The Multiband Tuned Doublet Antenna

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I'm frequently asked by newcomers to our HF bands: "What's the best antenna for high frequency (HF) operation?" There's no one answer to this question. Ask a dozen radio amateurs and get a dozen different answers. No single antenna can be expected to perform optimally over the 16-fold range of frequency (1.8 MHz to 29.7 MHz) and wavelength (160 to 10 meters) that our nine HF amateur bands encompass. In perhaps more familiar territory a 16-fold frequency range is 50 MHz to 800 MHz, or 144 MHz to 2304 MHz. None of us, I'd guess, would expect a single antenna to work well on all frequencies within these ranges. The same is true of most HF antennas.

It seems the only reasonable solution to the HF antenna problem is to put up a separate frequency-specific (resonant) antenna for each band. But the prospect of installing nine separate antennas can be daunting for even the most experienced (and well heeled) among us. Fortunately there is one antenna that can provide effective communication on all, or near all, HF bands: the multiband tuned doublet antenna—or, as it is often called, the **center-fed Zepp** (Note 1).
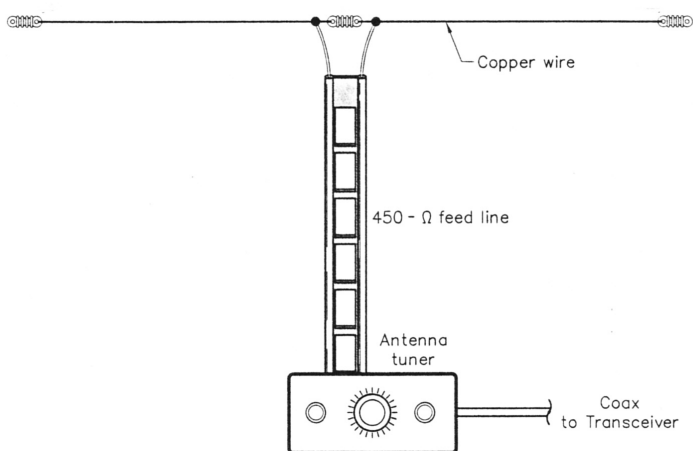

Figure 1. *Schematic layout of the center-fed Zepp. The feedline must be affixed to the antenna more securely than the drawing shows. Tuner adjustments are monitored in an SWR bridge or directional watt-meter (not shown).*

The overall layout of the center-fed Zepp is shown in **Figure 1**. It's a horizontal dipole fed at the center with parallel wire transmission line. The antenna differs little from the familiar half-wavelength resonant dipole we're all familiar with. The main differences are the use of parallel wire feedline instead of the more familiar coaxial cable, and the use of an antenna tuner with a balanced output. Properly designed, this antenna can operate effectively on most frequencies on or above the frequency at which it is a half wavelength long (Note 2). The antenna is efficient, adjustable for operation within each HF band, and easily assembled and installed. It even provides useful signal gain at the higher HF frequencies. The center-fed Zepp won't match the performance of a set of nine multi-element monoband Yagis, but for simplicity and low cost it's hard to beat.

Understanding the operation of the center-fed Zepp requires a shift in perspective from the familiar case of a resonant antenna matched at its feedpoint to a coaxial feedline. The central feature of the Zepp is that at nearly every frequency *the characteristic impedance of the transmission line does not match the antenna's feedpoint impedance*. While this may seem to contradict everything we've been told about antennas, the explanation lies in the unique properties of parallel wire transmission lines, as described in the next two sections.

Transmission lines

In a coaxial feedline, radio frequency (RF) currents flow on the outer surface of the center conductor, and on the inside surface of the cylindrical outer conductor. At any point along the line, and at any instant of time, RF currents on the two conductors are of equal magnitude but of opposite polarity. This means that the electromagnetic fields induced by the RF currents cancel one another out. No net RF field forms within the line—in the space between the center wire and the cylindrical shield—and no RF energy is radiated from the line. If the antenna's feedpoint impedance is identical to the characteristic imped-

ance of the coax, RF voltage and current will be constant along the line, and all the RF energy will be transferred to the antenna and (we hope) radiated outward. The coax forms a closed transmission path for RF energy going from transmitter to antenna (or from antenna to receiver).

Now, suppose there's an impedance mismatch at the antenna feedpoint. Some of the RF energy will be reflected back down the coax. Again, half the reflected current will flow on the center conductor, and half on the outer conductor. But reflected RF currents may also flow on the *outside surface* of the outer conductor. The electromagnetic field induced by these outside currents is unbalanced by any countervailing field, and RF energy is radiated from the coax along its entire length (and potentially back into the radio room). Radiation from the coax means less energy reaching, and being radiated by, the antenna itself.

Consider now an impedance mismatch at the feedpoint of an antenna fed with balanced, parallel wire transmission line. (Typically, parallel wire lines have characteristic impedances of several hundred ohms, instead of the familiar 50 ohms of most coax.) As in the coax case, some of the incident RF energy will be reflected back down the transmission line. But the reflected RF currents on the two wires will, like the incident RF currents, still be of equal magnitude and opposite polarity, and no net electromagnetic field will form. There will be no RF radiation from the parallel wire transmission line, and nearly all the transmitted RF power will (eventually) reach the antenna.

