"My Feed Line Tunes My Antenna!"†

Plain talk about a fancy subject.

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Maybe we could stop running this *QST* classic if ham misunderstandings about feed-line length and SWR vanished forever. But doing so would also deny newer hams a chance to enjoy the inimitable style of one of *QST*'s masters of the technical tutorial. Reality itself reveals our only true alternative: Enough hams keep eluding a solid understanding of the basic relationship between an antenna and its feed line to justify our letting Goodman have the floor again.

You don't have to be in ham radio very long before you hear some self-styled antenna expert talking about "cutting the line to reduce the standing-wave ratio." An allied problem—and misconception—is exemplified by the card that came in the mail some time ago:

"I carefully cut an antenna for 7 MHz according to the formula in the *ARRL Handbook* and fed it in the center with 300-Ω Twin-Lead. Using a dip meter, I found the frequency was 5 MHz instead of 7. And it also had dips at 10, 20 and 25 MHz. Adding more 300-Ω Twin-Lead brought the frequency up to 7 MHz, but what I don't understand is why the feed-line length affects the resonant frequency of the dipole. If it is supposed to, how can I check the resonant frequency of the dipole itself?"

This is a good subject. If you know the correct answers to all of the questions in the quote above, you aren't likely to have trouble understanding most of the common feed-line problems. Let's see what it's all about.

Transmission Lines

Ask any amateur if he knows all about coaxial cables and he will probably say, "Sure, RG-8 and -58 are 50-Ω lines, and RG-11 and -59 are 75-Ω lines. What else is there to know?" The answer to that one is "Everything."

In the first place, RG-8 is *not* 50-Ω line. It has a "characteristic impedance" of 50 Ω.[1] This fancy language can best be illuminated by Fig 1. Here we show a long length of RG-8 with a 50-Ω resistor connected at one end (we'll call that end the "load" end). If we measure the impedance at the input end (by using an impedance bridge), it will measure 50 Ω. This, of course, is just what you expect, and you're probably wondering what we're driving at. Patience, please.

Now suppose we take this same piece of RG-8 and connect a 100-Ω resistor at the load end, as shown in Fig 2. Measuring the impedance at the input end, what should we get for an answer? 50 Ω? 100 Ω? 200 Ω?

If you came up with an answer, any answer, you had better continue reading this article, because there isn't any answer to the question in the preceding paragraph! There isn't any answer because the problem isn't definite enough to be capable of solution. In order to know what the input end of the 50-Ω line looks like when a 100-Ω resistor is connected at the load end, you must also know the *electrical length* of the line. This is another way of saying that you have to know the operating frequency and the physical length, from which you can compute the electrical length. (Electrical length is measured in wavelengths [λ], so any given length of line has an electrical length that varies with the frequency. A line 1 λ long at a given frequency is 2 λ long at twice that frequency, etc.)

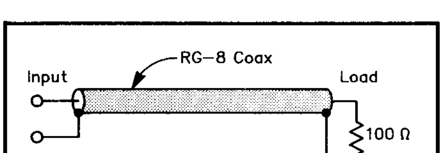

Fig 1—A length of RG-8 with 50 Ω connected across one end will look like 50 Ω at the input end of the line.

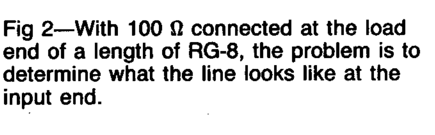

Fig 2—With 100 Ω connected at the load end of a length of RG-8, the problem is to determine what the line looks like at the input end.

Actually, with the "50-Ω" line terminated in 100 Ω, some interesting things happen along the line. Take the lines shown in Fig 3. If the line is ¼ λ long, we find that the impedance bridge would measure the input impedance as 25 Ω. If the line is ½ λ long, the bridge would come up with an answer of 100 Ω. If the line is 1/8 λ long, the bridge would measure the input as a 40-Ω resistance in series with a capacitor, and a 3/8-λ line would be measured as 40 Ω in series with an inductor! These effects repeat every half wavelength along the line, as shown in Fig 4A.

The example we just discussed used a load for the transmission line that was higher than the characteristic impedance of the line. When the termination is lower than the characteristic impedance of the line, the impedance varies along the line in the manner shown in Fig 4B.

Now let's get back to that "characteristic impedance" thing again. Here's what it is: *The characteristic impedance of a transmission line is the value of resistance that, when used as a termination for the line, makes the input impedance of the line independent of the electrical length of the line.*[2]

Measuring Antenna Impedance

By now you may begin to see where the card-sender of the opening paragraph went astray. He connected an antenna to a length of "300-Ω line" and expected that the line

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[1] Notes appear on page 35.

†Reprinted from B. Goodman, "My Feedline Tunes My Antenna!," *QST*, Mar 1956, pp 49-51 and 124; also in *QST*, Apr 1977, pp 40-42.

