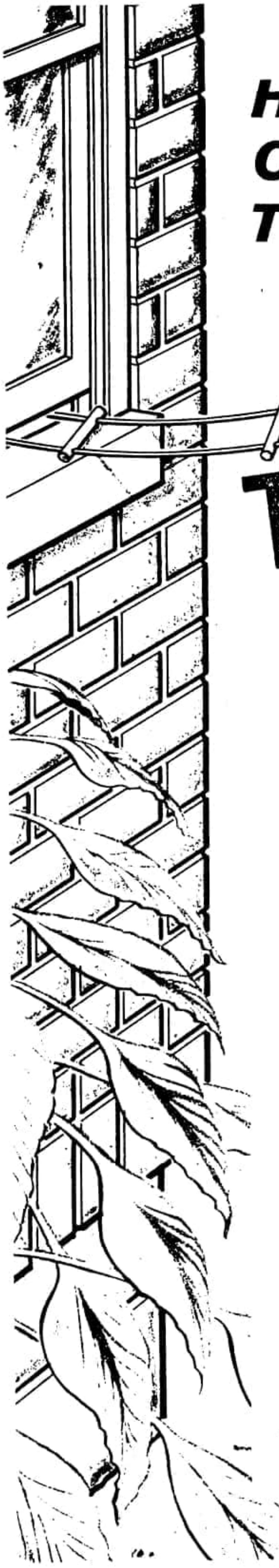


HOW TO CHOOSE THE RIGHT TRANSMISSION LINE

By Al Toler

WELL, your ticket finally arrived! Now you can plug in the transmitter. Everything's legal. But hold off a second. How are you planning to connect it to that dipole you strung up last spring? Lamp wire or that old TV lead-in are out of the question. You've got a small problem, OM, in getting your signal from the transmitter to the antenna without losing half your power along the way.

A special transmission line is the answer, and the type you use can make or break your station's performance. Actually, you could use ordinary lamp cord, but there would be big losses. Your 200 watts at the transmitter might become 10 watts at the antenna.

When you look for transmission lines in a parts catalog you may be surprised by the many types and specifications: twinlead, coaxial cable, 72 ohms, 300 ohms, 52 ohms. Where do you start? The situation assuredly can be confusing, but if you're armed with the advice in this article you should have little trouble deciding which line is best for your station.

Those readings in ohms represent the most important piece of information to consider when you're looking for a feedline. They refer to a line's characteristic impedance, also called surge impedance. (Impedance is to an AC circuit what resistance is to a DC circuit.)

Characteristic Impedance. To find out what the term means, let's take an extremely short piece of twinlead like that attached to your TV set and examine its electrical properties. First, think of the two little pieces of stranded wire as the two plates of a capacitor, between which there is a measurable capacitance. In Fig. 1 this capacitance is represented by the capacitor symbols. Each wire has inductance, too, and this is represented by the circles of arrows. When radio-frequency (RF) power is fed into this minute section of line (Fig. 2) each wire appears as a series impedance to the RF. Knowing the voltage and current of the RF, we can compute the impedance the signal sees when looking into A and B.

To this short section of line let's add a few more sections of like length—in fact, let's add an infinite number of sections as in Fig. 3. Each section we add is in parallel with the one before it and, therefore, it lowers the impedance at A and B. But each section adds a smaller and smaller amount of impedance.

In an infinitely long line the impedance doesn't continue to fall

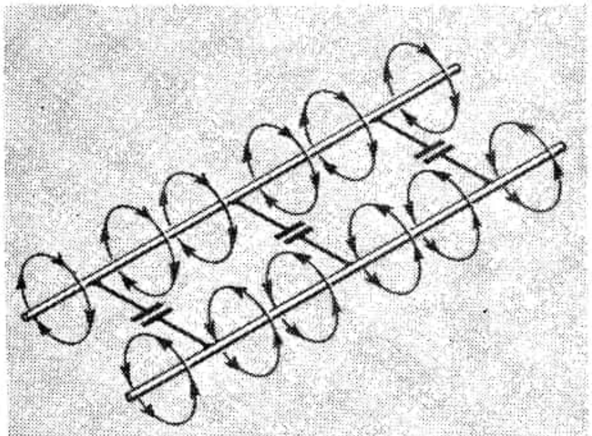


Fig. 1—Parallel wires act as capacitor. Wires have inductance, too, so current creates magnetic lines of force (arrows).