These cases are illustrated in **Figure 2**. **A** depicts a parallel wire transmission line. The transmitter (Tx) is at the left end of the line; the resistor at the right end of the line represents the antenna. (The resistor is termed the "load," symbolized as R_L.) The arrows along the line are intended to show the flow of RF currents, which (for equal impedances of line and load) are of equal magnitude but of opposite polarity everywhere along the line. At **B** I've drawn a transmission line with a complete short at the antenna end. RF currents are reflected back down the line, and we end up with a hodge-podge of back and forth currents. Even so, at every point along the line the currents on the two wires will be of equal magnitude and opposite polarity, and no energy will be radiated by the line.

It may be useful to think of the center-fed Zepp as two upside-down, back-to-back L-shaped wires, as shown in **Figure 1**. The horizontal legs of the L's
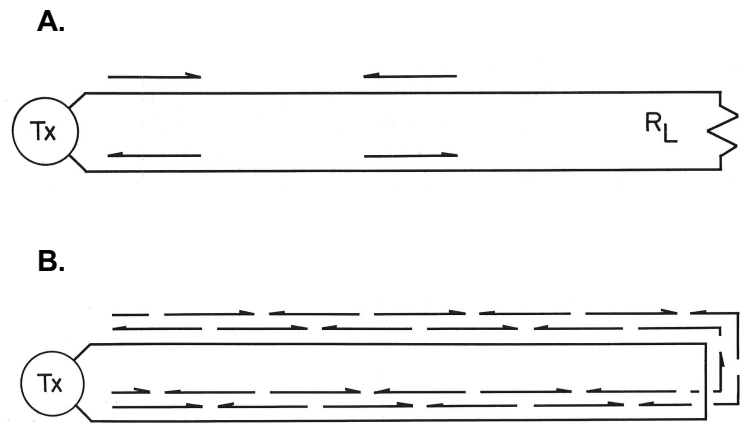

A.

B.

Figure 2. A. *Transmission line with transmitter (Tx) at left and antenna (R_L) at right.* **B.** *Transmission line with complete short at the antenna; reflected currents are present on the line. In both cases RF currents on the line's two wires are of equal magnitude and opposite polarity. See text for details.*

form the dipole, and the vertical legs, running close together in parallel, form non-radiating extensions of each half dipole. Seen in this way, the center-fed Zepp's actual feedpoint is not at the center of the dipole, but lies at the lower ends of the two vertical extensions—that is, at the output of the antenna tuner.

In the center-fed Zepp, concerns about antenna feedpoint impedance matching; reflected power and standing wave ratio (SWR); and antenna resonant bandwidth all become less important. More important for this antenna are the design of the antenna tuner; the structure of the parallel-wire transmission line; and the patterns of far-field RF radiation.

Standing waves and feedline lengths

The impedance mismatch at the center-fed Zepp's designated "feedpoint" (the dipole center) means that standing waves occur on the parallel wire transmission line. These arise as the reflected and incident RF currents combine to form a series of regularly repeated voltage (and current) peaks and valleys along the line. The RF peaks can significantly exceed the incident RF voltage and current; in the valleys they can sometimes decline to zero. The standing wave *ratio* (SWR) is expressed as the maximum voltage (or current) divided by the minimum voltage (or current) (Note 3).

Figure 3 illustrates voltage distributions along a transmission line. The transmitter is off to the left, and the antenna or load is at the right, "0" on the horizontal scale. The vertical scale is a measure of voltage relative to the incident voltage, that is, the voltage coming from the transmitter, E_I. Note that there are two complete standing wave "cycles" for each complete wavelength (360°) along the line.
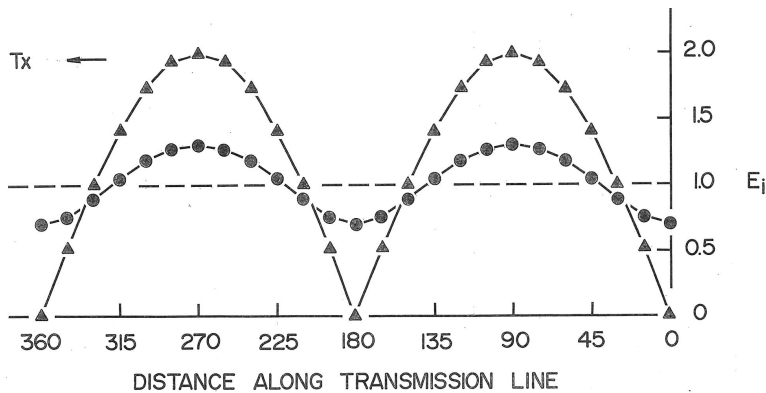

