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NØAX

HANDS-ON RADIO

Experiment 96
Open Wire Transmission Lines

Over the past few years, the open wire transmission line has enjoyed something of a rebirth in ham radio. Before coaxial feed lines were still impractical for the ordinary ham, open wire line was often homebrewed. Insulators, ceramic or waterproofed wood, separated solid copper wire by up to 6 inches. Link or transformer coupling was used to connect the transmitter output circuits to the balanced feed line. The science of open wire lines was a hot topic as in an excellent January 1934 *QST* article.[1] The back of *QST* contained numerous ads for insulators and feed-through insulators and other necessary parts for "rolling your own."

Figure 1 shows a familiar transmission line configurations (two wire) and three not so familiar configurations (single wire, four wire and five wire). The balanced four wire and unbalanced five wire lines were widely used for high power HF applications long after World War II and are still found at some shortwave broadcast stations. The five wire configuration is a sort of "skeleton coax."

While coaxial cable is far more convenient to use, there are applications in which it is not a good choice for an antenna system. The lower loss of open wire line compared to coaxial cable makes it an effective choice with high SWR, such as from non-resonant antennas or those with a high feed point impedance. For very long feed lines, such as to a distant tower or to antennas in the upper HF/lower VHF spectrum, open wire line may be a very cost effective solution compared to hardline. Open wire line can also be used to make two wire switched direction Beverage antennas.[2]

Why Don't Open Wire Lines Radiate?

With properly terminated coaxial cable, the field of a high frequency signal is completely contained between the inner surface of the outer shield and the outer surface of the center conductor. If there are no breaks in the shield, the field cannot escape. Neither can a high frequency signal from outside the cable cause current to flow inside the cable. This is fairly intuitive. Open wire lines, however, have both (or all) conductors exposed. Why don't they radiate?

Well, actually, they *do* radiate a little bit as given in the following formula for two wire lines with a wire to wire spacing S of less than $\frac{1}{10}$ of a wavelength:

$$\text{Radiated power} = 160 \times I^2 \times (\pi \times S/\lambda)^2$$

where I is the line current and S/λ is the *electrical line spacing*.[3] (This equation also requires the line to be non-resonant, meaning not an integral number of ¼ wavelengths long.) For example, if a 600 Ω line with wire to wire separation of 2 inches is carrying 1 kW at a frequency of 14 MHz, the line current, $I = \sqrt{(1000 / 600)} = 1.29$ A and the line spacing is 0.0024 λ. The radiated power is then $160\ (1.29)^2\ (3.14 \times 0.0024)^2 = 0.015$ W, which is 48 dB below the power being carried in the line.

The real question is why don't they radiate *more*? Each individual conductor in the line does radiate an electromagnetic field as would a single, isolated wire. In a symmetric, balanced line, such as our two wire example, however, the currents in the two wires have opposite polarities and radiate fields that cancel almost completely at distances more than a few line spacings away. As the electrical line spacing, S/λ, increases you can see from the formula that radiated power also increases, either because physical distance between wires increases or as the frequency of the signal in the line increases — or both! A good rule of thumb is not to use open wire lines with line spacings greater than $\frac{1}{10}$ of a

[3]F. Terman, *Radio Engineer's Handbook,* First Edition, 1943, McGraw-Hill.

