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TAMING THE END-FED ANTENNA

The single wire antenna directly connected to the transmitter is often discouraged in the amateur radio manuals because of the close proximity of the radiating element to house wiring and domestic equipment. This undesirable feature is aggravated by the fact that wild excursions of feed impedance occur when changing operation from band to band and good matching is sometimes difficult to achieve.

All in all, however, the antenna is simple, cheap, easy to erect, suits many house and garden layouts, and is easily amenable to base or portable operation. It is not surprising that the end-fed wire is often pressed into service by old hands and newcomers alike, who are prepared to work on its more wayward characteristics to produce a thoroughly acceptable multiband antenna.

This article sets out to show how the length of an end-fed antenna can be optimized to serve a given set of bands, tuned to resonance (minimum feed impedance) on each band and then coupled to the transmitter using a wideband matching transformer and any required length of coaxial cable to distance the antenna wire from the operating position. Such an antenna can then be operated against real earth (if a suitable terminal is close at hand) or, more likely, a substitute in the form of a radial (or several) or a counterpoise wire.

Background

The end-fed antenna has traditionally been designed to resonate on one lower band in the HF spectrum, say a quarter wavelength on 80 meters where the current feed will meet an impedance of around 50 ohms. At a half wavelength on 40 meters, the input impedance will rise to a high value presenting a voltage feed to the source. The next band, 30 meters, will fall in the vicinity of current feed again at three quarters of a wavelength and present a fairly low impedance. The next move to 20 meters will meet a high impedance again and then through an off-tune 17 meters to another high at 15 meters. The sequence continues with some extra complication in that odd multiples of wavelength will show generally increasing impedance with frequency whereas even multiples of wavelength (the half-wave points) will show decreasing impedance as the band is ascended.

To achieve a moderate feed impedance on all bands, some means must be found of selecting

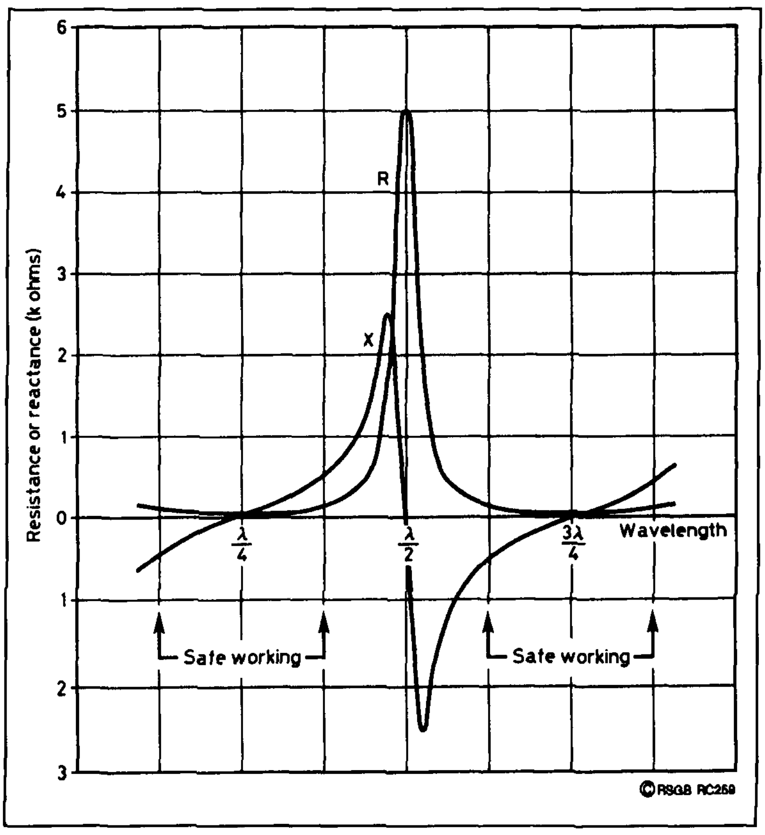


Figure 1. End-fed impedance characteristics of wire from λ/4 to 3λ/4.