Figure 3. *Voltage distributions (standing waves) on a transmission line. The transmitter (Tx) is off to the left; the antenna is at the termination at right (0). The voltages are in units of the incident voltage, E_I. The dashed line is the voltage distribution when antenna and feedline impedances are identical ($R_L = Z_O$). The triangles describe voltage when all the incident RF is reflected back by the antenna ($R_L = 0$). The closed circles describe the voltage when the antenna impedance is less than the line impedance ($R_L < Z_O$), and 30% of the incident RF energy is reflected back.*

There are three curves on the graph: the horizontal dashed line shows the voltage distribution when the load and feedline impedances are identical ($R_L = Z_O$); the triangles identify the voltage distribution when all the incident voltage is reflected back by the load as the result of a complete short ($R_L = 0$); and the closed circles show the voltage distribution when the load resistance is less than the line impedance such that 30% of the incident RF energy is reflected back ($R_L < Z_O$). Even with the lumpy voltage distributions brought about by the impedance mismatches, the RF currents on the parallel wire transmission line remain balanced; no RF energy is radiated from the line; and power losses from this source are minimal.

There is, however, another source of feedline power loss that must be taken into account. All feedlines, whether coax or parallel wire, have inherent losses from the resistance of the wires ("I^2R loss") and from RF absorption by the non-conducting material be-

tween the wires ("E^2/R loss"). When standing waves are present on the line, the peaks of elevated voltage and current represent increases in the average or effective voltage and current, and the resistive and absorptive losses can also increase. In coaxial feedlines the power losses can consume a substantial portion of the applied RF power; in parallel wire feedlines the power losses are not zero, but they are significantly less than in coax.

Let's take an example. At 28 MHz, say, an SWR of 20 (an admittedly extreme case) will cause a 4.8 dB added power loss per 100 feet of average 50-ohm coax (RG8). For 100 feet of commercial 450-ohm ladder line the corresponding loss is 1.25 dB. For 100 feet of open wire line (parallel feedline with mostly air between the two wires) the added loss is 0.81 dB. *Total* power losses are 6.1 dB for the coax (meaning one-fourth of the applied power reaches the antenna), 1.4 dB for the ladder line, and 0.91 dB for the open wire line. Clearly, for an antenna system operated without regard for feedpoint impedance matching, and where high SWRs may be present, parallel wire transmission line is much to be preferred.

Published descriptions of the center-fed Zepp nearly always state that the feedline can be of "any length." As a generality, this isn't completely wrong, but at certain feedline-plus-dipole lengths and at certain fre-

Length (ft)	Bands (m)
75 ± 2	40, 30, 17, 15, 12, 10
95.5 ± 3	40, 30, 17, 15, 12, 10
109 ± 3	80, 40, 30, 20, 17, 15, 12, 10
145 ± 3	80, 40, 30, 20, 17, 15, 12, 10
159 ± 1	80, 40, 30, 20, 17, 15, 12, 10
199 ± 3	160, 80, 40, 30, 20, 17, 15, 12, 10

Table 1. *Suggested dimensions for the center-fed Zepp. Lengths are the sum of the feedline length plus* half *the length of the dipole. The bands are those for which a half-wavelength (or greater) dipole can be accomodated* (Note 2).

quencies, a standing wave voltage peak can end up right at the antenna turner, and cause undesired instability. Careful choice of feedline lengths can sidestep this problem, as shown in **Table 1**, which comes from a chart that used to appear in ARRL's *Antenna Book*. The lengths in the left column are the *sum* of the feedline length plus *half* the length of the horizontal dipole. The amateur bands listed for each entry are those for which this combined length allows the dipole portion of the antenna to be a half-wavelength (or more). For instance, the 75 ± 2 ft. entry permits a dipole of, say 65 feet in total length (about a half-wavelength on 40 meters) and a 42.5-foot length of feedline:

$$[½ (65) + 42.5 = 75].$$

Similarly, the 109 ± 3 ft. entry allows a dipole 135 feet in length (a half-wavelength on 80 meters) and a feedline length of 41.5 feet:

$$[½ (135) + 41.5 = 109].$$

Since antenna resonance is not a major consideration in the center-fed Zepp, neither dipole length nor feedline length need be precisely fixed. The center-fed Zepp allows considerable dimensional flexibility. The recommended lengths in **Table 1** each lie at the center of a range of lengths extending over several feet, and are intended to provide starting points for your own center-fed Zepp installation. If you run into difficulty on a particular band, it is a simple matter to add or trim feedline or, less simply, to trim or extend half-dipole lengths.

Radiation patterns

Figures 3 through **7** show computer-generated azimuth and elevation RF radiation patterns for a 135-foot center-fed Zepp mounted 50 feet above ground. If you are unfamiliar with these kinds of charts, the following digression might help.

