Clean your glasses. It's time for a sharp, clear look at amateur radio's workhorse—feed line.

Another Look At Feed Lines

BY LEW McCOY*, W1ICP

New amateurs, and some who have been around for a while, still appear to be somewhat confused when it comes to the subject of coax and open-wire (or ladder) line. Here I will attempt to break down the differences between these two popular lines and show their advantages and disadvantages. First, however, a bit of history is in order.

One of the very early types of transmission line used by amateurs was known as "open" wire line. This line consisted of two conductors, equally spaced, using what was known as "spreaders." Various line-spacing dimensions were used. Two and four inch spacing was common, and some amateurs even used six inch spacing. The wire most often used was No. 12 or No. 14 solid copper, and the spreaders were usually situated along the line and spaced to keep the two wires nearly as perfectly parallel to each other as possible.

One point to bear in mind is that all feed lines have loss. Just how much loss depends on several factors, which we will discuss later. What is important here is to understand that open-wire line such as that mentioned (two, four, or six inch spacing) has an extremely low-loss figure, while coax does not. The impedance of an open-wire line is based on the size of wire used, the spacing between the wires, and the dielectric material used to separate the wires. Of course, air was the common material between open-wire lines.

Shortly after World War II, when TV started to come into its own, we saw the introduction of plastics to electronic manufacturing. Manufacturers quickly came up with the use of plastics to separate twin lines, the most common being 300 ohm television twinlead. The 300 ohm number is the designator for the ohmic impedance of the line. The impedance of open-wire line or parallel-spaced conductors is determined by the size of the wire used, the spacing between the lines, and the dielectric material used (if there is any), such as plastic, to hold the lines in place. Naturally, the two, four, and six inch spaced open-wire lines are separated by air, which is just about the best dielectric there is (a pure vacuum would be best).

Amateurs were quick to utilize the 300 ohm *twinlead,* as the TV feed line was called. It was cheap, it could handle fair amounts of power (as much as 1000 watts in some cases), and it was easy to use. In fact, the folded dipole is still a very good and popular antenna. This antennas was a natural for 300 ohm twinlead. I will show such an antenna a little later.

It wasn't very long before transmission-line manufacturers realized that there was a market for a line that would be more rugged and would handle more power than the common twinlead. This led to what we now call ladder line. These lines are made with much heavier wire, have greater separation (usually on the order of one inch), and the phenolic or material is cut out in symmetrical sections, making the line look like a ladder. Less loss is achieved by removing about half of the phenolic insulation. The inherent losses in this type of line are not as low as with regular open-wire line, but for amateur applications ladder line is very good.

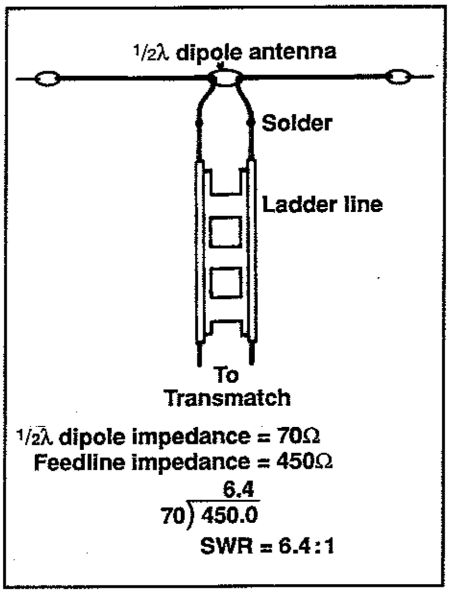


Fig. 1– As described in the text, a half-wavelength dipole has an impedance of approximately 70 ohms. If fed at its resonant frequency with ladder line, the resulting mismatch (but with practically zero loss!) would be 6.4 to 1 SWR. However, with a wide-range tuner or with a Transmatch, the antenna could be used on any band.

The normal impedance of ladder line is on the order of 450 ohms. The current types now available in 450 ohm line will easily handle the amateur legal limit. I have used 300 ohm twinlead at 1000 watts, but in some instances (with poor quality line) the phenolic material melted!

