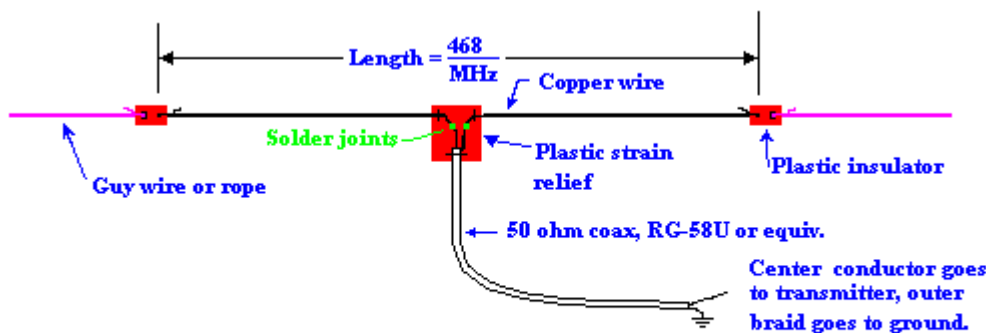
antenna works well for both jobs.

The long wire

The simplest, most versatile antenna is a “long wire.” It is literally a long piece of wire, ideally $1/4$ wavelength long or larger. For example, for 40 meters, it must be at least 33 feet long and should be strung up in a tree or other place as high as possible. In general, if you connect a random length of long wire to a transmitter, it will not be resonant with your hamband and you must “match it” with an impedance transformer called a *transmatch* or *antenna tuner*. Fortunately, an antenna tuner can be quite simple and can be put together in a couple hours. An example is described in Chapter 9.

The 40 meter dipole

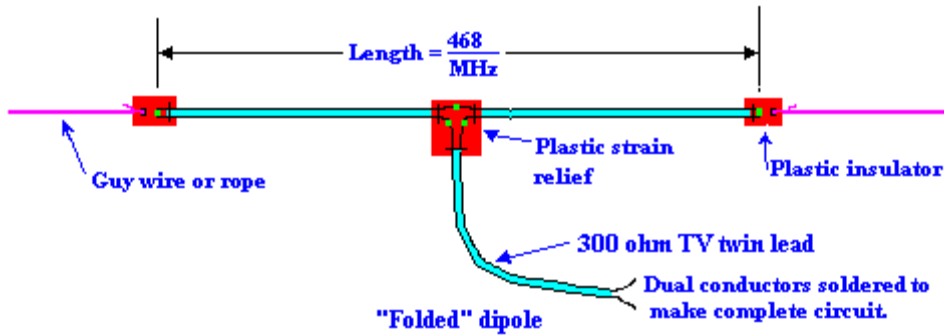
If I could only have one antenna, this is the one I would build. This simple antenna works well for both 40 meters and 15 meters (7 MHz and 21 MHz). As will be explained later, extra antenna arms can be added so it will work on most of the other hambands. The advantage of a dipole antenna is that they have an impedance of roughly 50 ohms that is easily loaded by a ham transmitter. So, although an antenna tuner is still helpful, this antenna will transmit quite efficiently without much tuning.



For 40 meters the length is 66 feet. The coax feed line can be any length, but shorter is better.

Where do I get antenna materials?

Radio Shack stocks RG-58U coax, insulators, and heavy, multistrand copper wire that are perfect for dipoles. I usually make my insulators out of plastic scrap from a local plastic fabrication shop or I use ABS plastic pipe sections from the hardware store. If you have trees, a roof, or other tall objects on which you can mount an antenna, you're in business. Hang it as high as you can.



The folded dipole

Homebrew dipoles come in two basic flavors, “regular” and “folded.” Back when I was young and impoverished, my favorite dipole was “folded” and made entirely from 300 ohm TV twin lead. The dual conductors of all three arms of the “T” are soldered together to complete the circuit in a “loop.” I had one antenna cut for 40 meters that I used primarily for 40 and 15. It even worked OK on 75 meters for the local AM phone round tables our club used to hold. Aside from being made from cheap wire, another advantage of the folded dipole is that flat 300 ohm twin lead can slip through a slightly open window without mashing a fat, round cable or without drilling holes in the window sash.

Yeah, I know. 300 ohm balanced folded antennas need a *balun coil* and a transmatch to match the transmitter. When I was a happy, dumb novice, I just loaded it directly with my unbalanced π (pi) output class C vacuum tube transmitter and it worked very well, thank you. Then, when I learned how balanced antennas are supposed to be driven, I bought some fancy balun coils. I was disgusted when I observed no difference in performance.