First, it's useful to think of these displays as *contour maps* of the relative strength of RF power produced by an antenna, as if electromagnetic energy could be made visible. Second, each circular map (the horizontal or "azimuth" radiation pattern, at left), or half-circular map (the above-ground vertical or "elevation" radiation pattern, at right), is calibrated relative to the maximum level of radiated power, set at the outer ring of the contour maps and called "0 dB." The

inner rings of the maps represent power levels less than the maximum, measured in decibels below 0 dB, or −dB. Each map plots RF power as a function of angle, in degrees, relative to the antenna wire (the "azimuth" angle) or the angle relative to ground (the "elevation" angle). Third, you'll notice that the radiation patterns are different at different frequencies; this is because, even though our center-fed Zepp is the same length and height (in feet) at all frequencies, its length and height above ground *in wavelengths* both increase with frequency.

In the horizontal maps, the antenna (the wire dipole in this case) is located at the center of the concentric circles, and extends left to right, east to west. Most of the electromagnetic energy is radiated at right angles to the wire: top and bottom, north and south. Picture yourself in a balloon hovering high over a very large, flat field; the circular grid lines are laid out on the field, and the dipole at the center appears so small you can't make it out. In the vertical maps, the dipole is also at the center but viewed from the side so that the wire is end-on. In this case picture yourself standing on the ground very far from the antenna; if you could see the antenna, it would be a mere dot fifty feet above the ground. This sideways viewpoint allows the vertical radiation patterns, usually perpendicular to the wire, to be seen in profile.

By convention, the radiation patterns on the horizontal maps are taken at the elevation angle, relative to the ground, at which the radiated power is a maximum. Similarly, the vertical map patterns are those found at the horizontal angle, relative to the wire, at which the radiated power is a maximum. The two maps are thus interdependent. Together they provide a fuller picture of the shape of the three-dimensional "lobes" of radiated energy from the antenna. Now, back to our center-fed Zepp.

On **80 meters** (**Figure 3**) the center-fed Zepp is a half-wavelength dipole. The 50-foot height is too low for optimal effectiveness, and much of the radiated RF energy goes straight up, as seen in the vertical pattern (right). This allows for good short distance communication, but the antenna is less effective for long distances. The antenna is nearly omnidirectional, as seen in the horizontal pattern (left): at the 45° elevation angle selected for the horizontal pattern (an arbitrary choice in this case), the radiated signal power level off the ends of the dipole (E—W) is only 4 dB down relative to the power level perpendicular to the dipole (N—S).
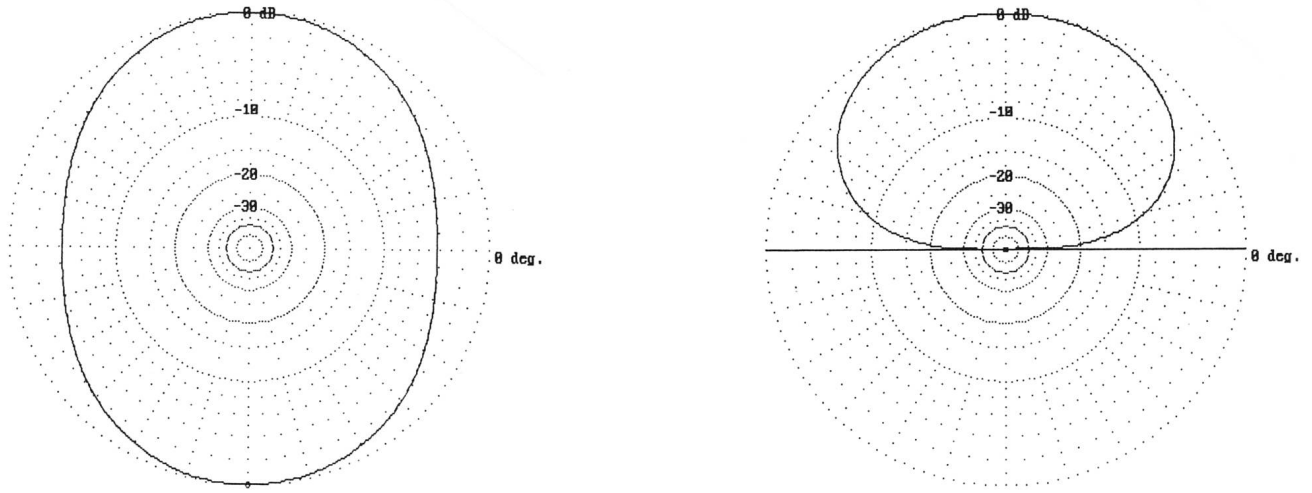
Figure 3. *Azimuth (left) and elevation (right) radiation patterns of a 135-foot center-fed Zepp modeled at 3.5 MHz and at 50 feet above average ground.*
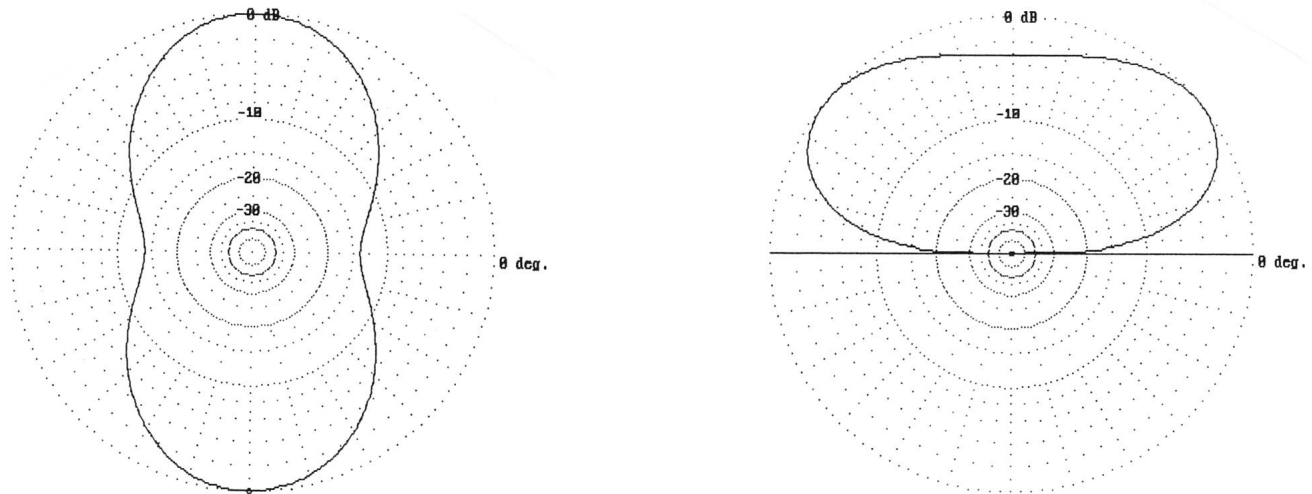