As an aside, years ago I used 300 ohm twinlead to feed a 160 meter antenna. My shack was on the upper floor, and one night my wife came up to the shack and said, "You had better look out the back window." I shut off the rig and went to look out at my dipole. The twinlead had caught fire and was slowly burning, the fire coming back towards the shack. It took some quick action on my part to keep the fire out of the shack. That would not have happened with modern 450 ohm ladder line, and of course could never have happened with open-wire line.

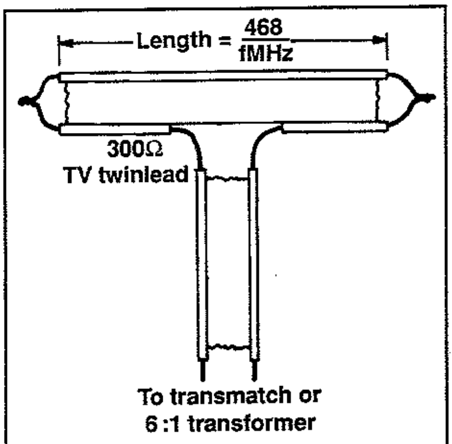
One important point that bears mentioning: 300 ohm twinlead can be affected by rain or snow, and the effect can be appreciable in that it will cause detuning of your transmitter. Ladder line can also be affected by rain or moisture in that the impedance of the line changes. Also, 300 ohm line, or even ladder line, should not run parallel to or tightly along metal, such as a tower. My rule of thumb is to mount such lines at least 12 inches away from metal structures.

We need to digress a little here and discuss SWR (standing-wave ratio). The main function of any feed line is to carry power from the transmitter to the antenna, and to do so without radiating. If the line radiates, then it isn't a feed line; it becomes another antenna. Standing-wave ratio, a bugaboo to all amateurs, is the ratio of the maximum RF current or voltage in one feed line conductor to the current or voltage in the other conductor. The ideal situation, in most cases, is to have as low an SWR ratio as possible—in other words, a ratio of one to one. Why? Simply because you obtain the greatest efficiency. Line losses will increase as the SWR increases, so unless you use a lossless line—for example, open-wire or ladder line—you must work to keep the SWR low.

There are other reasons to strive for a low SWR, and I'll discuss some of those later. But for now, here is a very important point. For all practical purposes, open-wire or ladder line is a very low loss line, and this means that very high SWRs can exist without any really measureable losses taking place. In your amateur career you probably will hear that a high SWR will cause a feed line to radiate. That is not so. Regardless of the SWR, the current or voltages in the two conductors are supposed to cancel each other's radiation. However, there is a condition in which a feed line can radiate, and I will discuss that a little further on, when we discuss coaxial line.

Let's get a little practical at this point and discuss the actual use of open-wire line. Most of us know, or should know, that the impedance of a half-wavelength dipole is on the order of 70 ohms, depending on the antenna's height and the ground conditions below the antenna. Suppose we feed this dipole with open-wire line, one side of the line going to one side of the dipole and the other side of the line to the other side of the dipole, as in fig. 1. The SWR on the line is determined easily because we can divide the 70 ohm antenna impedance into the 450 line impedance, giving us a ratio of 6.4 to 1. This is a high SWR, and in fact, with modern transceivers with solid-state finals, we would not be able to feed any power into the

*Technical Editor, CQ, 1500 West Idaho St., Silver City, NM 88061
e-mail mccoy@zianet.com



Basic dipole length

MHz	Feet
28.4	16.5
21.2	22.0
18.1	25.9
14.2	33.0
7.2	65.0

Fig. 2– This diagram gives information on the at one time very popular folded dipole. The folded dipole gives slightly greater bandwidth than an ordinary dipole. There is some amateur radio "mystique" to a folded dipole, as users have reported unusual results with it. Dimensions are given for many of the popular bands.

line at the transceiver. The transceiver would self-protect and shut down at 6 to 1. We must transform that 6 to 1 SWR mismatch to a 1 to 1 load for the rig to put out power. That's simple with a Transmatch or antenna tuning device.