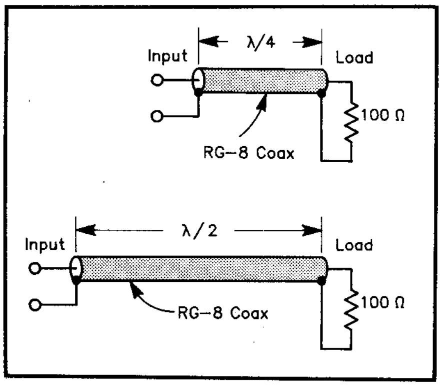

Fig 3—Part of the answer to the problem posed in Fig 2. When the line is ¼ λ long, it looks like 25 Ω at the input end when the load is 100 Ω. When the line is ½ λ long, the input end shows an impedance equal to that connected at the load end.

was acting as a direct connection between the antenna center and the shack, adding no effects of its own. It wasn't, of course. The antenna was probably resonant at 7 MHz, and a ½-λ antenna looks like 70 Ω at its center. Hence, this was the same as connecting a 70-Ω resistor to the end of the 300-Ω line, for measurements made at 7 MHz. At other frequencies, the antenna becomes a complex termination, involving both resistance and reactance. From the previous discussion, you know that the 300-Ω line terminated in something other than 300 Ω is going to show various values of resistance and reactance at the input end, depending upon the electrical length of the line. Consequently, the resonant frequencies checked with the dip meter (these would be the frequencies where pure resistance showed at the input end of the line) have no bearing whatsoever on the resonant frequency of the antenna proper. By changing the physical length of the line our friend was able to get a length that showed "resonance" at the frequency for which he cut the antenna, but all this means is that his electrical line length at 7 MHz is now a multiple of a quarter wavelength, since it takes that length to show pure resistance at the input end when the load is a pure resistance (we're assuming it is).

Okay, how do you measure the resonant frequency of the antenna? Well, it isn't too easy, but fortunately, it isn't too important.

(WHAT?!!! It isn't important that the antenna be resonant? What kind of sacrilege is this?)

Our friend of the postcard is using what is known as a "tuned antenna system." He is terminating a 300-Ω line with a load other than the characteristic impedance, and consequently, what the impedance looks like at the input end of the line depends upon the electrical length of the line (see Fig 4). To put power into the antenna, the line is connected to the transmitter through a network that compensates for any reactance showing at the input end of the line, and a resistive load is presented to the transmitter. In plain language, the "network" is the output-stage plate, collector or drain tuned circuit(s) or, to handle a wider range of conditions, the plate, collector or drain tuned circuit(s) plus an antenna tuner (sometimes called a Transmatch, antenna coupler, antenna tuning unit [ATU] or antenna-system tuning unit [ASTU]).

Perhaps we should mention at this point that only resistance can use up power; reactance can't. You know this from practical work; you can pass ac through a capacitor, but the capacitor never gets hot (if it's a pure capacitor) or uses power in any other way. The same is true of a pure inductance, but they are harder to come by because the conductor of the coil has some resistance. When a coil heats up, it is the resistance of the coil that causes this, not the reactance.

Since only resistance can use up power, what difference does it make if the antenna is resonant or not? When the antenna is resonant it appears as a pure resistance (made up of the conductor resistance plus the antenna's *radiation resistance*), but when it isn't resonant it looks like a resistance and a reactance. Only the resistive part can use up power, so we don't throw anything away. We do want the antenna to be resonant and look like a resistance if we are planning to use it as a load for an "untuned" transmission line, but to do this we have to use a line with a characteristic impedance equal or close to the value of resistance the resonant antenna shows. We can't feed a 70-Ω antenna with a 300-Ω line and expect it to be anything but a "tuned antenna system," exhibiting the variations shown in Fig 4. We can feed a 70-Ω antenna with 70-Ω line, and then no matter how long we make the line, it will always look like 70 Ω at the input end, and we won't have to use an antenna tuner if 70 Ω will load the transmitter satisfactorily. But the antenna *has* to be a 70-Ω antenna, resonant at the frequency we're interested in.