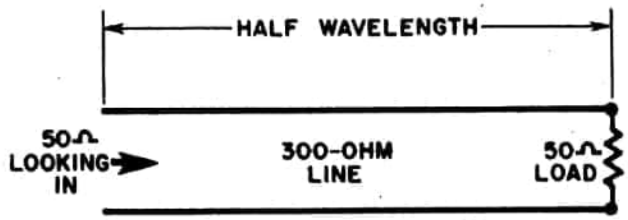


Fig. 4—If a line is half-wavelength long, impedance looking in always equals load impedance regardless of line's characteristic impedance.

but, rather, eventually assumes a definite value and stays there. To a transmitter connected to A and B in Fig. 3, the infinite number of little feedline sections looks like a pure resistance. This impedance value is known as the characteristic or surge impedance of the line. It is stated in ohms. (The symbol for impedance is Z while the standard symbol for resistance is R.) Characteristic impedance so far as open line is concerned is a function of the diameter of the wires and the space between them. Engineering handbooks give formulas if you want to calculate it.

What we've been talking about is the impedance that a feedline presents to an RF signal. But after the signal finally fights its way through, it faces still another impedance—that represented by the antenna, which in this context is referred to as the *load*. A transmission line's input impedance is the same as its characteristic impedance only when the characteristic impedance and the *load* impedance are equal. Take a piece of 300-ohm twinlead, put a 300-ohm resistor across the far end to represent the antenna, and the transmitter will see exactly 300 ohms. Only under this condition will all the power fed into a line be absorbed by the load (this neglects other line losses, which we'll discuss in a moment).

If the load impedance is not the same as the line's characteristic impedance, some of the power is reflected back down the line and is dissipated as heat. The greater the mismatch, the less RF will get to the load.

The mismatch is expressed by the term standing-wave ratio, or SWR (see WHAT SWR MEANS TO YOU on page 63).

SWR is the ratio of the line's characteristic impedance to the load impedance compared to 1. If the line's characteristic impedance is 300 ohms and the load impedance is 50 ohms, the SWR is 300/50 or 6 (it is written as 6:1).

The power reflected back because of a mismatch sets up what are called standing waves on the line. Standing waves will make the line's input impedance a different value from its characteristic impedance. We won't go into the reasons for it here, but the thing to remember is that the input impedance of a random

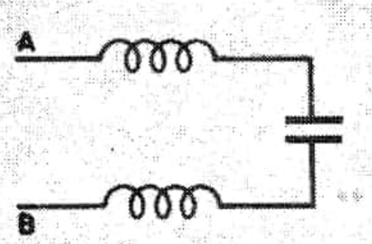


Fig. 2—Inductance and capacitance combined in a very small section of two-wire line.

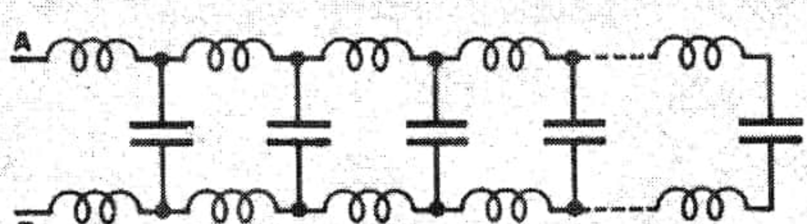


Fig. 3—Infinite number of sections in Fig. 2 are connected in parallel here. Voltage applied at A and B causes current flow through network. Characteristic impedance equals E/I.