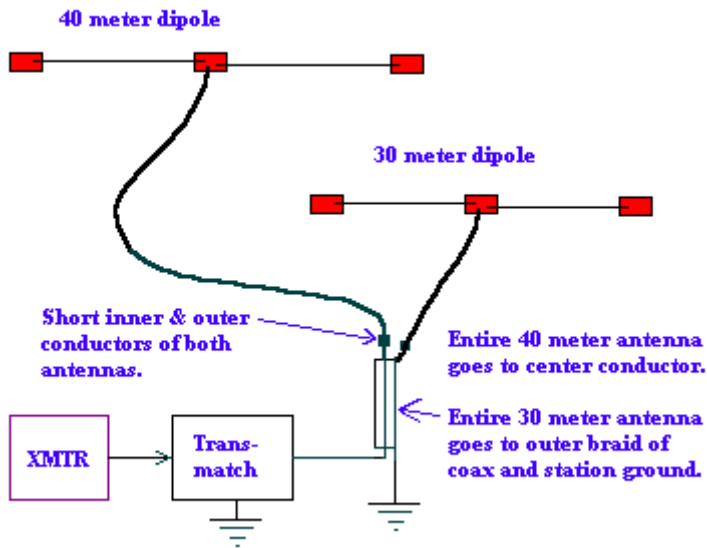
Multi-band Dipoles

Today we have four more HF bands than 40 years ago and I can’t resist trying them all. Any band I can’t work MUST be wonderful, right? I have a “regular” 40 meter dipole in the front yard and a 30 meter one in the back yard. I guess I have room for an 80 meter Zepp, but I’ve been too lazy to build one. Jack Ciaccia, WMØG, uses the gutters and drainpipes on his house as an 80 meter “longwire.” This sounded like a terrific solution. Unfortunately, my laziness soared when he began talking about “the buried radial ground field.” In other words, I was supposed to dig long ditches across the lawn in several directions and bury multiple ground wires. My wife would be thrilled with that.

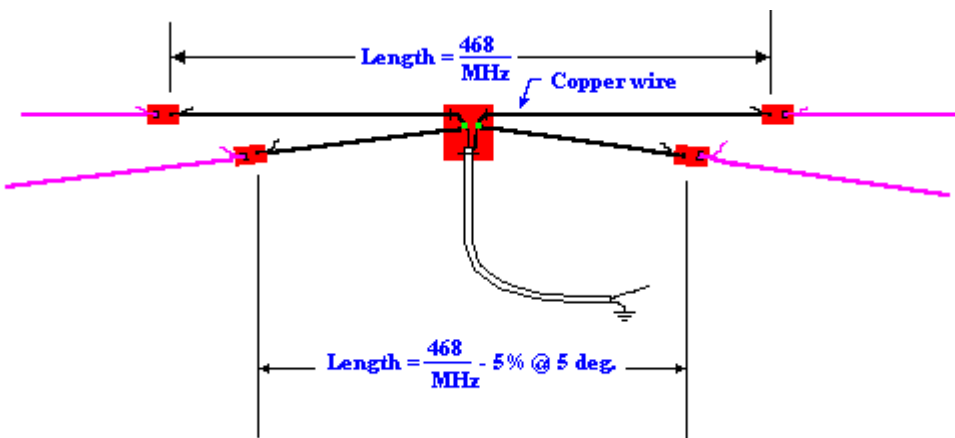
A year later Jack told me that deep heroic ditches are unnecessary. He waters his lawn to soften the dirt and roots. Then he digs his “ditches” with a large pizza roller cutter. He cuts a slit in the turf a couple inches deep. He slips the radial wires into the slits and, when the turf grows back, the wires are sealed under the grass.

Several years ago the 80 meter band was exceptionally “hot” with dozens of CW stations on every night. I was eager to get on the air. I tried loading my 40 meter dipole on 80. I managed to do it, but there were hundreds of volts at the station end of the coax. (With a 40 meter antenna, the transmitting impedance is a tad high on 80 meters.) After a couple hours of calling and tweaking, no one answered me. It seemed clear that I wasn’t getting out and I

needed a better plan.