Standing-Wave Ratio

By this time it may or may not have occurred to you that all this talk about the way the input impedance varies with a mismatched line may have something to do with that old conversation piece, the "standing-wave ratio." It does. Since the power at any point along the line must be constant, you can see that as the resistance and reactance vary along the line, so must the voltage and current. Take the line of

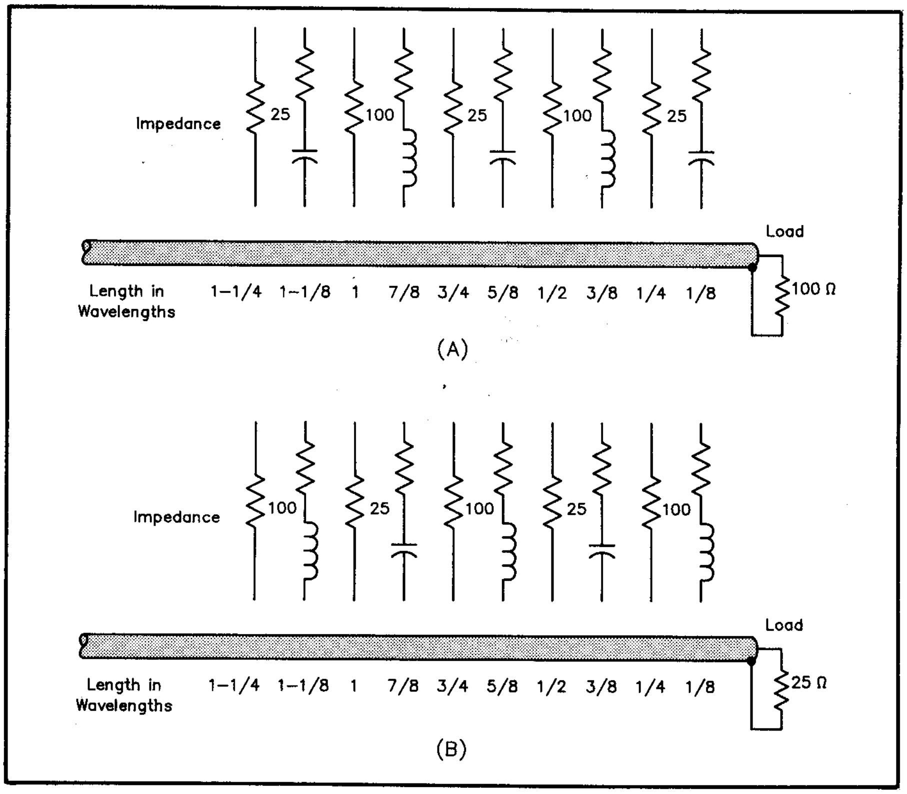

Fig 4—These two examples show how the input impedance of a 50-Ω line varies with the length of the line when the line is terminated in something other than the characteristic impedance of the line. It should be realized that the impedance is continually changing along the line, repeating every half wavelength. The impedance is purely resistive only at the ¼-λ (and multiples) point, and it becomes reactive either side of this point. When the load includes reactance as well as resistance, the impedance along the line varies in the same manner as shown here, but the purely resistive points do not occur at multiples of ¼ λ from the load.

Fig 4A. Let's say we're putting 100 W into that 100-Ω load. The current at that point is 1 A and the voltage is 100; $P = I^2R = E^2 \div R$. A quarter wavelength from the load, the line looks like 25 Ω, and 100 W at this resistance level is a current of 2 A and a voltage of 50. At the half-wave point from the load we're back to 1 A and 100 V. Thus you can see that the current and voltage vary along the line, and of course they can be measured and that will give us something called the "standing-wave ratio." This SWR is the ratio of a current maximum to a current minimum, or the ratio of the voltage maximum to the voltage minimum, and in this case it is equal to 2.0. We say, "The SWR of the line is 2.0." Note that this ratio of 2.0 is also the ratio of the resistive load to the characteristic impedance of the line (100 ÷ 50 = 2). It always works out this way; the SWR of the line is equal to the ratio of mismatch between load and line, for resistive loads. (When the load is smaller than the characteristic impedance, you divide by the load, because the SWR is normally stated as a ratio larger than 1.0) The solution is more complicated with some reactance in the load.

And now you can see why those "brains" who change the SWR on the line by changing the line length just don't know what they're talking about. What they are doing is adjusting the length of the line so that at the input end it looks like a resistance and hence becomes a little easier to couple to. But *the SWR is determined by the load,* and don't you forget it.

That's about it. If you've learned that the SWR is determined by the load and not by the line length, and if you've learned that the antenna resonant frequency isn't important when you're using a tuned line, you've come a long way. Of course, the latter doesn't mean you can use a very short (less than 1/8-λ) antenna and get out just as well as with a full-sized one. In this latter case, the ohmic resistance of the antenna and loading devices may be greater than the radiation resistance of the antenna, and much of your power goes into heating the loading devices and the feed line.

Other Considerations

To keep this discussion simple, we have of necessity left out a number of points that often must be considered. For example, a piece of open-wire transmission line and a piece of Twin-Lead (or coaxial line) of the same physical length do not have the same electrical length. The reason for this is that the radio waves travel slower through the solid dielectric of the Twin-Lead than they do through the air dielectric of the open line, so a wavelength in air (for a given frequency) is longer than a wavelength in solid dielectric. The "velocity of propagation" in air is considered to be 1.0 and the "VP" (also called *VF*, for *velocity factor*) in a solid dielectric will be something less, depending upon the material. VP values for various lines are given in any good antenna book, and they must be considered when you compute the electrical length of a line.