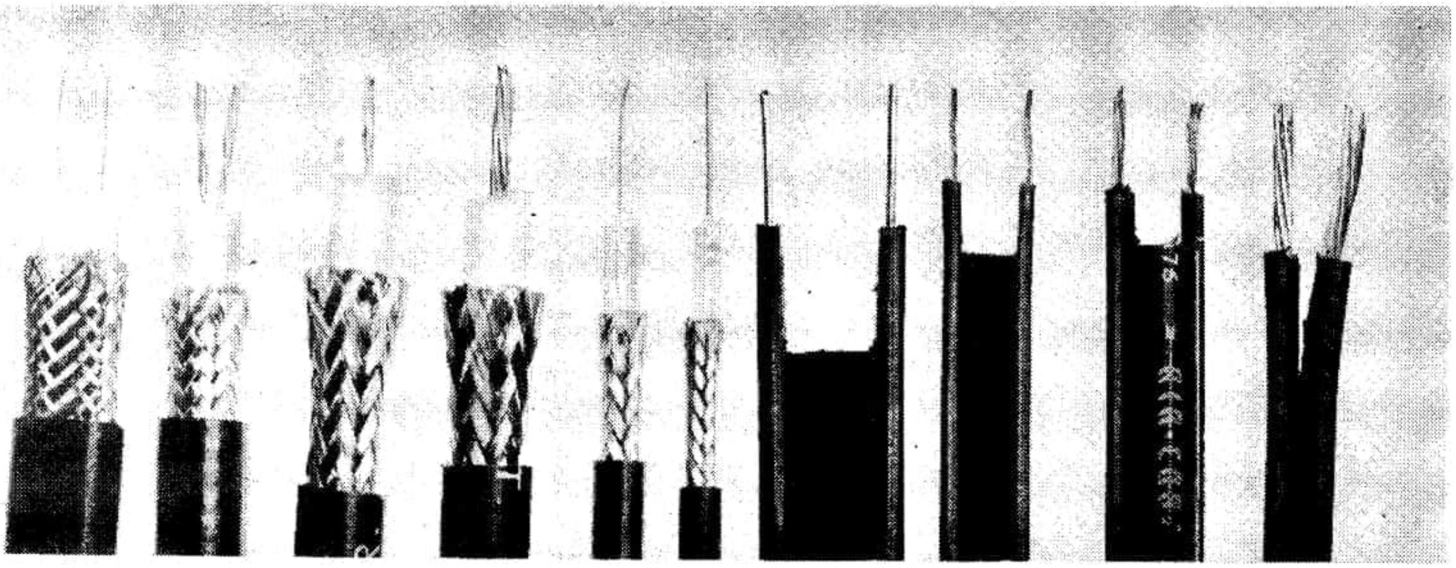


Fig. 5—Actual size of transmission lines. L to R: K-111, 300-ohm shielded twinlead; RG22/U, 95-ohm shielded twinlead; RG11/U, 75 ohms; RG8/U, 52 ohms; RG59/U, 73 ohms; RG58/U, 53.5 ohms; Amphenol 214-022, 300 ohms, TV 300 ohms; Amphenol 214-076, 300-ohm air-core; Amphenol 214-023, 75 ohms.

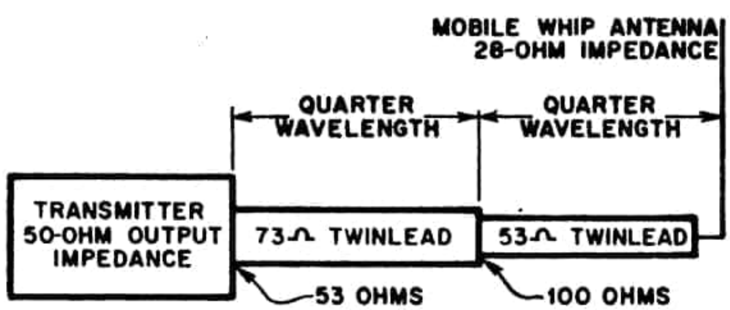
length of line that is *not matched* to its load may be considerably higher or lower than its characteristic impedance at the point where it is connected to the transmitter. Under this condition, the transmitter will not be able to transfer all its power into the line.

