Coax and Other Feedlines

For this discussion we will review the information supplied previously in our description of the complex nature of antennae and feed line. The illustration below is a visualization of a coax or feedline such as twinlead or open wire “ladder line” using discreet component equivalences. It is not difficult to see the interactive effects of the two conductors that make up the feedline. As with our vertical antenna, feedlines exhibit inductive properties along the axial length, and shunt capacitance between the conductors.

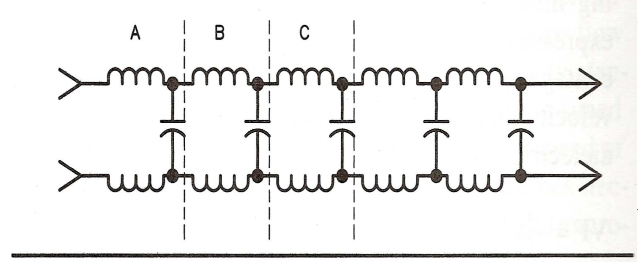
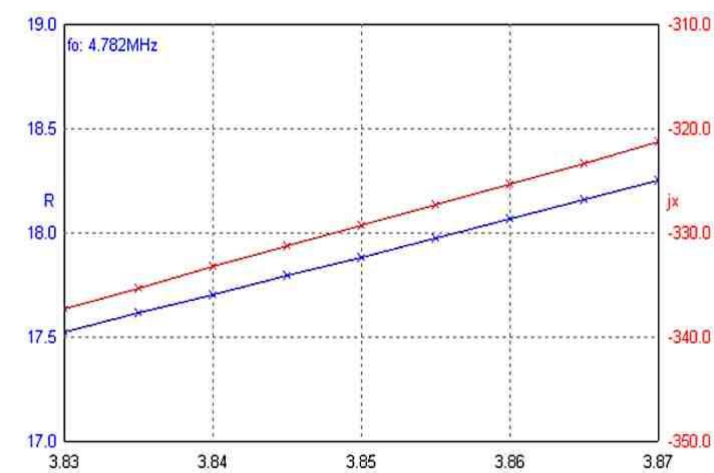


Fig 5—Equivalent of an ideal (lossless) transmission line in terms of ordinary circuit elements (lumped constants). The values of inductance and capacitance depend on the line construction.

Courtesy ARRL Antenna Book© 20th Edition

The characteristic impedance of feedlines is often expressed in ohms for simplicity. While there is some discussion as to how short a feedline must be to exhibit its characteristic impedance, there is no controversy when using 100 feet as a nominal length to publish impedances, velocity factor, and I^2R loss. These figures are important to the ham when evaluating efficiency of an operational antenna on various bands. To illustrate this, let's create a scenario that may be common for the typical ham shack.

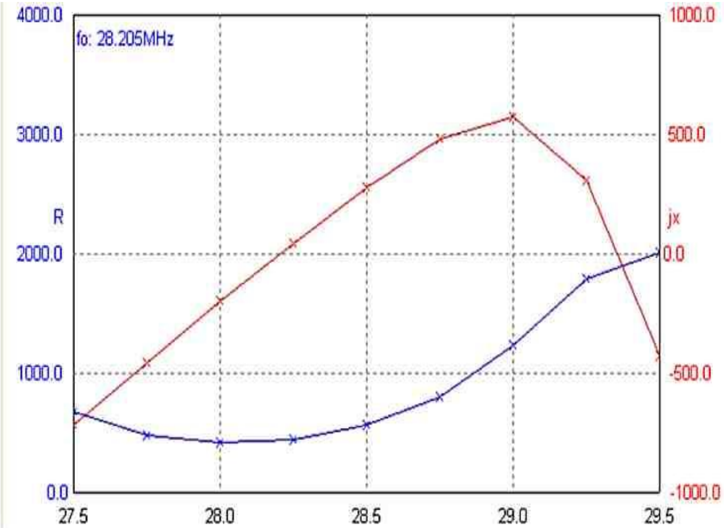
Our hypothetical antenna is a 100 foot long flat-top dipole with 100 feet of RG-8U coax. We will use calculated measurements of antenna impedances and the resulting feedline loss due to SWR at various frequencies. This system is completely unoptimized to illustrate the losses involved in unmatched systems. The illustration shown is for the 80 meter band with our 100 foot dipole at only 30 feet.



100 ft. horizontal dipole characteristics at a height of only 30 feet

At our 80 meter frequency, this antenna exhibits a very low impedance of only 18 ohms. Even with a balun, this antenna will have a very high SWR and will require a matching network or antenna tuner to operate on 80 meters. At the other end of the HF frequency spectrum is our 100 foot dipole at 28.400 mhz. The next chart indicates the impedances at that band of frequencies.