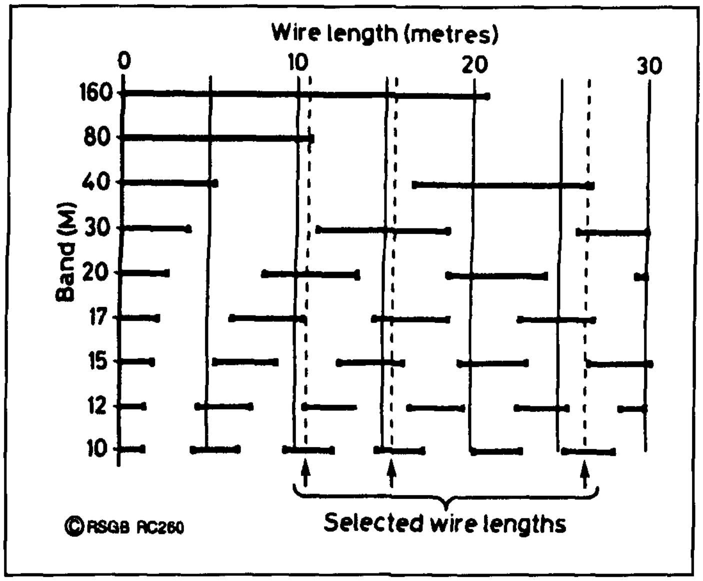


Figure 2. Antenna wire lengths showing "no-go" lengths for various bands.

a wire length that steers well clear of the half-wave points. **Figure 1** illustrates resistance and reactance plotted against electrical length from below a quarter wavelength to three quarters of a wavelength and beyond. It can be seen that dramatic changes begin to occur as the half wave resonant point is approached. These dramatic changes are repeated at multiples of $\lambda/2$ and these regions must be avoided if the impedances of a multiband antenna are to be kept reasonably low and uncomplicated on all bands of operation.

In general, the magnitude of the half wave multiple resistive and reactive excursions decrease as the electrical length of the antenna is increased.

To make a start, it was decided that the sector within $\pm \lambda/8$ from the $\lambda/4$ point represented fairly "safe" working conditions within which the wire could be tuned by adding the appropriate sign of reactance at the feed end.

In other words, wires on the low side of the $\lambda 4$ point (too short) would be tuned by inserting inductive reactance in series with the wire, while lengths on the high side of the $\lambda/4$ point (too long) would be tuned by inserting capacitive reactance in series. It follows that entry into the "danger" areas within $\pm\lambda 8$ from the $\lambda/2$ resonance peak should be undertaken with care. The same principle applies for subsequent quarter and half wavelength regions on longer wires.

In **Figure 2**, wire length is shown against each of the nine HF bands (including 160 meters) with "no-go" portions indicated by the heavy lines. To avoid unnecessary complication, wavelengths were calculated from the lower band edge frequency in each case and no corrections were made for the "end effect" on a real antenna.

To use the chart, a perpendicular straightedge is dropped from the horizontal axis and moved along until a clear way through the gaps between the no-go sectors is found. Thus, for a wire length of 10.5 meters, the straightedge just clips the end of the 80-meter no-go line, then goes through the middle of the 40-meter safe sector and on through the 30-meter gap. At 20 meters, the straightedge is blocked, but there are clear openings at 17, 15, and 12 meters.

The next opportunity presents itself at a wire length of 15.5 meters where openings appear at 80, 40, and 20 meters and, if some tolerance is permitted, at 17 and 15 meters, and then through the clearance at 12 meters. The very next choice of the bands becomes available at a wire length of 26.5 meters which gives all eight bands including 160 meters but not, unfortunately, 10 meters where special arrangements have to be made. The wire lengths quoted here may need some small adjustment when the practical system is built.

Tuning and matching

It can be seen, from **Figure 2**, that there is at least one band for each wire length where the straightedge goes through the center (or very nearly) of a safe working region. At this point, the feed impedance will be fairly low. For other bands, where the straightedge lies to the left or right of the gap center, the impedance will be higher in value and capacitively or inductively reactive. The reactive component is tuned out by inserting an inductor or capacitor of the appropriate value close to the feedpoint leaving a non-reactive antenna feed of moderate value to be matched very easily to the transmitter.

Some general points need to be made here to assist in the selection and adjustment of tuning and matching components. Near the center of the safe working regions, relatively small values of reactance will be required to bring the antenna to resonance; at the extremities, larger values will necessary. The outer limits of these regions may be extended by a small amount as practical examples given in the section "The Practical System" will show. Because the antenna is pre-tuned on each band and designed to offer only a moderate range of resistive input impedances, it only remains to add a simple wideband transformer to match the antenna to the transmitter via 50-ohm cable. Such a transformer is described in **Reference 1**.