Let's see what happens if we use 300-ohm line to connect a transmitter to a 50-ohm antenna. The 50-600 output impedance of many transmitters would be matched to the line in theory. However, because of the mismatch between transmission line and antenna, the line may appear to the transmitter as, say, 1,000 ohms. So only part of the transmitter's power would ever be coupled into the transmission line. This would be indicated by a failure to load to rated input current. So in addition to the loss caused by the line/antenna mismatch, we have added a transmitter power-transfer loss.

How to Match Impedances. For maximum power transfer to the antenna, impedances must match everywhere. This isn't difficult to achieve since most amateur transmitters have an output impedance that corresponds to the impedance of most of the popular antennas that are available at parts distributors and are used by hams.

If the antenna impedance differs from the transmitter impedance, matching devices such as an antenna coupler or balun are available. Whenever possible, match the antenna to the line and then use a matching device to couple the transmitter to the line rather than the other way around. Even with a severe line/load mismatch there are ways to get the transmitter's power into the antenna efficiently. Take a look at Fig. 4. If you use a line that is exactly a half-wavelength or a multiple of a half-wavelength long, the input impedance of the line will be exactly the same as the impedance at the load, regardless of the SWR. For example, if we connect a 50-ohm antenna to a half-wave 300-ohm line, the input to the line will appear to the transmitter as 50 ohms. So far as the transmitter is concerned, it is working

Fig. 6—Transmission lines used as impedance inverters can match 28-ohm antenna to 50-ohm transmitter. Input to quarter-wavelength of 53-ohm line connected to 28-ohm antenna is 100 ohms. Input to quarter-wavelength of 73-ohm line connected to first section is 53 ohms, which is close enough to the transmitter's 50-ohm output impedance.



into 50 ohms. This is often evidenced as a 1:1 SWR on a VSWR meter even though there is a mismatch between the line and the load. Even when the line *is* matched to the load, as a safety measure, cut the line to a half-wavelength or multiple thereof to minimize line-impedance variations and SWR losses.

We just showed how the half-wavelength line is an impedance matching device—a 1:1 transformer. But a quarter-wavelength line is an *impedance inverter*. That is, if the output end of the quarter-wave line is connected to a low-impedance load, the input to the line appears as a high impedance. This property is useful when matching transmitters and antennas whose impedances differ from the impedance of common transmission lines. Here's a practical example:

A quarter-wave mobile whip antenna (Fig. 6) may have an impedance of 28 ohms. If the transmitter has an output impedance of 50 ohms, you have a matching problem. Here's how you solve it. If a quarter-wave section of 53-ohm line is connected to the 28-ohm antenna, the impedance at the input of the line will be 100 ohms. We can now consider this 100 ohms to be the load and use another quarter-wave section to match into the transmitter. If we connect a quarter-wavelength section of 73-ohm line to the 100-ohm input of the 53-ohm line the input of the 73-ohm line will appear as 53 ohms, a close match to the

ATTENUATION CHART

TYPE	MAXIMUM RATING	CHARACTERISTIC IMPEDANCE (OHMS)	ATTENUATION db per 100 feet (SWR=1:1) Frequency (mc)						
			3.5	7	14	21	28	50	144
Open wire		200-800	.03	.05	.07	.08	.10	.13	.25
Coaxial									
RG8/U	1 kw	52	.28	.42	.64	.81	1.0	1.4	2.6
RG11/U	1 kw	75	.26	.41	.61	.75	.92	1.3	2.4
RG58/U*		53.5	.53	.8	1.2	1.6	1.9	2.7	5.1
RG59/U*		73	.55	.81	1.2	1.6	1.8	2.5	4.6
Twinlead									
214-076**	1 kw	300	.16	.23	.34	.41	.51	.69	1.3
214-022**	1 kw	300	.13	.19	.28	.33	.41	.54	.90
214-023**	1 kw	75	.28	.50	.88	1.1	1.5	2.3	5.0

*Receiving types; suitable for low-power transmitters.
**Amphenol numbers.

50-ohm transmitter output impedance. For really difficult matching problems, consult an antenna manual, such as the ARRL Antenna Book.

