# 160-meter transmission line antenna

## If height or space is a problem, try this

**If you're like me,** you don't have adequate yard space to put up a half-wave dipole on the 160-meter band or a tower to load as a short vertical. In the past, I tried not to let this discourage me from getting on 160, but the RF burns and unanswered calls that resulted from loading up a 40-meter dipole forced me to come up with a better antenna!

Short transmission line antennas have been used at UHF and microwave frequencies for quite some time.[1] Small slots carved into the bodies of fast-moving vehicles (airplanes and rockets) have been used to effectively radiate RF energy using transmission line principles. In fact the folded dipole, commonly used with FM receivers, uses these same principles to receive RF signals. Other types of transmission line antennas include the "low-profile" type used on trains and emergency vehicles, where the antenna structure protrudes just fractions of a wavelength above the vehicle body. These antennas are advantageous when antenna size and height are extremely limited.

I live in an apartment complex. The tallest structures are a couple of 30-foot trees in my small backyard. I have also found that good grounding is a problem, making the use of an "RF-free" tuner difficult. After attempting to work the top band with my existing 20-meter and 40-meter dipoles (none too successfully), I decided to give these transmission line ideas a try. The results have been gratifying, to say the least. I now have a resonant 160-meter antenna that requires no tuner, is directly coax-fed, has given no trace of RF in the shack, and provides enhanced reception due to very low noise pick-up.

### how it works

Many people associate the term "transmission line" with the coaxial cable or ladder line that feeds their antenna — something that "carries power to the antenna," and not something that should, itself, radiate RF. Of course, it is undesirable to have our feedline radiate, but many successful antennas, such as the longwire, the rhombic, and the Beverage are indeed unbalanced (radiating) transmission line extensions of their feed systems. By configuring these lines properly, resulting current distributions along the wires enable these transmission line extensions to emit and receive far-field RF energy. By analyzing a familiar transmission line antenna, the half-wave folded dipole, we can get a feel for how and why a transmission line antenna works.

Consider a folded dipole made of twin-lead transmission line (**fig. 1**). This type of feedline typically has a 300-ohm characteristic impedance. We can think of this antenna as being driven by our transmitter, an unbalanced RF source voltage. A common and useful technique used to analyze transmission lines is the superposition principle, where the original source voltage is replaced by several different sources which, when combined, add to give the equivalent voltage of the original source. Superposition is used to reconfigure the folded dipole as shown in **fig. 2**. By breaking down the superposition model, it is possible to construct and identify distinctive modes that characterize the behavior of the antenna. **Figure 3A** shows "push-push" or even-mode feeding, in which both wires in the twin-lead transmission line are excited by the same voltage, and have currents traveling in phase. **Figure 3C** illustrates "push-pull," or odd-mode feeding, where the two wires of the twin-lead have currents traveling in opposite directions at any time. The impedances presented by the even and odd modes in terms of the excitation voltage and currents are easily found with the superposition model.

**By Ted S. Rappaport, N9NB**, Box 283, Electrical Engineering, Purdue University, West Lafayette, Indiana 47907



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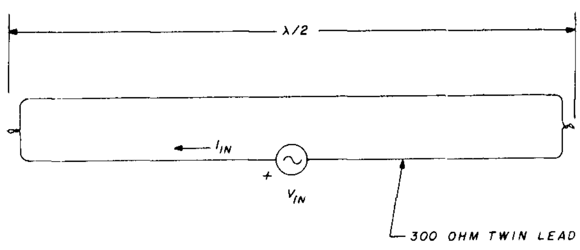


**fig. 1. Folded dipole antenna.**

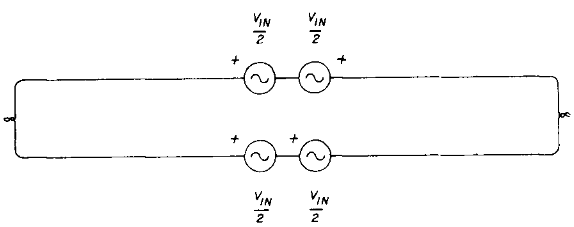


**fig. 2. Equivalent folded dipole model using superposition.**

For the even mode case:

$$Z_{even} = \frac{\left[\frac{V}{2}\right]}{I_{even}} = \frac{V}{2I_{even}} \text{ (even mode)} \quad \textbf{(1)}$$

Since the pair of voltage sources in push-push are similar to just a single source voltage V/2 driving two parallel strands of wire (assuming the twin-lead spacing is much less than a wavelength), the even-mode impedence is that of a "wide" dipole *($Z_{even}$ = 50 to 75 ohms)*. This simplification is shown in **fig. 3B**. Because the even (push-push) mode does the radiating, it is sometimes called the antenna mode. Note that the value of current in each of the transmission line wires is half of the total even-mode current.