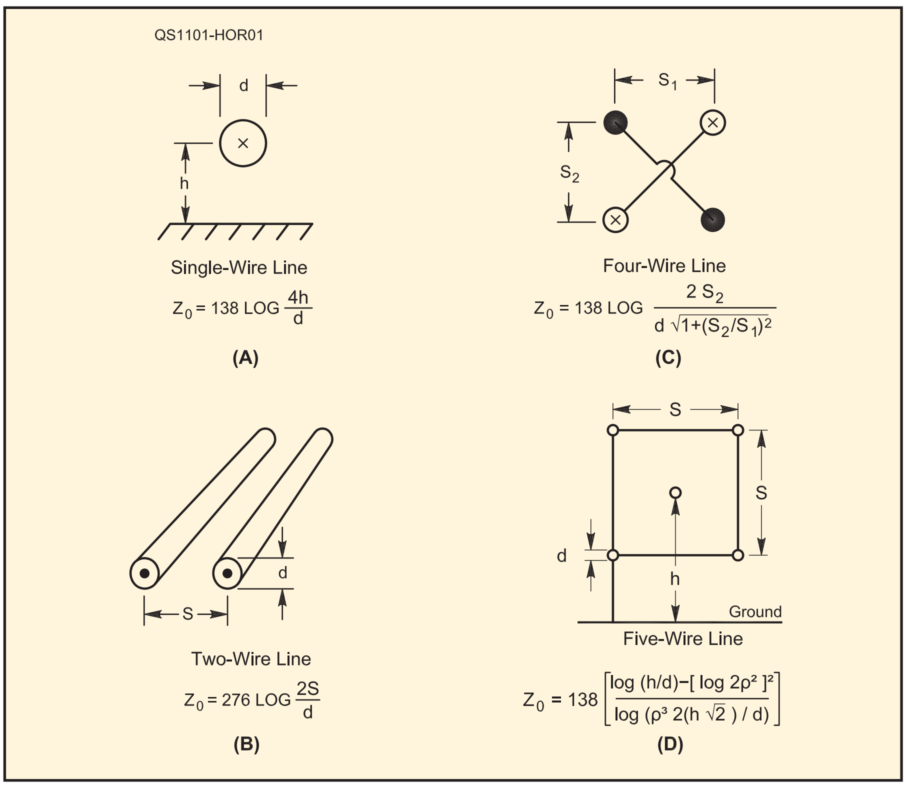

Figure 1 — Several types of transmission lines and the formulas that determine their characteristic impedance. Note in (D) ρ = zh/s.

[1]R. Glover, "A Practical Transmission-Line System for the Doublet Antenna," *QST,* Jan 1934, pp 17-22. *QST* articles more than four years old can be viewed by ARRL members by using the ARRL Periodicals Archive and Search, **www.arrl.org/arrl-periodicals-archive-search**.

[2]W. Silver, NØAX, "A Cool Beverage Four-Pack," *QST,* Apr 2006, pp 33-36.

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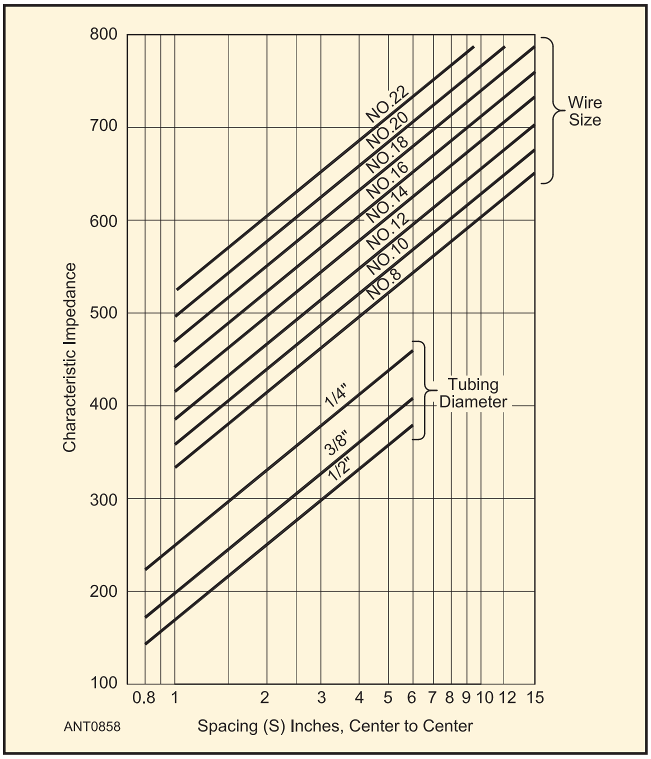

Figure 2 — Characteristic impedance as a function of conductor spacing and size for two wire lines.

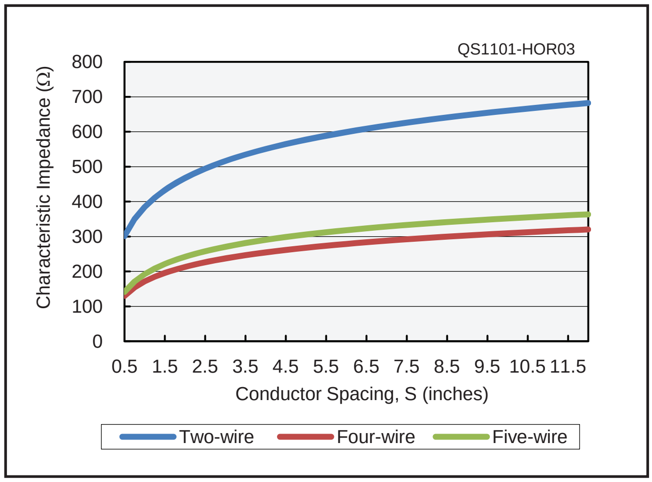

Figure 3 — Characteristic impedance for two, four and five wire lines made from #12 AWG wire 60 inches above ground. Height above ground affects the unbalanced five wire configuration. The spreadsheet is available for download from the Hands-On Radio Web page.

wavelength (0.1 λ), at which point radiation from the line approaches 20 dB below the carried signal.