Line Losses. A further factor you must consider when selecting a transmission line is the loss or signal attenuation caused by the dielectric between the leads. The thing that makes a special transmission line superior to lamp wire is its lower losses. Typical lamp wire can have a characteristic impedance of about 72 ohms. For many years it *was* used as transmission line. The problem was that the rubber insulation cracked and when it got wet the characteristic impedance changed, increasing SWR losses. But today transmission lines can withstand weather deterioration for many years.

Open Line. Open line is exactly what the name implies—two wires held apart by a low-loss insulator spaced every few inches. It looks like the line shown on the first page of this story. Notice in the table that the losses are low for open line, even at 144 mc. Open line, then, might appear to be an ideal choice, but it is difficult to work with. If spacing between wires is changed during installation an impedance bump appears at that point and the SWR increases. Therefore, the line has to be installed on insulators and with great care. If possible, avoid open line. It's a pain in the neck to handle.

Twinlead. Twinlead is just modified open line imbedded in polyethylene to insure constant spacing. You can bend and twist twinlead without worrying about impedance changes. Of course, using a plastic dielectric increases line losses. Considering how easy it is to handle, its lower losses and low cost, 300-ohm transmitting twinlead generally is the best deal for the newcomer to ham radio. But the important thing to remember is not to use light twinlead, such as is used for TV, to handle high RF power. Most modern transmitter outputs will match the line's 300-ohm impedance, and 300-ohm antennas for use below 30 mc can be made easily. (See HAM ANTENNA FACTS on page 54)

As a general rule, it is better to use twinlead than coaxial cable if your antenna is a dipole. The dipole and the folded dipole are balanced antennas and perform best when fed by a *balanced line,* such as twinlead. Depending on your transmitter, you may have to use an antenna coupler or a balun to feed an unbalanced transmitter into a balanced line. Coax, unless the shield is not grounded (and then there's no advantage to using it), is unbalanced with respect to ground and the performance from a balanced antenna will not be as good as with twinlead.

Coaxial Cable. Coaxial cable is easier to install. It can be buried underground or snaked through a wall without producing extra losses as would twinlead if it is near metallic objects. The usual coaxial cable has a life of two or three years. It may look satisfactory to the eye, but if it's over three years old, replace it. For this reason, always buy new coax at the outset. War-surplus coax may be selling at rock-bottom prices but its performance may be just as low. Coax is available for both receiving (RG58/U, RG59/U) and transmitting (RG8/U, RG11/U) applications. While either type can be used below 200 watts, the line losses (due to the dielectric capacitance between the inner lead and outer shield) are greater than for twinlead. At the higher amateur frequencies, the line loss becomes appreciable, particularly for receiving-type coax.

Since coax frequently is used above 30 mc, and since losses in any coax above 30 mc become appreciable, you have to consider carefully whether the lower cost and greater attenuation of the receiving type will be worth the power sacrifice.

If you really want to keep attenuation losses down, specify Polyfoam dielectric when ordering RG8/U or RG59/U. It costs more but you will suffer only about half the loss of the usual coax line.

As you can see, choosing the correct transmission line involves more than buying merely the least expensive type. The difference between an efficient installation and one that turns your signal into a peanut whistle is a few dollars at most.

STOP THAT (RF) LEAK!

IT WAS ONLY recently that shielded meters became standard equipment in small transmitters and other gear. You might put in hours of labor TVI-proofing your equipment, only to have RF escape out the meter holes. (Aha! *That's* how the RF is getting around your low-pass filter!)

What to do about it? Simply shield your meters with aluminum foil. Coil dope, household cement, "Scotch" tape, etc., will hold the foil in place. Carefully cut holes in the foil to pass the terminals, of course. And in your final wrapping of the body of the meter leave enough of a "skirt" to line the back of the meter bezel. And be sure some corner or tab of the foil is left over to go under one of the mounting screws (and a washer). To insure good grounding to the front panel sand off a patch of paint where the meter mounting screws come through. Sand or steel-wool the inside of the meter hole to remove rust.—*Nicholas Rosa,* W1NOA