For the push-pull case, the odd mode impedance is given by:

$$Z_{odd} = \frac{\left[\frac{V_{in}}{2}\right]}{I_{odd}} = \frac{V_{in}}{2I_{odd}} \text{ (odd-mode)} \quad \textbf{(2)}$$

$Z_{odd}$ is the parallel combination of the impedances of each of the short-circuited ends of the folded dipole, reflected 1/4 wavelength back to the center feedpoint. Recall that a short-circuited transmission-line offers a near infinite impedance when the source is placed one-quarter wavelength from the short. The odd mode (sometimes known as the transmission line mode) impedance is made very high in this manner. Instead of short circuits, resistors can be placed at various nodes to alter even and odd mode impedances, as well as current distributions. This is sometimes done with rhombic antennas and vee beams. For our folded dipole example, we can observe that the antenna mode offers an impedance to RF on the order of a dipole antenna, whereas the transmission line mode offers extremely high resistances to RF.

Specifically, the input impedance to the antenna is easily computed (using superposition) as:

$$Z_{in} = \left(\frac{V_{in}}{I_{in}}\right) = \frac{V_{in}}{\left[(I_{even}/2) + I_{odd}\right]}$$

$$= \frac{V_{in}}{\left[\left(\frac{V_{in}}{4Z_{even}}\right) + \left(\frac{V_{in}}{2Z_{odd}}\right)\right]} \quad \textbf{(3)}$$

$$= \frac{4Z_{even}Z_{odd}}{(2Z_{even} + Z_{odd})}$$

Observe that for $Z_{odd}$ very large (as is the case here):

$$Z_{in} = 4Z_{even} \cong 300 \text{ ohms}$$

We find that not only does this transmission-line antenna radiate, but it also has an input impedance of four times that of a conventional dipole. Conveniently, this structure can be fabricated out of 300-ohm twin-lead, and can also be fed with 300-ohm twin-lead, providing a good match to a 300-ohm receiver. In the case of Yagi antennas, where the mutual impedance effects drop the antenna feedpoint to below 20 ohms, a folded driven element can be used to increase feedpoint resistance by roughly a factor of four.[2]

## using the ground as an image

By using the ground to electrically provide half of the antenna system, we can think in terms of a single wire above ground. **Figure 4** shows something that looks like a folded-dipole using an image. Note that the wire height must be much less than a wavelength for the transmission line principles to hold. Since horizontal image currents always travel in opposite directions as do the wire currents, the horizontal portion of this structure, unlike the original folded dipole, will tend to cancel out in the far-field (i.e., the even mode impedance for this antenna is extremely high). The vertical shorting segments, however, will provide a vertical radiation pattern, enabling this antenna to emit and receive RF energy.

Closer inspection reveals that the antenna of **fig. 4A** is identical to the odd-mode excitation of the original folded dipole. Recall that the odd-mode impedance was calculated by considering the parallel combination of the two transmission lines transferred back to the feedpoint. By this technique, it is easy to predict that the input impedance of the structure in **fig. 4A** will be very high, and the radiation will be due primarily to the short vertical segments at the ends of the structure.