Once again the antenna characteristic impedances are well above a good operational limit. This is not to say that the antenna is not resonate. You will notice from the chart that it is indeed resonate at 28.205 mHz and again at 29.223 mHz. However, the real impedance is some 500 to 2000 ohms. Also, this antenna on 10 meters will require a matching network or tuner to operate with our equipment and 50 ohm coax.

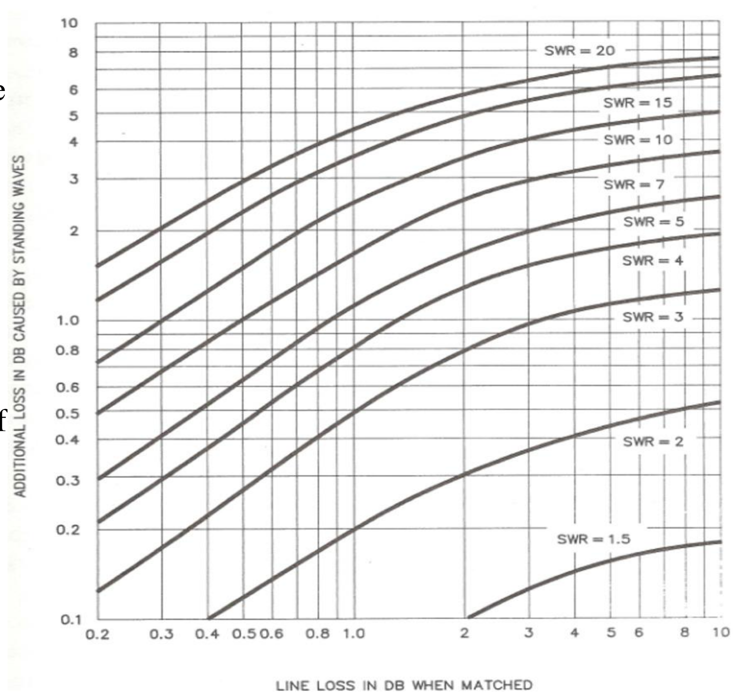


100 foot horizontal dipole characteristics at 30 feet on 10 meters

From our discussions so far, it should be easy for you to conclude that the SWR on these band limits would be very high. Aside from the destructive implications of high voltage arching and matching network saturation, etc. we should consider how much of our signal will actually be radiated. This is a consideration when taking in to account the losses of our feed line at this very high SWR condition. This is especially true when using a matchbox in the shack instead of a matching network at the feedpoint of the antenna or a tuner at the antenna. You need only recall our admonition about what the tuner does.

The tuner does not eliminate the impedance mismatch between the antenna and the coax when located in the shack. The reflected power does not enter the tank circuit of your amp or rig (review Myth #1 in chapter 1). The reflected traveling waves' power is re-directed by the matchbox toward the antenna and in-phase with the incident wave until power is completely dissipated or radiated. So, if the antenna to coax mismatch is still there, it is correct to assume power will be lost in the feedline and matchbox. How much is lost depends on the SWR and the rated loss per 100 feet given by the manufacturer. Our scenario uses a particular manufacturers' RG-8U cable that has a solid PE dielectric. This cable is rated at 50 ohms and a loss of only .211 db per 100 ft. for 3 mHz. That same coax will have .68 db loss per 100 ft. at 30 mHz. This rating assumes a good impedance match. The chart provided indicates how much additional loss could be expected under SWR conditions we may find in our shack. With only a 3:1 SWR at 30 mHz, the RG-8U cable will have an additional .373 db. The rated .68 plus loss due to high SWR amounts to 1.052 db loss at 30 mHz. This loss doubles to 1.969 db at 7:1 SWR and etc.

It is not difficult to see that the I^2R losses are not significant in the HF range for RG-8U cable. However, losses above 30 mHz become very significant. RG-8U coax, while very efficient on HF frequencies, is only appropriate above 30 mHz where there is a very good match between the coax and the antenna and a high grade of coax is used. The well made RG-8U cable we speak of has a loss of 1.547 db at 145 mHz when perfectly matched. This doesn't sound like much, but translated to power delivered to the antenna of only 70.129 watts out of 100 watts from our transmitter, it means a 30% loss of power in the coax. Our chart for additional loss due to SWR is still appropriate. So a 3:1 SWR should be rendered as 2.228 db loss at 145 mHz. A SWR of 6:1 could yield as much as 3.396 db loss per 100 feet of cable (only 45.85 watts reaches the antenna for 100 watts



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in). Quite a difference, to say the least. The more appropriate choice of cable (if feedpoint impedance is in the 50 ohm range) is LMR type cable or ½ or ¾ inch hardline for distances approaching or exceeding 100 feet, (either PE foam or air helix) with only .8 db loss per 100 ft. at the same frequency (2.03 db in our 6:1 SWR case in point – 62.989 watts delivered to the antenna).