Then the cerebral lightbulb dawned! Why not use the entire 40 meter dipole, coax and all, as a longwire? For a counterpoise I first used my station ground, which is heavy copper wire connected to a water pipe. This loaded better than the 40 meter dipole but still didn't work very well. Next I connected the entire 30 meter dipole, coax and all, to the station ground. My 30-meter dipole is in the back yard and well separated from the 40 meter dipole. Presto! I suddenly had a low impedance 80 meter antenna that loaded beautifully. There was one little glitch: My wife stormed downstairs and told me that I was obliterating the TV pretty much on all channels. Oh well, after that experience I got on 80 after she went to bed. I think (pray) the TVI is limited to inside my house. My theory is that I'm loading up the house wiring and the TV is immersed in the antenna near field. More recently we bought a much more modern TV. It seems to be immune to not only my 80 meter signal, but my signals on all the HF bands.



The multi-band dipole

When I tried to get on 20 meters with my 40 meter dipole, I had a high impedance problem similar to using the 40 meter dipole on 80. However, using the antenna tuner described

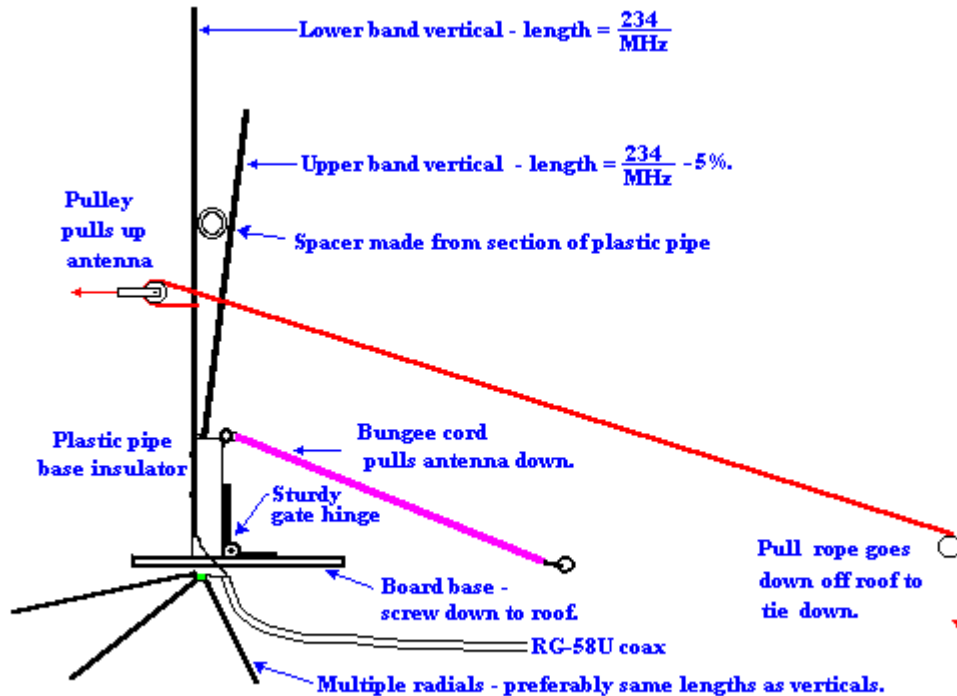
in chapter 9, I still managed to work folks. Consulting the ARRL handbook, I added 20 meter elements to my 40 meter dipole to turn it into a two-band dipole. A simple formula for the length of both of the secondary elements taken together is $468 / \text{frequency in MHz} \text{ minus } 5\%$. Each arm of the dipole is offset from its neighbor by about 5 degrees. This lowered the impedance on 20 meters to something near 50 ohms and has been quite successful.

Now suppose you want to add elements to the 40/20 meter dual band dipole to cover other bands, such as 30, 17, 12, and 10. Yes, it's possible to do this. Steve, WØSGC, built a five-band dipole just like this. The ARRL handbook doesn't recommend this because such an all-band array tends to radiate every stray harmonic your transmitter may generate. In other words, it works too well! On the other hand, three-banders, such as 30/17/12 meters or 40/20/10 meters are recommended. Notice that you don't need to add an element for 15 meters because the 40 meter elements already work well on 15 meters. Therefore a tri-bander built for 40, 20, and 10 is actually a four-band antenna.

The length of the third dipole is calculated just like the second dipole. Suppose you already have the 40 and 20 meter dual band dipole and want to add another dipole for 10 meters (28.1 MHz). The length would be $468 / 28.1 \text{ MHz}$ or 16.65 feet minus 5% or 15.82 feet. (15 feet 9.8 inches). The third antenna would also be offset from the center (20 meter) dipole by 5 degrees. Do *NOT* decrease the length by 5% a second time.