Figure 4. *Azimuth (left) and elevation (right) radiation patterns of the center-fed Zepp at 7 MHz.*
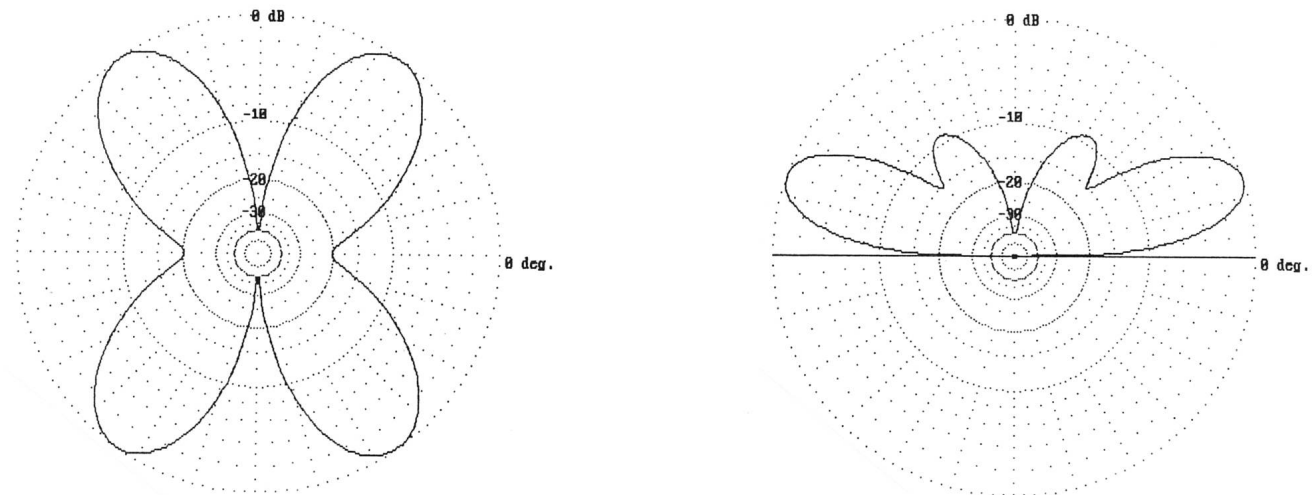