However, and this is important, the open-wire line loss feeding a dipole, and having an SWR of 6 or 7 to 1, is not worth worrying about. The line loss because of standing-wave ratio is less than one decibel, even on 10 meters. (As an example, an SWR of as much as 10 to 1 with open-wire or ladder line is still less than one decibel—not even a measurable loss.) Our problem would still exist, though, in that we would have to transform the SWR mismatch to match the 50 ohm output of our rig. We would have to use a Transmatch to transform the impedance of the 450 ohm line down to 50 ohms. This is a very simple process, but necessary in order to have our transceiver working properly.

When we look at an antenna fed with open-wire line, the system should be viewed as a "package." To explain, let's assume we have enough room to put up a dipole that is 160 feet long—in other words, two 80 foot lengths of wire fed at the center with 450 ohm ladder line. To further confuse our problem, we plan to use this antenna on all bands—say, 160 meters clear down through 10 meters. The impedance of that antenna is going to vary all over the map. It can go from below 50 ohms to well over 4000 ohms, depending on which band we are on. We bring the end of our 450 ohm line into the shack and connect it to the Transmatch. What is this load that we have attached to the Transmatch? It certainly isn't 450 ohms. (It could be on one frequency, somewhere, but that's highly unlikely.) This load, which the Transmatch sees, is very complex. Our Transmatch has the job of transforming this varying load into a constant 50 ohm load to match the output of the transceiver. We put an SWR bridge in the line from the rig to the Transmatch, and then by observing the SWR bridge meter, we adjust the Transmatch so that we have a 1 to 1 SWR showing. This means that the Transmatch is converting the *unknown load* to a perfect 50 ohm load. Think of the Transmatch or antenna tuner in the same manner as a transformer. In fact, that's what it is. It transforms the unknown antenna system load into a 50 ohm, pure resistive load. The Transmatch takes the unknown antenna system load, and whatever that load is, high or low impedance, with reactance in it, converts the whole thing to a perfect 50 ohm resonant load.

We know for sure that there is almost certainly going to be an SWR of greater than 2 or 3 to 1 on the ladder line. However, we also don't care what the SWR is because we are using a practically lossless line. The line cannot radiate, so our power is going to go to our antenna and be radiated. What is more important, though, is our simple dipole antenna of 160 feet length is a very good antenna.

As you think about what you have just read, ask yourself, "Is the overall length of the dipole that important, and must it be a half wave long or longer?" The answer to those two items is important in understanding this system.

Always keep in mind that you are using an essentially lossless line. It should become apparent that theoretically you can use an antenna of any length for multiband operation. There are some limits as to how small—or rather how short—you can make the antenna, however. Always remember that bigger as well as higher is better in antenna construction. But most of us are strapped for antenna space, so let's be practical. I would recommend an antenna that is at least a quarter wavelength long overall. In other words, a 65 foot dipole will work on 80 (even 160), and when you tune the system to a higher band, that antenna will exhibit gain in some directions. You can use an inverted-V type of dipole; you can even fold the ends at 90 degrees to increase the overall length. You can make your own G5RV antenna simply by making the dipole 102 feet, center fed. In the case of our 160 foot dipole example, longer is always better. With a Transmatch you can use end-fed antennas or just long-wire antennas, although from experience, I prefer center-fed dipoles.

Also keep in mind that when your Transmatch is tuned to match the unknown antenna system load to the transmitter, you have set up the maximum transfer of power. Another advantage is that your transceiver is in all likelihood designed to have a 50 ohm input for the receiver. You therefore also improve your reception by matching the antenna system to the receiver. In addition, if you happen to be bothered by cross-modulation or other types of interference from a nearby broadcast station, the Transmatch provides more selectivity for your receiver and will give you better protection. Frequently I have been asked whether I use a Transmatch with all my antennas, including my beam, which has a 50 ohm feed. The answer is simple: I always use the Transmatch merely because I want my equipment always to work into its design impedance, which is 50 ohms.