Compare the figures for RG-8U to the more common RG-58A. Losses for this type cable are 2.095 db per 100 ft. at 30 mHz – twice the loss in db (that translates to 4.26 times as much power loss) as RG-8U! Knowing what we know about signal attenuation and loss, RG-58A, AU and AX become inappropriate for frequencies above 30 mHz where the cable exceeds more than 20 feet. In fact, if we take a detailed look at the cable specs, power limits for this type of cable are in the under 500 watt safety range even in the HF frequencies.

Here is a good site to visit for data on different types of coax and twin wire feed:
http://www.ocarc.ca/coax.htm

Now lets look at a non-coaxial feedline. The common twin wire feed line in use today is fondly called "ladderline" or "window" twin line. This descriptive name is due to the way the dielectric is manufactured with rectangular holes cut in the dielectric between the wires at regular intervals. The dielectric is normally brown or black polyethylene (PE) separating #14 or #16 stranded wire. The holes are used to lower the velocity factor (i.e. propagation delay) from where it would be with solid dielectric the entire length as with TV twin lead. As a general rule, the lower the velocity factor (i.e. the larger the number approaching 1.00), the lower the attenuation losses of the feedline. Twin-wire "window" line and open wire "ladder" line provide the best velocity factor (i.e. The larger numbers approaching 1.00) and also the lowest loss of all types of coax and feed line types with the possible exception of 6 inch, air dielectric, nitrogen filled, coaxial hard line for commercial broadcast use.

Every curious ham radio enthusiast and CB'er has heard that it is best to "cut your coax to length" to work "right". What does that mean - "cut it to length"? This phrase references the a misunderstood phenomenon we have been studying about complex impedances on antennas. It is a fact that coax or twin wire "ladderline" can be resonant too. However, a number of factors are in play when calculating the "correct" wavelength of feedline. The primary determining factor (other than frequency) is the velocity factor. Earlier we described velocity factor to mean the delay in propagation of RF along the feedline with a solid dielectric versus transmission wires separated by air. The reference of air dielectric is a 1.00 velocity factor (no delay). Solid PE dielectric very often provides a .66 to .68 velocity factor. Foam PE velocity factor will vary (according to the foam density) from .72 to .87. Since foam PE does not hold its shape very well, a loss of form factor will cause additional losses of other types as well as impedance variations in a wide range when the center conductor migrates toward the shield due to compression of the foam dielectric.

The wavelength of transmission line (coax or "window" line) is measured by calculating the electrical wavelength and multiplying the result by the velocity factor to get the appropriate actual or physical length. For instance, the half-wavelength of 20 meters is 10 meters or about 32.7 feet. The physical half-wavelength of RG-8U cable will be much shorter (approximately 21.6 to 22.79 feet depending on the quality of the cable used). For comparison, the 6 inch nitrogen filled hard line coax mentioned previously has a velocity factor of .95-.98 with only .077 db loss at frequencies up to 1.2 gHz. The very low velocity factor makes figuring the physical length of "tuned" coax easy. The ARRL Antenna Book provides a CD ROM that has a calculator program to do this figuring for you. You may also visit the Web site included above.

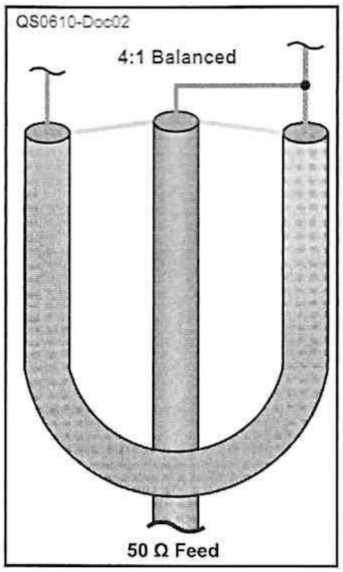
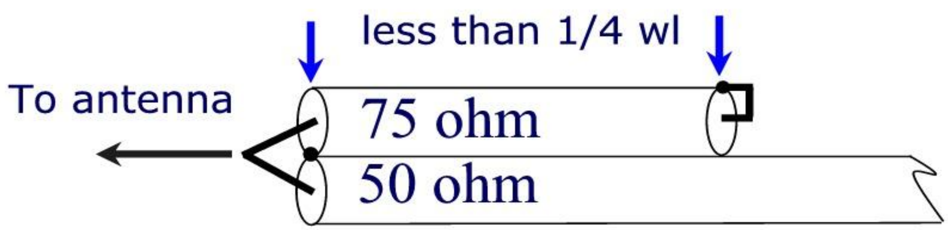


Figure 2 — Drawing of the construction details of a λ/2 balun from a recent *QST* article.