Figure 5. *Azimuth (left) and elevation (right) radiation patterns of the center-fed Zepp at 14 MHz, modeled at the elevation and azimuth angles of maximum gain.*
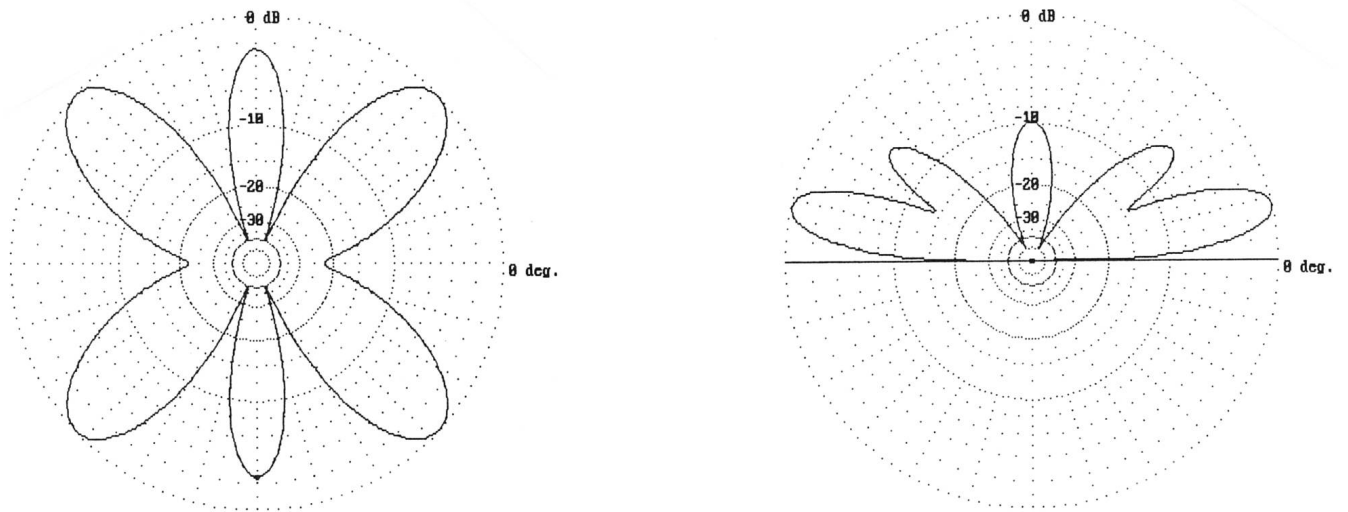
Figure 6. *Azimuth (left) and elevation (right) radiation patterns of the center-fed Zepp at 21 MHz.*
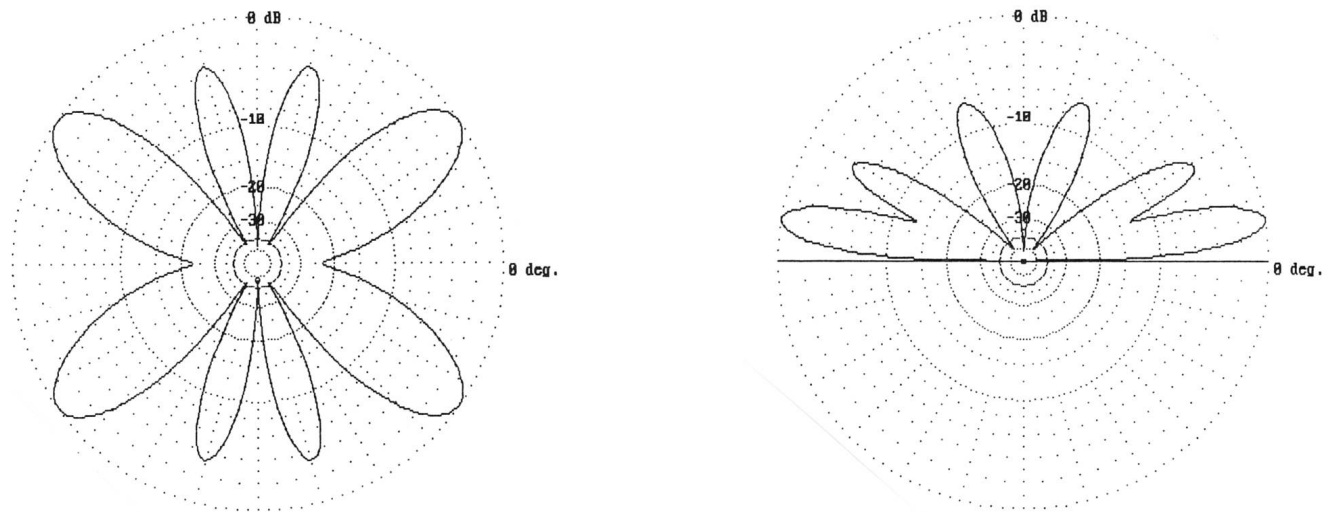