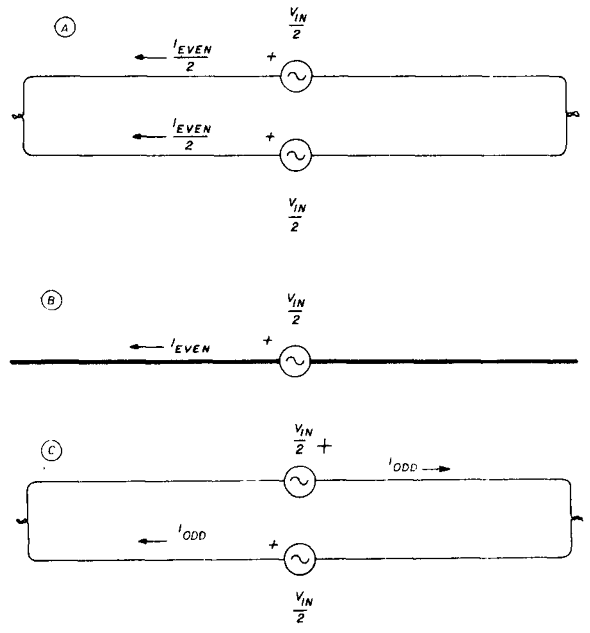


**fig. 3. Even and odd antenna mode configurations for a folded dipole: (*A*) even-mode excitation; (*B*) even-mode simplification — dipole antenna; and (*C*) odd-mode excitation.**

Now suppose instead of folding both sides of the antenna to ground, we open one of them and move the feedpoint to a "strategic" location **fig. 4B**). This type of antenna is known as a low-profile antenna, and has effectively been used at low frequency (LF) and medium frequency (MF) bands, as well as at microwave frequencies.[3]

## low profile antenna

To calculate the input impedance of the low profile antenna at a particular feedpoint we need only deal with the odd mode, since, as was the case for the antenna in **fig. 4A**, the even mode offers an extremely high impedance because of image current cancellation.

Again, we must combine in parallel the impedances of the open and shorted (folded) sides of the structure. For any transmission line, input impedance values may be found by:

$$Z_{short}(x) = Z_0 Tanh(\gamma x) \text{ and } Z_{open}(y) = Z_0 Coth(\gamma y) \quad \textbf{(4)}$$

where *Tanh*( ) and *Coth*( ) are hyperbolic trigonometric functions, $Z_0$ is the characteristic impedance of the transmission line, $x$ is the distance from the feedpoint to a short-circuit termination, $y$ is the distance from the feedpoint to an open-circuit termination, and $\gamma$ is the complex propagation constant of the transmission line, made up of a real attenuation factor, $\alpha$, and imaginary term, $j\beta$, representing the emission wavelength of the source ($\gamma = \alpha + j\beta$).

The characteristic impedance of the single wire (and its image) is dependent upon many factors. These include height above ground, ground conductivity, and moisture of the air, to cite just a few. At 1.8 MHz, an approximate value for the characteristic impedance of a wire 6 meters above ground is about 800 ohms. The value of $Z_0$ is really not important, though. The success of this antenna lies in the parameter $\gamma$.

Naturally occurring losses in the ground and in the wire cause some slight attenuation in electromagnetic waves as they propagate through the line. This attenuation, $\alpha$, is expressed in units of relative voltage decrease per unit length (dB/m), and yields the real part of $\gamma$. It is instructive to compare a lossy and lossless model of the low-profile antenna to see exactly how it loads.

For lossless transmission lines, where $\gamma = j\beta$, the expressions for short-circuit and open-circuit transmission lines simplify to:

$$Z_{short}(x) = jZ_0 Tan(\beta x) \text{ and}$$
$$Z_{open}(y) = -jZ_0 Cot(\beta y) \quad \textbf{(5)}$$

where *Tan( )* and *Cot( )* are trigonometric functions, and $j$ is the imaginary operator, or a 90-degree phase shift. For this ideal case, the parallel combination of the open and short-circuited line yields an imaginary result for any value of $x$ or $y$ ! Since it is impossible to deliver power to a purely reactive load the SWR is infinity for the ideal case. However, when losses are considered, it is possible to solve for values of $x$ and $y$ which yield a purely real $Z_{in}$. This indicates that we are using the naturally occurring losses of a transmission line to provide a purely resistive RF load for our transmitter! The end result is an antenna that can be made to resonate at any real impedance, provided the correct lengths of open and short-circuited transmission line are used.