I mentioned the 300 ohm twinlead folded dipole. This antenna has been around for many, many years and is an excellent performer. It is unlike the ordinary dipole because the antenna is folded back on itself. Fig. 2 shows the antenna and its 300 ohm twinlead feed. It is also slightly more broadband than an ordinary dipole. Of course, from what I have just shown you, you can see that the impedance of the system is 300 ohms, the same as the impedance of the line. You'll still need a Transmatch or a 6 to 1 ratio balun to get down to 50 ohms. The common 4 to 1 balun should work okay. Jerry Sevick's book *Building and Using Baluns and Ununs* gives details on making 6 to 1 (or practically any other value) transformers. (The book is available from *CQ*.)

The formula for figuring out the length of a folded dipole is 468 divided by the frequency to be used. A Novice 10 meter folded dipole would be 468 divided by 28.5, giving a length of 16.47 feet. One of the very first antennas I made was a folded dipole for 10 meters. I taped the dipole to a length of bamboo and hand-rotated it. I worked well over 100 countries with that antenna, and it cost less than ten dollars.

If you go to yard sales, you might look for 8 foot long, non-metal fishing poles. Two of these will be long enough to tape to them a 10 meter folded dipole made from twinlead or ladder line. It shouldn't be any problem to make up a simple rotating system using a TV rotator, and you then will have one very fine rotatable, directional antenna. Ten meters will be coming back into its own within the next few years. If you want to make your own open-wire feeders, you may find it tough to find the necessary spreaders. However, women's plastic hair curlers are cheap, and there are many types available. If you can find plastic or poly dowel rods, they can be cut to the desired length and used.

Coaxial Feed Lines

Coax feed line is without a doubt today's most popular transmission line in use by amateurs. Coaxial line consists of (usually) two conductors—an inner conductor and an outer conductor, which also serves as a shield. A protective jacket usually made from a poly material surrounds the outer conductor. The material used in this outer covering can be a type that is impervious to weather. In fact, with some coax the lines actually can be buried underground without affecting their performance. However, compared to open-wire line, coax suffers as to efficiency. Because of the close spacing of the conductors and the dielectric material used to surround the inner conductor, losses can be quite high. This, of course, will depend on how well the coax is designed and manufactured.

A simple example explains this problem. One hundred feet of RG58/U feeding an antenna on 2 meters will have very high losses. Assume 100 watts is being fed from the transmitter. Just about 70 watts will never reach the antenna, but will be dissipated as heat. That's what I call inefficiency! This loss occurs when the coax's impedance (50 ohms) is matched to a 50 ohm antenna. If we have a mismatch, the losses will rise.

There are some facets of SWR that are very important. First, and of course most important, is the design of your transceiver. Nearly all solid-state transceivers are designed so that they simply cannot tolerate an SWR of more than 2 to 1. Simply put, when the SWR exceeds this value, the transmitter final amplifier turns itself off. If the load were to exceed 3 to 1, the voltages and currents could go so high that they would destroy the final transmitter transistors.

Therefore, there are circuits built into the rig to protect the final stage against this condition.

There are a couple of answers to this problem. First, you can match your antenna system to your feed line and also match the feed-line load to the transceiver. This can be a fixed adjustment that never needs changing. Unfortunately, it also means that your system likely will be confined to a single frequency or a very narrow bandwidth. When you QSY, the values all change, so you would require more flexible adjustments.

The next answer is the use of a Transmatch with your transceiver. Today, many transceivers have built-in Transmatches—or if you will, antenna tuners. Unfortunately, most of these have very limited matching ranges; usually they will handle no more than a 3 to 1 SWR. Remember, a 450 ohm ladder feed line connected to a halfwave dipole will have a 6 to 1 SWR. The obvious answer, therefore, is to use a wide-range Transmatch. In my system I use a commercial Transmatch which handles either coax or open-wire line, or even single-wire feed. This following statement may shock you, but I can easily match SWRs of 40 to 1 or higher on my ladder-line feed.