So why would you want to cut your coax to length? In practice, there are several occasions that precise lengths of coax are not only appropriate, but desirable. One situation was mentioned in an earlier chapter when talking about matching antenna impedances to coax. The following illustration is an example.

This strange looking arrangement provides an impedance transformation of 4:1 just as a transformer type balun would. The advantage is that this balun is much easier and cheaper to construct. The “U” shaped part is made from higher impedance cable like RG-213 or other low loss 75 to 150 ohm coax. The length is fixed at 1/2 the wavelength of the center frequency to be matched. This type of matching arrangement is most often seen at VHF and UHF frequencies (less frequently on 6 meters) due to the length of coax needed for matching. The length needed for matching 10 meters (e.g. 28.350 mHz) would be 11.45 feet assuming a velocity factor of .66. You could see the impracticality of using this kind of balun on frequencies below about 6 meters.

Another situation would be where we wish to tune out the reactive part of an otherwise effective antenna. Let's assume our antenna radiates well as a 5/8 wave length vertical. This is not a resonate antenna at 50 ohms. At resonance, it calculates to be 12 -j125. Coax and ladder line exhibit an unusual phenomenon when cut to very short lengths (less than 1/4 wavelength). If measured with both ends open, the coax will exhibit very capacitive characteristics. While shorting one end will cause just the opposite reaction (inductive characteristics). This phenomenon becomes happily convenient when we wish to offset minor reactive and impedance variations in a non-resonate antenna. Our 5/8 wave vertical can be matched with a shorted stub of coax that will equal and oppose the highly capacitive value of the antenna alone. The combined result is a real impedance very near our 50 ohm coax. The diagram below shows how the antenna wire and coax are combined to form the stub matched antenna-coax connection.



If this combination is not a high enough impedance (which is usually the case with this type antenna), a fractional wavelength of 75 ohm coax can be added in series with the antenna before the stub to raise the overall impedance. Millions of CB and marine antennas have been manufactured to just such a specification (mainly due to the very low relative cost and ease of construction).

The third situation is appropriate only when an antenna is used on one band primarily with little use on other frequencies. The single-band, single-use antenna system will likely contain a feedline that is a ½ wavelength multiple of the center operating frequency. In this way, the coax contributes little to the system other than transmission of RF from rig to antenna. The match is very close and power delivered to the antenna is as efficient as possible.

This last situation is of particular importance due to a phenomenon that occurs on sections of coax or feedline that are ½ wavelength multiples. When the line length is a multiple of ½ wavelength, the input reactance (the antenna) is equal to the load reactance (seen at the shack). In more familiar terms, the impedances seen at the rig end of the coax very nearly equal the impedances at the antenna feedpoint terminals. It does not matter whether the impedance exists at the antenna end or the rig end. It does not matter whether the impedance is a simple resistive value or complex with multiple conjugate values (as expressed by our R+jX notation). Sections of coax or "ladderline" in ½ wavelength multiples can be added or subtracted without changing the other system performance conditions, with the possible exception of I^2R losses. This means that sections of coax or feedline of half wavelength multiples will exhibit their characteristic impedances when one end is shorted. When the need arises to combine two impedances to result in a closer match to our coax, we use this type of arrangement. Practically known as the ½ wave stub, matching of this type has been used on a variety of antenna types for most of the existence of ham radio. A very good illustration of stub tuning is given in the ARRL Antenna Book Chapter 18 page 27 (20th Edition). The 6 meter Yagi shown in the illustration at the bottom of the page is resonated with a ½ wavelength "hairpin" stub and a coaxial stub is used as a balun. Both methods have been discussed here in previous text.

The exact opposite is true of ¼ wavelength multiple sections. The impedance seen at the rig is an inverse function of the antenna end. If the antenna end is very low impedance, the rig end of the ¼ wave line will be a very high impedance. In sections shorter than ¼ wavelength, the coax will exhibit wave mechanics as explained earlier (shorted acts as inductive reactance and open acts as capacitive reactance).

One note of caution is appropriate in this discussion. When highly reactive loads are used with commonly used transmission lines, especially coax, the overall losses resulting can be of unacceptable levels depending on frequency and grade of coax used.

The reasons for this type of wave reflection mechanics are numerous and mathematically complex. For the purpose of this document it is sufficient to state this phenomenon in simple terms. Detailed explanatory text is available in the referenced text given at the end of this book.