A limitation, or possibly an advantage, of a dipole is that it transmits the most energy perpendicular to the wire. It also radiates significant power in line with the dipole. That is, dipoles are somewhat directional. Therefore, if you wish to talk to South America or over the North Pole to Russia, ideally in the US your dipole should be oriented east to west. Conversely, if you wish to talk across the US to the east and west coasts, the dipole should be oriented north and south. This isn't a big deal in performance, but if you have your choice in places to string the antenna, it is something to consider.

The curtain rod vertical



A dual band, dual vertical, hinged for lightning protection

I wanted antennas for 10 and 15 meters that would be higher off the ground and less directional than my dipoles. Vertical antennas are simply metal poles $\frac{1}{4}$ wavelength long sticking straight up. They are really just dipoles standing on end. Therefore, although we talk about the vertical part, we also need the counterpoise portion connected to the coax cable outer shield. The counterpoise consists of "radials" preferably the same length as the vertical extending out along the roof or ground in all directions. In theory, like a dipole, a single radial will work, but in practice multiple radials equal or longer than the vertical work best.

I started with a 15 meter vertical consisting of an 11 foot curtain rod lashed to my chimney. (234 divided by 21.1 MHz) Four thin wire radials fanned out down the roof in four directions. It worked well the first time I loaded it. The fun of using a real curtain rod is that, when you tell someone your antenna is "a vertical made from a curtain rod," they usually comment on it as if you had built a nuclear reactor out of a washing machine. Interesting psychology. Obviously these guys have never built anything themselves.

Trap antennas

Next I tried to add 10 meter capability by adding a parallel LC resonant trap tuned to 10 meters about 8 feet up the vertical. The idea is that, if a tuned LC resonant circuit is added at the right distance up the antenna, the trap will prevent RF current from traveling up the antenna past the trap. In other words, for higher frequency bands the trap makes the antenna appear shorter than it really is. In this way a long antenna can also work well for a frequency much higher than its length would suggest. After I built a trap resonant for 10 meters, I adjusted the distances above and below the trap dozens of times. But even with an antenna tuner, I could never get it to load well on either band. It turns out that homemade trap antennas are hard to build.

You may have noticed that in an LC resonant circuit, the sizes of the L and the sizes of the C are not fixed. In other words, the LC circuit will be resonant at the desired frequency so long as:

$$\omega = 1 / (LC)^{1/2}$$

or, $\omega^2 = 1 / (LC)$

where $\omega = (2 \times \pi \times \text{Frequency})$

$\pi = \text{Pi}, 3.1416.$

L = inductance

and, C = capacitance

(an exponent of $\frac{1}{2}$ means the square root)

$$2 \times \pi \times \text{Frequency} = 1 / (LC)^{1/2}$$

Unfortunately, the sizes of the L or C do matter in a trap. This is because a capacitor or an inductor shift the phases of the current and voltage and affect the reflections of the waves along the wires. To design a trap properly, the distances above and below the LC as well as the sizes of the L and the C all have to work together to make the whole apparatus look like a 50 ohm resistor as seen by a radio wave. Good luck!

It turns out that this is a problem for Smith charts. These are a way of mapping out inductive reactances, that is, current phasing, so that they cancel and the antenna will look resistive. I haven't figured out a practical way to do this and the handbooks don't help, unless you copy their trap antenna designs precisely. In the end, I just applied the same dual-dipole principle as the multi-band dipoles discussed earlier. I added a second vertical to the first, separated by about 5° degrees and about 5% shorter than it would have been if it were standing alone. I added two more radial wires cut for 10 meters, but I'm not convinced they were essential. Once again, it worked perfectly on both bands the first time I loaded it.

Caution: ***Remember that "the vertical antenna" begins at the exact inch where the coax inner conductor first separates from the outer braid.*** A common mistake is to ignore an extra 6 inches of inner conductor that may be adding to the effective length of the driven element. The dual band vertical has worked beautifully. I've also used it on 12 meters successfully. Much to my surprise, it also worked on 17 meters, although the SWR (Standing Wave Ratio) isn't great. In other words, when there are standing waves on the antenna because the length is wrong, it takes extra voltage to drive it. I was probably losing some power on 12 and 17 meters.

Two years later, 10 and 15 meters were no long open but 17 meters was still active. To make the 15 meter vertical work well on 17, I tacked on an additional 1.9 feet in length and added some 16 foot long radial wires which are suitable for 20 meters. After this modification the antenna loaded easily on 17 meters and I got good signal reports. I can summarize verticals by saying that all you need to do is calculate the length in feet using the formula $234 / \text{frequency}$ and it will work well the first time you try it.