## implementation

Solving for the lengths $x$ and $y$ is much too impractical because of the many variables that exist at an antenna site. Trial and error is the easiest way to "zero in" on the particular lengths needed for a desired impedance and a given configuration. For a 50-ohm antenna impedance, I wound up with the dimensions shown in **fig. 5**. Only four tries were required to get the SWR below 1.5:1 in the 1800 kHz to 1850 kHz band, pruning only the longer (open) length of wire. I also discovered that other configurations are possible, at the expense of some bandwidth (**fig. 5B**). Since different locations will use slightly different configurations, it is impossible to derive explicit formulas for the

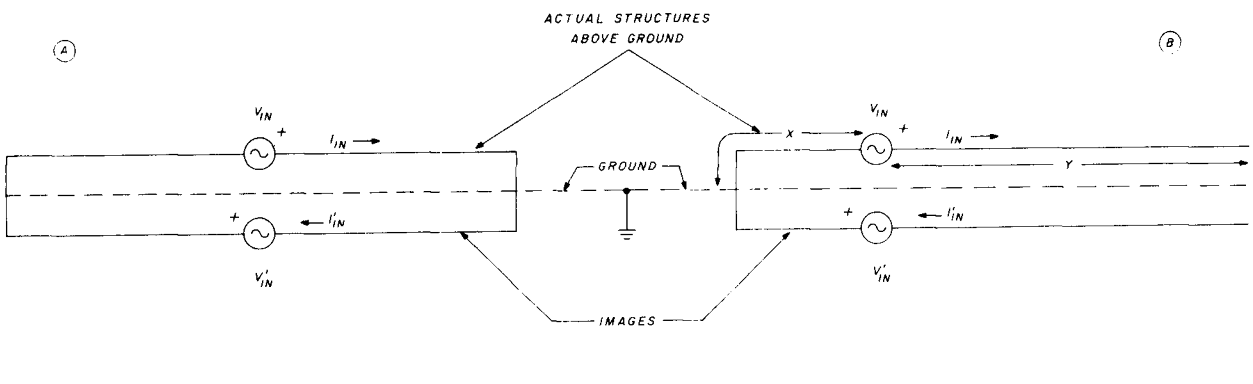


**fig. 4. Example of antennas with images: (*A*) pseudo-folded dipole with image; (*B*) low-profile antenna.**

wire lengths; however, it is safe to say that the open-circuit length will not exceed 40 meters (0.24 λ), and the short-circuit length should not exceed 9 meters (0.05 λ). To tune the antenna, start with these lengths and trim the longer wire (open-circuited transmission-line) by removing 0.5 meter lengths of wire until the SWR approaches 3:1 at the frequency of interest. Then, very finely prune both the open and short-circuit lines for best SWR. Small lengths of wire may have to be re-inserted after course pruning to optimize the match to the transmitter. It is important to be sure that all antenna SWR measurements are made with the antenna at its operating height, as the wire height above ground critically effects the tuning (in fact, this is another parameter that can be varied in the pruning process to provide the best match). It should be possible to achieve an SWR well below 1.5:1 if patience is exercised in trimming the antenna.

Wire heights from 2 to 8 meters make the transmission line approximation valid, although I would think that heights greater than this could also be made to resonate. The antenna feed system is simply a random length run of RG-58U coaxial cable. The open-circuit wire is connected to the coax center conductor, while the coax braid is soldered to the short-circuit wire, which is terminated at a ground stake (**fig. 6**).