Earth plane

Using the principles described in the selection of wire length and tuning, it is now neces-

Tuning and Matching Data

Band (meters)	Tune	Match (ohms)	Notes
25.60-meter wire			
160	32–10 µH	50	Various ground planes
80	150 pF	112	
40	6 µH	112	
30	50 pF	200	
20	>100 pF	112	Near series resonance
17	2 µH	200	
15	25 pF	450	
12	>50 pF	112	Near series resonance
10	1 µH/25 pF	800	Parallel resonance (see text)
15-meter wire			
80	14–10 µH	25–50	
40	100 pF	50	
20	>50 pF	112	Near series resonance
17	25 pF	450	
15	4 µH	450	
12	>50 pF	450	Near series resonance
10	1 µH/25 pF	800	Parallel resonance (see text)
10-meter wire			
80	20–14 µH	25–50	
40	>100 pF	50	Near series resonance
30	50 pF	200	
17	2 µH	112	
15	>50 pF	200	Near series resonance
12	25 pF	450	
10	1 µH/25 pF	800	Parallel resonance (see text)

Table 1. Tuning and matching guidance data for each band against three lengths of antenna wire (elevated or grounded).

sary to consider the earth plane, real or substitute, against which the antenna will operate.

In general, a good earth connection is hard to find and only practicable from a ground floor room. Unless the earth can be reached within a very short distance, the "earth substitute" (radial or counterpoise) comprising a single quarter wavelength wire from the aerial feedpoint is hard to beat and the technique will also ensure minimum RF voltage at this point. The earth stake version, although often less efficient, is convenient for portable operation and avoids the chore of erecting more wires.

The practical system

The full range of tuning component values and feed impedances for each HF band against wires of three lengths is shown in **Table 1**. Any one length of wire can be operated either elevated well above ground using substitute earths or very near ground using a real earth connection via a short lead. The longest wire (26.50 meters) will provide full coverage on all nine bands while the shorter wires (15 and 10 meters) will cover seven bands each with some overlapping. It can be seen from **Table 1** that two wires, used selectively, will provide full coverage without the complication of inductor tuning.

The main wire is measured to the dimensions given in **Table 1** and, after marking, it may be prudent to allow a little extra for fine adjustment during installation; this is accomplished on the 20-meter band for the 26.50- and 15-meter wires and on the 40-meter band for the 10-meter wire where natural resonance occurs in each case. Although it is physically possible to tune the wire to any part of the band as required by the cut-and-try method and avoid the need for the tuning capacitor altogether, it is generally preferable to place the natural resonance a little below the lower band edge frequency and use the variable capacitor (at relatively high value) to move the resonance point up into the band.

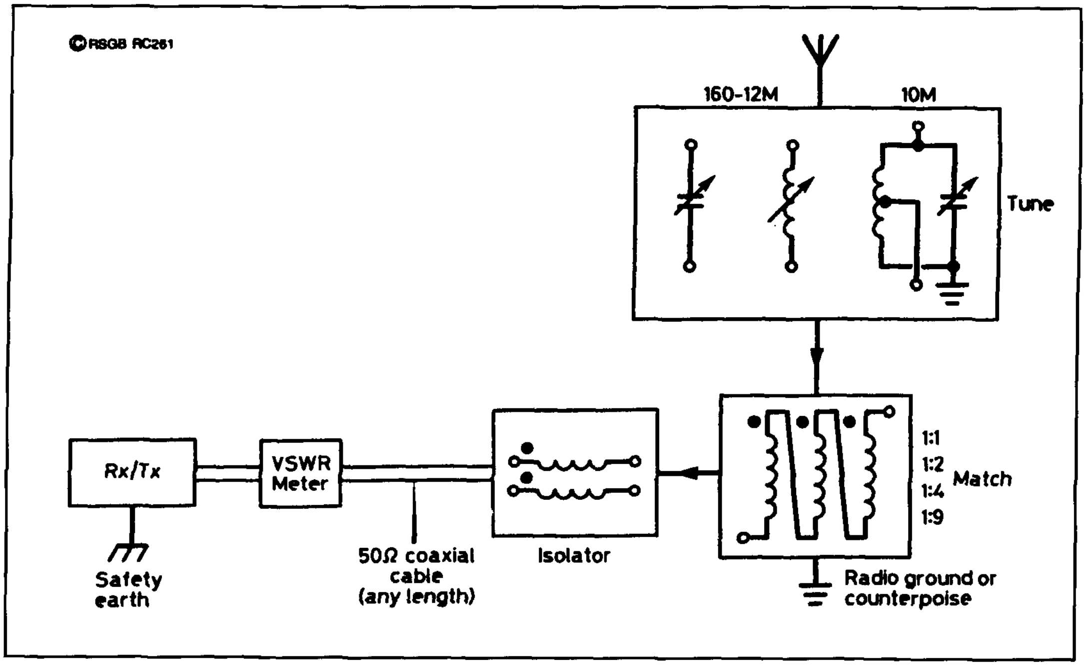


Figure 3. Layout of antenna to transmitter interface.