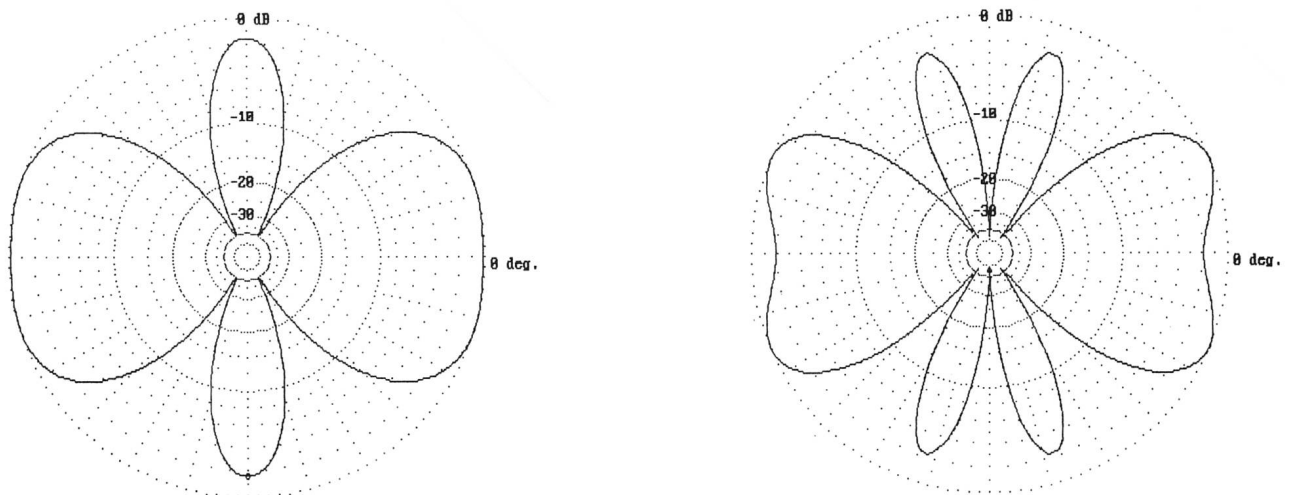**Figure 7.** *Azimuth (left) and elevation (right) radiation patterns of the center-fed Zepp at 28 MHz.*

Figure 8. *Azimuth patterns at 21 MHz (left) and 28 MHz (right) of the center-fed Zepp's secondary lobes at 43° (21 MHz) and 31° (28 MHz) elevation*

On **40 meters** (**Figure 4**) the antenna is a full wave-length long, the equivalent of two half-wavelength dipoles. As it happens, the two dipoles in this case are *in phase*. This means that RF currents are of the same magnitude and direction at corresponding positions on the two half-wavelength wires. The two wires function cooperatively (additively) as two antennas, and produce about 1.5 dB bidirectional gain (at 40° elevation) when compared to a single half-wavelength dipole at the same height above ground. Radiation off the ends of the wire is 14 dB down from the signal level perpendicular to the wire.

On **20**, **15**, and **10 meters** (**Figures 5**, **6**, and **7**) the antenna is four, six and eight half-wavelengths long, and the radiation patterns are characterized by four major lobes extending diagonally with respect to the wire. With increasing frequency, additional minor lobes also appear, and the azimuth angle the main lobes make with the wire decreases. On **20 meters** (**Figure 5**) the azimuth pattern (left) is that found at the elevation angle (19°) of maximum power indicated by the vertical pattern (right). The vertical pattern, in turn, is that found at the azimuth angle (54°) of maximum power shown on the horizontal map. The same approach is taken to generate the maps for **15** and **10 meters** (**Figures 6** and **7**).

Band (m)	Length/Height (λ)	Azimuth/Elevation (degrees)	Gain (dBi)
80m	0.54/0.19	90°/45°	5.0
40m	1.03/0.36	90°/40°	7.7
20m	2.05/0.72	54°/19°	9.4
15m	3.07/1.08	42°/13°	9.9
10m	4.17/1.47	35°/10°	10.6

Table 2. *Calculated properties of a 135-foot center-fed Zepp, modeled at a height of 50 feet. The height and length numbers are expressed as multiples of the wavelength (λ) at the center of each band. Gain was determined at the elevation and azimuth angles at which power levels were maximal, expressed in dB relative to an isotropic antenna (see text).*

Table 2 summarizes the center-fed Zepp's properties and performance on the five main HF bands. Antenna length and height are listed as multiples of the operating wavelength (λ) on each band. The middle column lists the angles, in degrees, of maximum RF power: the angle with respect to the wire antenna ("azimuth"), and the angle with respect to ground ("elevation"). The gain numbers in the last column should be viewed skeptically, for the following reasons. First, the numbers are given in "dBi," gain relative to an "isotropic" antenna that radiates equally in all directions (up, down; east-west; north-south). This unrealistic "theoretical" antenna is a common reference antenna in studies of this kind. A standard half-wavelength dipole antenna at infinite height (in "free space") has a gain (perpendicular to the wire) of 2.15 dBi. The same dipole over actual ground picks up additional gain from reflections of the signal off the ground. The "reflection gain" depends on the elevation angle at which the measurement (or calculation) is made, and the electrical conductivity of the ground. An antenna mounted above the deep blue sea (conductive salt water) will perform better than the same antenna mounted at the same height above East Tennessee limestone.

With these considerations, it's hard to make meaningful comparisons between the center-fed Zepp and a single-band, resonant half-wavelength dipole at the same height. This is especially true at the higher frequencies where the Zepp's four-lobe radiation pattern differs so markedly from the bidirectional dipole pattern. Comparing the main lobes one-on-one, without regard to azimuth angles, the Zepp offers roughly a 2 dB gain advantage over the corresponding dipoles on **20** and **15 meters**, and a bit over 3 dB on **10 meters**.