Kaboom! What about lightning?

Looking up at the metal poles on my roof, they looked more like lightning rods than curtain rods. I'm probably more paranoid than necessary, but I've had experiences with lightning. When I was a novice, fuses blew in my rig during a thunderstorm. A buddy of mine had his oscilloscope fried and a hole blown in his roof. On mountaintops I've felt my hair stand on end and heard my ice axe hiss as we galloped down the mountain in terror. Once I had the grim duty of carrying three deceased lightning victims down from Arapaho Glacier. Lightning scares the heck out of me and that vertical looked like a disaster waiting to happen.

My solution was the base hinge and bungee cord shown above. During the summer I raise the antenna by tugging on the rope whenever I need it, then lower the vertical when I'm done. The hinge also has stealth advantages. One important point is that the rope pulls it **UP**, while the bungee makes sure it folds back **DOWN**. I tried to have the bungee pull it up, but that worked poorly. There was too much torque on the vertical and the bungee wouldn't let the antenna fold flat against the roof.

How lightning forms and how likely it is to occur

According to the National Lightning Safety Institute of Louisville, Colorado, lightning begins with "leaders" of corona coming down the clouds. These leaders of charged air produce high voltage with respect to the ground. In response "streamers" of charge rise up from the ground and are most easily launched skyward by sharp conductive objects. When the streamers meet the leaders the ion path from cloud to ground is complete and the current flow enters the "arc phase." Once the path is complete, a lightning bolt begins. Lightning can be postponed or even prevented if the streamer paths can be suppressed and streamers don't merge with the leaders. ***Fortunately, except for the highest peaks and tall metal towers, lightning strikes are rare and capricious.*** Your best bet for safety, (but not for DX), is to keep your antennas no higher than the local trees and buildings.

Fuzzy metal brushes on an antenna are controversial

A relatively new approach to lightning prevention is to bleed the excess local charge off a vulnerable metal tower with metal brushes before it can attract a full-fledged lightning bolt. In contrast, ***the National Lightning Safety Institute (www.lightningsafety.com) strongly condemns using lightning rods of any sort.*** They say that lightning rods are allowing the streamer to begin earlier and are therefore attracting lightning. The fact that this is controversial demonstrates that lightning really is capricious. After 200 years of research it still isn't obvious whether lightning rods are good or bad! This tells us that, statistically speaking, lightning is not a big risk.

The Lightning Safety Institute has an ongoing research project up on a bare, rocky ridge high above timberline at 11,500 feet above sea level near Nederland, Colorado. The location looks like a good place to avoid during a lightning storm. I have been up there three times and examined their array of various lightning rods. They have pointed ones, square ones, and round ones. The rods are connected to ground through fuses. The first time I was up there, they were using 20 ampere fuses but none of them had blown. The next year they were using 2 ampere fuses and still none of them had blown. That must have been frustrating! By the same token I have recently encountered two 60 foot high spruce trees that were struck by lightning. The trees were literally exploded into giant chunks of log weighing hundreds of pounds. These trees were located among thousands of other 60 foot high trees in relatively flat high altitude forests. What

was special about those trees? Apparently nothing. Those trees were just unlucky. In summary, ***lightning is extremely random and difficult to predict.***

The 2005 ARRL Handbook doesn't discuss antennas as lightning rods. Instead ARRL stresses grounding antenna towers and placing lightning arrestors on lead-in coax and wires. They don't even mention using spiky points on antennas. ARRL emphasizes that ***it is difficult or impossible for a ham to protect from DIRECT strikes.*** This is because the spike of current produced by a lightning bolt is so huge and so sudden that, lightning not only has thousands of amperes, the abrupt rise in current means that any wire or metal conductor we could install will have too much inductance to ground to shunt the whole pulse away. The current pulse and big voltages will divide and jump to other objects. The best we can do is protect our house and equipment from surges due to *nearby* strikes. ARRL also recommends surge protectors on power cords to prevent damage to line powered equipment. Battery powered ham stations obviously don't need surge protectors and battery-power has other advantages as described in chapter 8.

In summary, unless you live on a mountaintop or have a huge metal tower, lightning is not an imminent threat and you don't have to be paranoid. If you're like me, your antennas are no higher than the local power lines and trees. I haven't had any incidents since 1960. However, I still crank my vertical antenna down in the summer whenever I'm not on the air and I unplug my antennas from my rig.