The quarter wavelength substitute earth wire for the elevated antenna can be cut for the required frequency within each band less 5 percent for end effect. The measurements are not critical and no difficulty will be found in practice because any fine adjustment required will be taken up automatically when the main antenna wire is tuned. The lead length to the earth stake for the grounded version was fixed at 1 meter to maintain some degree of uniformity between the two versions and to ensure reproducibility of the design. The stake used was about 1.5 meters in length and the short connecting wire was adequate for portable operation from car, tent, or even garden shed but, if required, the lead may be extended by a small amount provided an equivalent reduction is made to the main wire. The grounded end-fed wire cannot match the performance of the elevated version unless a very good earthing system is employed. Nevertheless, the simple stake has been shown to provide a useful and convenient earth when operating from a temporary location.

The simplest way to provide the tuning function at any power level is by using one variable capacitor of adequate vane spacing and one variable inductor (roller coaster) connected in circuit as required. The units were calibrated and showed maximum values of 750 pF and 32 μH, respectively, although extra inductance was sometimes required at 160 meters. This was the arrangement used when compiling the data given in **Table 1**. Values given are "broad brush" based on many measurements taken during trials. A range of values is given where the band is particularly wide.

10-meter operation

An examination of **Figure 2** will show that, for the three preferred wire lengths, the vertical straightedge will go through the center (or very nearly) of one of the no-go sectors on 10 meters. Because this point coincides with one of the $\lambda/2$ positions on the wire, a relatively high impedance was expected, which by measurement turned out to be a fairly moderate 800 ohms. Even so, a parallel tuned circuit was called for at the feedpoint and good performance was obtained with a center-tapped inductor providing a convenient input of 200 ohms from the matching transformer. This is included in **Figure 3**. The inductor comprised 2+2 turns of 18 SWG wound on T130-6 powdered iron toroidal core and tuned with 25 pF.

Layout of antenna-to-transmitter interface

It was stated earlier that end feeding a wire antenna may not be in the best interests of avoiding RF breakthrough. Whatever else might be done to assist in this direction, the physical separation of antenna wire from in-house receivers and mains wiring, not to mention the amateur's own equipment, must be regarded as a major step forward. Physical separation of units will depend on local circumstances. At G3CCB the tuner, matching transformer, and isolator are located closed together at the antenna wire entry point and a long coaxial cable is used from this point to the operating position on the other side of the house. Portable operation may not call for the same degree of separation, and a short coaxial cable to the transmitter will then be all that is required.

All antenna wires are measured to the matching transformer terminals and the isolating transformer ensures that tuning is not affected by the way in which the equipment is connected up; e.g., whether or not the equipment is connected to mains earth. Portable or QRP rigs may not be earthed at all or might share this function with the antenna ground in which case the isolator can be safely left out.

A general layout of interface connections is given in **Figure 3**. The VSWR meter is shown connected at the transmitter end of the long coaxial cable where it can serve as a general monitor of the system from the operating position. During initial setting up, it will be beneficial to site the VSWR meter at the antenna terminal unit where the coaxial cable meets the isolator and matching transformer. Details of the isolator and matching transformer are given in **Reference 1**.

Alternative inductor tuning

The arrangements described above for varying the inductor might be considered to be quite appropriate for QRO use.

Where moderate power levels are used, especially down to genuine QRP, the roller coaster may be regarded as an unnecessarily complicated and expensive item. A technique to simulate variable inductance by employing a fixed inductor in combination with a variable capacitor will provide a satisfactory solution.[2] This has been employed on the elevated 26.50-meter wire where variable inductance is required on the 160-, 40-, and 17-meter bands and a version has been scaled down to suit QRP rigs. A brief note on the principle of simulated variable inductance is given in the **Appendix**.

Conclusion

The exercise has produced a set of three end-fed wires to provide coverage of all the amateur bands that can be operated from an elevated or grounded position and which can be very easily tuned and matched to 500 ohms. The opportunity has been taken to try out several interesting techniques which may be regarded as being unconventional, namely the wideband ferrite antenna matching transformer, the isolating transformer of similar construction, and the simulated variable inductor to avoid mechanical methods of adjustment. All these devices have contributed in their way to the simplification of tuning and matching and will assist in the development of remote control of these functions should this be required.