Characteristic Impedances

Figure 1 also gives the formulas for the characteristic impedance, Z_0, for each configuration of transmission line. Figure 2 shows Z_0 for a variety of the common two wire configurations. Figure 3 is the output from a spreadsheet on the Hands-On Radio Web page that specifies exact values for two, four and five wire lines.[4] The most common impedances of two wire lines used by hams are from 300 to 600 Ω because those lines have practical spacing and power handling capability and impedance transformers are easily made for 50 and 75 Ω systems.

Unrolling Your Own

You, too, can make your own transmission line. It's an interesting exercise and not many of today's hams can say they are using a homebrew feed line. The biggest decision after selecting a characteristic impedance is obtaining the line spacers. The construction process is summarized nicely in a December 2006 *QST* "Hints and Kinks" item by ACØAX, "Make Your Own 600 Ω Ladder Line."

Before running off to the hardware store for a reel of wire and insulator material, start by practicing with a short section of your two wire line. Constructing the line on the workbench is not particularly difficult — strip some wire and appropriate some paper or plastic drinking straws from the kitchen for insulators. Make two cuts halfway through the straw at the desired spacing, stretch the wire out straight, and press it into the cuts. Voila — transmission line!

How can you measure Z_0 to confirm your calculations? Rather than go to the trouble of making an impedance transformer for each different impedance, you can use your 50 Ω SWR analyzer to do the job by using a special property of ¼ wavelength lines — *impedance inversion*.

When a ¼ wavelength line with a characteristic impedance of Z_0 is terminated in a different impedance, Z_L, the input impedance at the other end of the line, Z_{IN}, is inverted about Z_0. Stated as an equation:

$$Z_{IN} / Z_0 = Z_0 / Z_L \text{ or } Z_{IN} = Z_0^2 / Z_L$$

By varying Z_L until the SWR analyzer shows an SWR of 1:1, you can then use the equation $Z_0 = \sqrt{(50\ Z_L)}$ to determine the Z_0 of your line. (If this looks familiar, it is the same equation used to determine the required impedance for a synchronous transformer as described in Experiment #81.)

Start by choosing a characteristic impedance and a convenient spacing. A 3 inch spacing and #12 AWG wire from a piece of house ac wiring cable result in a predicted Z_0 of 516 Ω. Make the line ¼ wavelength long at some convenient frequency for measurement. For example, at 29 MHz, ¼ wavelength of open wire line is about 7.7 feet. Hold the line above a nonmetallic work surface on nonconductive supports so that it is as straight as possible and with no kinks or abrupt bends. Use a binding post adapter such as a Pomona 1699 (UHF) to connect the one end of the line to the SWR analyzer or homebrew an adapter, keeping all connections short and direct. This is the input end. Leave the other end open with nothing contacting the unconnected wires.

Determine the frequency at which the line is exactly ¼ wavelength long by adjusting the analyzer frequency and watching the resistance value. SWR will remain infinite, but when R reaches a minimum, the line is ¼ wavelength long.

Without changing frequency, tack solder a noninductive resistor (carbon composition or carbon film will do) with a value approximately $Z_L = Z_0^2 / Z_{IN}$ across the open end of the line, In our example with a 516 Ω characteristic impedance, Z_L should be 5325 Ω. Using the closest standard value of 5.1 kΩ, the input impedance should be approximately $Z_0^2 / Z_L = 52$ Ω. If the analyzer reads a higher value, Z_0 is lower than 516 Ω and vice versa.

You can also use this technique to determine Z_0 of an unknown piece of open wire line. Start by shorting the load end of the line and finding the *lowest* frequency at which the value of R reaches a minimum value. The line is ½ wavelength long at this frequency, so it will be ¼ wavelength long at ½ that frequency. Now terminate the line in varying values of Z_L until you get an input impedance close to 50 Ω and the characteristic impedance of the line is $Z_0 = \sqrt{(50\ Z_L)}$.

[4]All previous Hands-On Radio experiments are available to ARRL members at **www.arrl.org/Hands-On-Radio**.