Another aspect that was not considered was the loss in a transmission line. If the line itself had no loss, then the SWR value would make no difference where losses are concerned. However, any practical line does have some loss, and this loss increases with the SWR, and the inherent loss of the line. This is a consideration in any antenna system requiring a long run of line, and is the reason that one shoots for a low SWR with coax or Twin-Lead but doesn't worry too much about it (from a loss standpoint) with open-wire line.

Notes

[1] Since this article first appeared in 1956, *RG-8* has come to specify a *class* of cables more than a type. Depending on the particular product involved, cable marked *RG-8* may exhibit a characteristic impedance from 50 to 57 Ω. This article assumes the 50-Ω variety. A similar fate has befallen RG-58, 59 and several other RG designators.—*Ed.*

[2] This is strictly true only for a lossless line, where the input impedance will be equal to the characteristic impedance for any length of line. Lines with appreciable loss will show a gradual variation in input impedance, depending upon the length, as a result of the cumulative effects of series resistance and shunt conductance.—*Ed.*

RF Power Amplifiers and the Conjugate Match

(continued from page 32)

[4] Accuracy of the R_S/R_L determination could be improved by considering the output-network loss. In Fig 2, observe that the P4 signal is attenuated twice by losses in the amplifier output network: once when it passes through the network as part of P3, and again when it returns as P4. Network losses are typically 5% to 20%, which corresponds to approximately 0.25 to 1.0 dB. Twice this estimated loss can be subtracted from the measured decibel difference to obtain a corrected decibel difference. The result is an even larger ratio of R_S/R_L (or R_L/R_S, whichever is greater than 1) than that shown in Fig 4.

[5] It is possible to make $R_S = R_L$ for a conjugate match by using a small amount (less than 6 dB) of RF voltage feedback in a linear amplifier. A conjugate match can also be obtained by using a quadrature hybrid to combine the outputs of two amplifier modules. This is often done at VHF and UHF.

Licensed since 1935, Warren Bruene has held the call signs W9TTK and W0TTK in addition to W5OLY. Three widely used circuits he originated are tetrode neutralization (used, for example, in most commercial Amateur Radio transmitters using 6146 and sweep-tube finals), RF feedback to improve linearity, and a directional-wattmeter circuit. The wattmeter circuit ("An Inside Picture of Directional Wattmeters," QST, *April 1959, pp 24-28) serves as the basis for most wattmeters used by hams today. In addition, he has been granted 22 patents. As a writer, Warren coauthored* Single Sideband Principles and Circuits *(New York: McGraw Hill, 1964) and authored the chapter on high-power linear amplifiers in* Single Sideband Principles and Systems *(New York: McGraw-Hill, 1987), as well as chapters in several engineering handbooks. A graduate of Iowa State University and an ARRL member, Warren is also a Life Fellow in the IEEE. His Fellow citation was for "advancing SSB radio communications."*

Warren spent 44 years with Collins Radio (Rockwell), where he designed the Collins 30K-1 amateur transmitter and the 30S-1 linear amplifier and many commercial, military and broadcast transmitters ranging from 500 W to 250 kW and from VLF to UHF. These transmitters included many firsts in automatic tuning systems and RF-power-amplifier and output-network design. He spent another six years with Electrospace Systems before retiring to part-time consulting.

Warren Bruene received the Engineer of the Year award from the Preston Trail Chapter, Texas Society of Professional Engineers in 1975; in 1982, an Engineer of the Year award from Rockwell International. He is listed in Who's Who in Engineering *and* Who's Who in America.

Strays

I would like to get in touch with...

☐ anyone who knows the settings for testing 6146 tubes in a Precision Apparatus Co Inc Model 10-12 tube tester. James Montress, W2JJM, 6 Doane Way, Harwich Port, MA 02646.

☐ anyone who has a schematic for an R101/ARN-6 receiver. Ron Freeman, W0LPZ, 446 S 159th Ave, Omaha, NE 68118.

☐ anyone who has a manual, schematic or spare parts for a Motorola U43HHT. Franklyn Brooker, 9Y4VU, 45 Sea View Dr, Battoo Land, Marabella, Trinidad.

☐ anyone with engineering data (for a building permit) for a Tristao CZ-354 3-section crank-up tower. Duane Heise, AA6EE, 16832 Whirlwind, Ramona, CA 92065.

☐ anyone who has a manual or schematic for an RCA AR-8516 receiver made in October 1960. Antonio Adami, PY2BYT, Rua Ricardo Severo 61-2nd, Perdizes, Sao Paulo, SP, Brazil.