The longest of the three wires (26.50 meters) is undoubtedly the most useful in taking in the whole HF spectrum, but there may be further

Appendix

The effective inductance of a fixed coil may be reduced to a limited extent by adding a variable capacitor in series.

For a series combination of L and C, the net reactance X' is equal to X_L-X_C and will be inductive when X_L>X_C. X' can be regarded as the reactance of a reduced inductance $L'=X_L'/2\pi f$. The reduced inductance will, unfortunately, exhibit a correspondingly reduced circuit Q because the loss resistance of the coil will remain unaltered while the inductance is lowered ($Q=2\pi fL/r$). This fact puts a constraint on the amount by which the inductance may be reduced. Fortunately, most amateur bands are relatively small in width and the inevitable reduction in Q can be kept within reasonable limits. The 160-meter band is a possible exception and it may be desirable to divide the band into two segments for tuning purposes.

For compactness, coils are wound on T130-2 powdered iron cores and tuned with a variable capacitor to the appropriate value shown in **Table 2**. The highest value of capacitance should be sought consistent with the tuning range required.

Tuning Components Lower Frequency Bands

Band	**160**	**40**	**17**	
Coil	40	7	2.5	μH
Former	T130-2	T130-2	T130-6	
Turns	60	25	16	
SWG	22	20	18	
Tuning	<750	>150	>50	pF

Table 2. Components required for tuning the lower frequency bands.

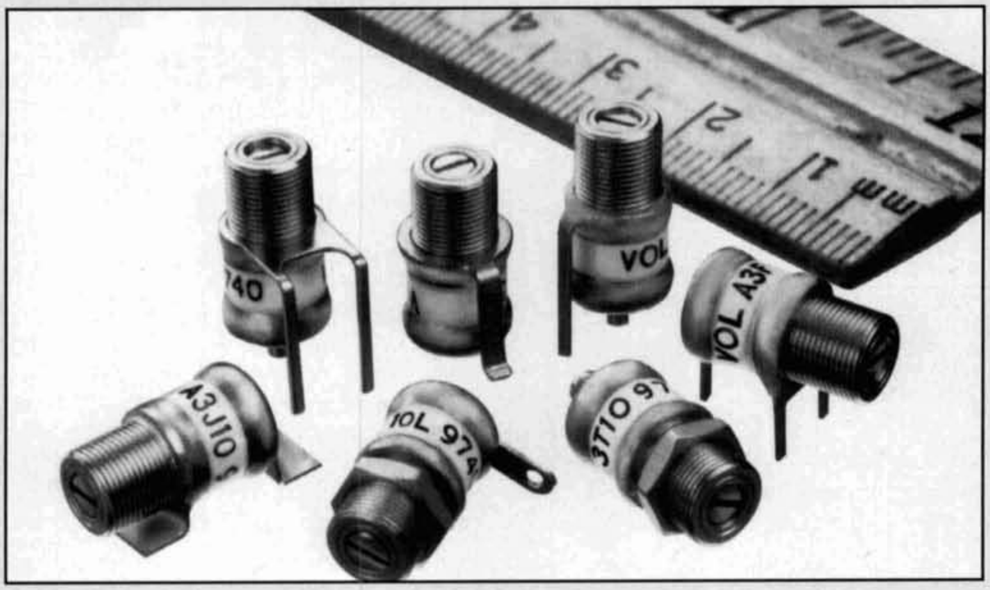
opportunities using longer antennas. For example, extrapolation of the data given in **Figure 2** shows a clear way through the bands from 160 to 10 meters at around a wire length of 55 meters. The longer wire would certainly produce a better antenna on 160 meters (near $5\lambda/8$), which could be tuned by a variable capacitor within this band but might result in generally higher impedances appearing throughout the remainder.

All antennas worked well showing a VSWR at the transmitter generally no worse that 1.5, but the on-air performance of the elevated counterpoise versions outshone the grounded wire by a significant margin. This is undoubtedly due to the modest stake in use for the earth connection, but it should also be appreciated that a grounded end-fed antenna cannot acquire much height—especially for the shorter wires. Perhaps kite flying and very long wires is the answer for portable operation on 160 meters! ■

REFERENCES

1. Alan Chester, G3CCB, "Two useful non-baluns," *RadCom*, October 1993.
2. Pat Hawker, G3VA, "The transmitter antenna interface," *Technical Topics*, December 1984.

PRODUCT INFORMATION



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