The elevation patterns for **15** and **10 meters** (**Figures 6** and **7**) show additional lobes, above the four main lobes, at 43° and 31°. A closer look at these secondary lobes reveals that their axes of radiation are broadly parallel to the antenna (that is, off the ends) as pictured in **Figure 8**. Though the gain advantage of these lobes (7.9 dBi and 8.7 dBi) is less than those of the four principal diagonal lobes, and though their higher elevation angles will yield shorter single-hop propagation distances, my experience has been that the antenna is an excellent long-distance performer on these two bands in the directions of the wire ends.

Radiation patterns of the center-fed Zepp on the three HF bands (30, 17 and 12 meters) that are

unrelated harmonically to the five traditional bands (and to one another) are discussed here without the pictures. On 30 meters, radiation is mainly perpendicular to the wire, like the pattern on 40 meters, but with significant side lobes that suggest the beginnings of the four-lobe 20-meter pattern; main lobe gain on 30 meters is 8.9 dBi. The radiation patterns on 17 and 12 meters are complex, with numerous minor lobes; the four main diagonal lobes lie closer to the wire (30$^{\text{o}}$ on 17 meters; 24$^{\text{o}}$ on 12 meters) than interpolating from the flanking bands would lead one to expect. Main-lobe gains are 9.5 dBi on 17 meters, and 9.9 dBi on 12 meters.

Antenna tuners

An antenna tuner is essential for proper operation of the center-fed Zepp. The tuner must convert the 50-ohm impedance (unbalanced) of the station transceiver to the often high impedances (balanced) presented by the antenna-plus-feedline system. Most commercial antenna tuners are capable of effecting impedance transformations over a wide range. But converting the *unbalanced* output of the transceiver to a *balanced* output for the Zepp's balanced feedline is a more difficult problem.

The proper way to bring about impedance transformation along with unbalanced-to-balanced conversion is to use a *balanced* antenna tuner. Commercial balanced antenna tuners are available (MFJ's 974 and 976 models), or you can build your own. Most antenna tuners are of *unbalanced* design (they're cheaper), and generate a balanced output by means of an internal toroidal balun at the tuner's output. Unless properly constructed, though, the balun's powdered-iron ceramic core can saturate and lead to heating and power losses. The balun may also fail to function as intended at some frequencies, or in certain combinations of impedance mismatch.

Despite these shortcomings, compromise tuners are in wide use and seem to perform well. The popular MFJ-949 unbalanced tuner, which I have used for almost three decades, tunes my center-fed Zepps without complaint, and with no evidence of toroid saturation or a poorly balanced output. The toroid balun in my '949C seems quite small for the tuner's claimed 300-watt rating. I've found no obvious toroid heating when transmitting 100 watts full carrier for ten seconds into a tuned 135-foot center-fed Zepp on 80-10 meters. Direct RMS voltage measurements at the balanced output of my tuner, determined for a range

of non-inductive loads, indicated good (thought not perfect) output balance. The balance deteriorates somewhat at higher load resistances and at higher frequencies, especially on 10 meters. These departures from perfection do not imply that the center-fed Zepp, fed through a compromise tuner, will not perform well. Other factors that affect antenna system balance—sloping ground, asymmetric placement of houses, trees and other antennas—can outweigh minor tuner-generated imbalances.

Center-fed Zepps of various lengths and heights have been my main antennas for many years. Even when ionospheric conditions are less than optimal (as we've experienced recently), I've had enjoyable contacts with radio amateurs from around the world, and easy fun operating in the DX contests.

One aim of this paper has been to present a more complete description of the center-fed Zepp than is usually found in amateur radio publications. The details should not discourage you from trying out this simple, inexpensive, easily tuned antenna. Construction is little different from that of any other wire antenna. Keep the two dipole halves of equal length and choose a feedline length appropriate to your location. The center-fed Zepp is a first-rate performer, especially on the upper HF bands, and is well worth the effort to build and install.

Notes

1. The term "Zepp" comes from Zeppelin. In these floating behemoths of the air, the radio antenna had to be kept far away from the flammable hydrogen gas. The antenna consisted of a long (1000s of feet) trailing wire, fed at its near end with parallel wire transmission line. At the feedpoint one of the two wires of the transmission line was connected to the antenna, and the other wire was left unconnected. (In ham radio parlance this design is now called the "end-fed" Zepp.) The proximity of the two parallel wires meant that no net electromagnetic field formed around the transmission line. Properly speaking, "center-fed Zepp," though descriptive, is probably a misnomer.

2. Some publications claim that the dipole part of the center-fed Zepp can be as short as a quarter wavelength long at the operating frequency and still work fine. I've found that dipoles much less than a half wavelength long are touchy to adjust, and prefer my center-fed Zepps to be closer to a half wavelength

long at the lowest operating frequency.

3. The standing wave ratio is usually measured as a ratio of voltages rather than of currents; measuring voltages in this case is easier. Even though SWR is the same independent of which parameter is measured, engineers like to remind us of their measurement method by using "VSWR" (*Voltage* SWR), pronounced "viz-wahr." This seems to me an unnecessary complexification for us hams.