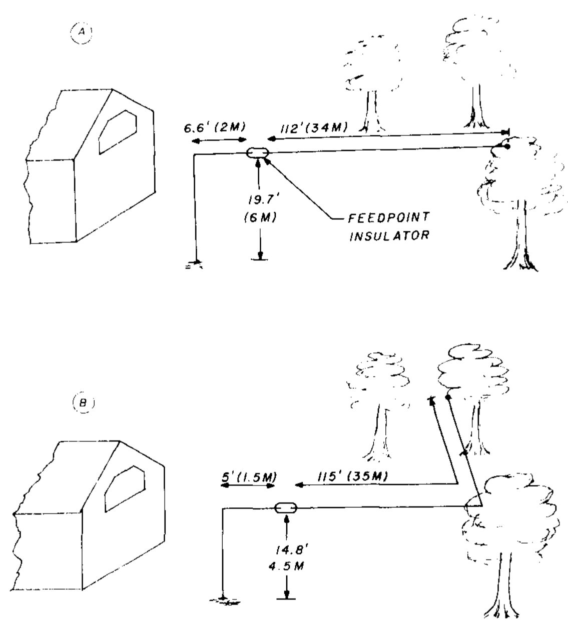


**fig. 5. Low profile antenna dimensions for 160-meter operation at N9NB: (*A*) low-profile antenna for 1850 kHz – 100 kHz bandwidth (dimensions: x = 8 meters, y = 34 meters, height = 6 meters); (*B*) low-profile antenna for 1850 kHz – 75 kHz bandwidth (dimensions x = 6 meters, y = 35 meters, height = 4.5 meters).**

## antenna performance

I was able to obtain an SWR of less than 2.0:1 from 1800 kHz to 1900 kHz using the configuration shown in **fig. 5A** while obtaining the same SWR over a 70 kHz bandwidth for the set-up shown in **fig. 5B**.

My first evening on 160 meters with this antenna was most enjoyable, as I rag-chewed with stations from Delaware to California! Never before have I been able to call CQ and get an answer. It sure beat the RF burns and weak signals I had been used to!

I've worked over 30 states and several DX stations (including two Europeans) in the past month using only a 1-meter long ground pipe and 100 watts of transmitter power. Also incredible is the low receiver noise level. There have been many times when I could copy DX stations, while many other stateside operators could not. This antenna may be of interest to those who don't have room for Beverage antennas but want to get away from the received noise characteristics of verticals and dipoles.

The antenna seems to exhibit a moderately high angle of radiation and has a radiation pattern similar to that of a short dipole combined with a short verti-

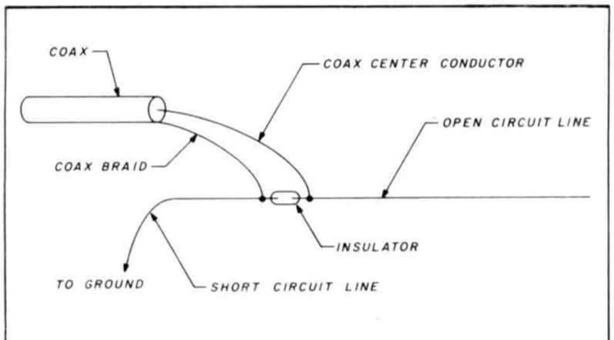


fig. 6. Simple feed method.

cal. The short-circuit line provides a vertical pattern, making this structure similar to a short vertical antenna. The open circuit wire provides some horizontal radiation, and is effective in tuning the antenna to resonance. The efficiency of this antenna is determined primarily by the ground conductivity at the antenna site. Unfortunately, soil is a very imperfect conductor. Ground radials may be used to increase efficiency, although they are not essential. In fact, a poor ground may actually be beneficial as it would prohibit complete cancellation of the horizontal current components in the far-field.

KS9J and WA2JQW have reproduced this structure at their locations using wire heights as low as 6 feet (1.9 meters) and short-circuit wire lengths as short as 8 feet (2.6 meters). They have indicated that low SWR is obtainable using an arbitrary wire configuration, at an arbitrary height, as long as care is taken to prune the antenna patiently.

## conclusion

After many frustrating attempts to work the 160-meter band without an adequate antenna, I have finally found something that keeps both me and my transmitter happy. The low SWR allows for operation without an antenna tuner, and the direct coax feedline minimizes RF in the shack. Most gratifying, though, are the many new friends I have made on 160 meters and the enjoyment that contacts on the "gentleman's band" can bring!

Those who are fortunate enough to have plenty of yard space, tall trees, or a tower might not want to use this type of antenna for 160-meter operation. But those of you who think you don't have the room to get on "top band," may want to give this tuner-less, trap-less transmission line antenna a try.

## references

1. Walter L. Weeks, *Antenna Engineering*, McGraw-Hill, Inc. 1968.
2. Technical Correspondence, *QST*, January, 1984, page 48.
3. Rudolf J. Guertler, "Isotropic Transmission line Antenna and its Toroid-pattern Modification," *IEEE Transactions on Antennas and Propagation*, May, 1977, page 386.

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