I mentioned earlier that RG58/U had that horrendous loss at 2 meters in a 100 foot run. One problem with having a high SWR is the increase in losses in the line as the SWR rises. How much the losses increase is very important. The statement that has been used is "additional losses due to SWR." Here is a very important point in this discussion. For all practical purposes, open-wire or ladder line is lossless up to 30 MHz. In fact, ladder line has a loss of only 0.3 decibels per 100 feet at 50 MHz. My SWR of 40 to 1 would mean no additional losses worth considering up to and through 10 meters. Another popular coax is RG8X. This is a relatively small diameter coax. Its loss on 10 meters is about 1.5 decibels (that can be appreciable).

It is important to know how RF energy flows in coax. The RF flows on the outside of the inner conductor and the inside on the outer shield. There should be no flow of energy on the outside of the outer shield. If RF flows on the outside, then the coax acts as an antenna and radiates. This is very undesired radiation if you are using a directional antenna, as it can either destroy or degrade the desired beam pattern.

The coaxial line with which we all are familiar is simply a tubular feed line with an inner conductor surrounded by a metal sheath. The inner conductor can be a solid or stranded wire, the stranded wire providing slightly more flexibility of the line. It is customary to enclose the inner conductor in a sheath of poly material and then surround the poly material with a copper or aluminum shield which is also the second conductor. This outer shield can be made from stranded copper wires or a solid shield. The solid shield is more expensive than the stranded, but does provide better shielding. One of the important factors of coax line is that it is a shielded transmission line in that all of the RF flowing on the line should be enclosed within the shield. In theory, there should be no radiation from the coaxial line when it is carrying RF energy, but that is in theory. In amateur practice it sometimes is difficult to keep the coax from radiating.

The impedance of a coaxial line is determined by the size of the conductors and the spacing between the inner conductor and the outer shield. Before WW II coax was not in common use by amateurs simply because it was hard to find and very expensive. However, after the war coax was readily available on the surplus market and was cheap. Amateurs were quick to use the line because it offered many advantages over the then-used open-wire line. Coax could be strapped to a metal tower, buried underground, and even run under water. Of course, all these features were a big advantage over the lines amateurs were accustomed to using. The commonly available impedance of the coax line then was either 50 or 75 ohms, but gradually amateurs came to accept 50 ohms as the standard.

This relatively low impedance completely changed transmitter and receiver design so that all modern equipment is designed to work into 50 ohm impedances. That, and the advent of television and the need to prevent TVI, hastened the use of coax. All of this may sound as though coaxial feed lines are the answer to all amateurs' prayers, but unfortunately that isn't so.

It is important to keep in mind that losses also occur on the receiving path. Weak signals coming into your antenna may never reach your receiver! I know amateurs still like to use RG58 coax on 2 meters when doing mobile installations, but it is so easy to lose a lot of your power with it, that it just isn't worth using it. In addition, we found out many years ago that if an absolutely perfect job isn't done when installing coax fittings on RG58 or RG8X, it is possible to lose as much as 10 decibels just in the fitting. Get the details for installing fittings from one of the handbooks and do a good job, not a sloppy one.

If you are planning a new antenna installation and you would like to consider burying your feed line (coax), do some homework first. There are several feed-line manufacturers and dealers who advertise on the pages of *CQ*. Write to them and ask for the coax types they have available and their prices. Study the jacket material and the recommendations for use. Also the loss characteristics are very important. For example, a commonly used designation is RG8 coax, which is about 1/2 inch in diameter. However, there are many different types of this line which amateurs commonly refer to as RG8 coax. For VHF and UHF you want the lowest possible loss coax within your price range.

I mentioned earlier that some amateurs prefer to use coax to come into their shack and to keep open-wire line outside. I normally don't like to recommend using lengths of coax to go outside and then connect to ladder line or open-wire line via a transformer. A problem exists in that very high voltages and currents could exist on that short coax line from the rig out to the open-wire line. If you are running high power, the SWR on that length of coaxial line can get so high it will puncture the line. Be aware that high power in such an installation could be a serious and dangerous problem.

The above should help motivate you to think about one of the least appreciated aspects of your station. If you're a new amateur just starting out during this cycle's rise, then you have plenty of time to do it right the first time. If you're an old timer who's been around for a while, it's likely that your coax is old enough to vote and drink in all 50 states, and maybe it's time to get in step with some modern products. ■