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Skylines for 160, Made Simpler

About a year ago the value of 160 meters as a ham band was much less than now. The regulations were too confining. New regulations, although complex, offer much more opportunity for local ragchewing, and some adventurous amateurs may be working transoceanic DX even as you sit reading this.

Your on-the-air competition on 160 will be far less than on 80, the propagation much steadier than on 20. Effective ranges are typically several tens or a few hundreds of miles. And at 160's low frequencies you can get by with inexpensive surplus transistors to try out those transmitter ideas. 160 is worth some of your time and money now.

There's a bit of history on 160, too. It is on the dividing line between two very different kinds of radio. Now it's at the bottom of the amateur spectrum, but there is a time in some men's memories when it was at the top. Communications engineers once believed you used long waves for long range communications, since nobody understood how short waves could get over the horizon.

The general thinking then was that the high frequencies had a low practical utility, and the amateurs wound up with a huge chunk of radio spectrum nobody else wanted. Many interesting records date from that time for the hams soon discovered the real potentialities of short-wave propagation.

Now we understand the differences between ground-wave and sky-wave propagation. We know why the ionosphere is responsible for sky-wave propagation, since its effects cannot be ignored by anybody and are very important for the DX that interests many amateurs. And we have a band where the special advantages of ground-wave propagation can be applied and enjoyed.

Ground-wave is made to order for local rag-chewing. Saving the higher-frequency bands for DX, we can easily build simple antennas optimized for 160 meter vertically polarized radiation. In a way this is making a virtue of necessity, but we can come back to that point later. First we should discuss the FCC's complex frequency and power assignments, and review some facts about 160 meter propagation.

Eight Pieces of Pie

When you tune your receiver across 1.8 to 2.0 MHz you will hear a variety of sharp regular beats, quite evidently for some purpose other than communication. These sounds first appeared on 160 during WW2, when a tremendous need was developing for some fast, reliable, and accurate method of navigation. Ship and airplane navigators observe the beats in pairs on an oscilloscope-like indicator. Then, using the resulting time measurements and special navigation tables, they quickly locate their vessels with an accuracy of a thousand feet or so. This service was very useful during the war, and has had a great commercial value since.

The system is called "loran," coined from "long-range navigation." Various engineering necessities plonked this service into the amateur 160 meter band, where it has stayed to the annoyance of many hams. With the loran usage receiving first priority and the hams reduced to low powers in the face of kilowatt pulse interference, 160 meters has become a less-than-popular band for amateur communications.

But navigation technology has been developing, and with the advent of new navigational space satellites, UHF beacon systems, inertial navigation, and computerization (which saves time and improves accuracy) the loran services have lost importance over the past ten or twenty years. Recently the FCC has raised and reallocated its 160 meter power limits. This easing together with the development of amateur technology has made the band interesting again.

Yet the 160 meter band is still a shared service, and the FCC has written a remarkably complex set of rules for the amateurs. The new regulations appear to occupy more space and text than all the other regulations for all the other amateur bands. If you intend to operate legally you have to 1) determine in which of 26 American or several zones you will operate; 2) discover which of the eight 25 kHz frequency segments are available to you in those zones; 3) make a list of the daytime power limits applicable, and 4) add a list of the much lower night-time power limits. Finally, look out for rules changes. Considering the complexity of the allocations, changes seem quite likely.

At this writing, the regulations break the continental U.S. into 26 areas. All dividing lines are among state lines. Some areas, such as California, Texas, or Florida, consist of only one state. And at the opposite extreme, the Northeast U.S. includes the entire W1 and W2 zones as a single allocation area. **Fig. 1** is a representative table of the allocations for New York State and some adjacent areas.

NEW YORK STATE

Segment	Day/Night Power
1800-1825 kHz	500/100 W.
1825-1850 kHz	100/25 W.
1850-1875 kHz	0
1875-1900 kHz	0
1900-1925 kHz	0
1925-1950 kHz	0
1950-1975 kHz	0
1975-2000 kHz	0

Fig. 1. Sample allocations for one state. Which limit applies at 1825 kHz?

In each of the allocation areas the 160 meter band is broken into eight 25 kHz segments with typically different power limitations for each segment. There is no clear pattern, except that the highest power limits *tend* to appear at the edges of the band, and there are very many parts of the U.S. in which the central two to four 25 kHz portions cannot be used at all.

The present power limits range from zero at any time right up to 1000 watts, with 200 and 500 watt limits being quite common. Power is measured in the standard manner. The power limits are reduced by a factor that is typically 4 and occasionally five when the sun goes down, and there are no night-time limits anywhere over 200 watts. This complicated power limit system is going to lead to considerable band-edge or cross-segment operation, and more than any other band 160 will be an easy one to earn a pink ticket for incorrect operation.

Fortunately all of the segment borders are at multiples of 25 kHz, so that you can use a frequency standard consisting of a 100 kHz oscillator followed by a pair of binaries to provide good 25 kHz markers. Since the recent incentive licensing regulations changes for the higher bands also place band segment borders on 25 kHz multiples, appropriate frequency standards are appearing on the market and should also be available as construction articles. Alternatively (since the segments are quite narrow) crystal controlled operation deserves consideration.

160 Meter Propagation

If you know something about radio wave propagation on the higher bands you will not need any new concepts for 160. The principles are about the same as on 80 or 40 but the emphasis has gone from sky waves to ground waves. When operating on 160 meters, especially at night, the skip distance is about zero so that sky and ground waves compete at all distances. 160 can offer severe fading problems.

This fading is minimized by antennas that minimize upward radiation. A 5/8 wave vertical would be a pretty good radiator for 160, and a set of three cophased half-waves stacked vertically would be even better. But all that is out of the question for any builder who is not financed by the Government or a large industry. Work out the dimensions and you'll see why. If you're typically limited in money and resources you must get by with some pieces of wire attached to available structures and trees. Or maybe you can do something with a few lengths of TV tower.

Ground-wave propagation is the apparent passage of the radiated *rf* along the ground. See **Fig. 2**. The wave fronts are the usual one-wavelength apart, and extend far up into the sky. They tilt forward because ground resistance is dissipating part of the wave energy. The tilt is an indication of the rate at which the wave is passing into the ground (where it is permanently lost) and depends

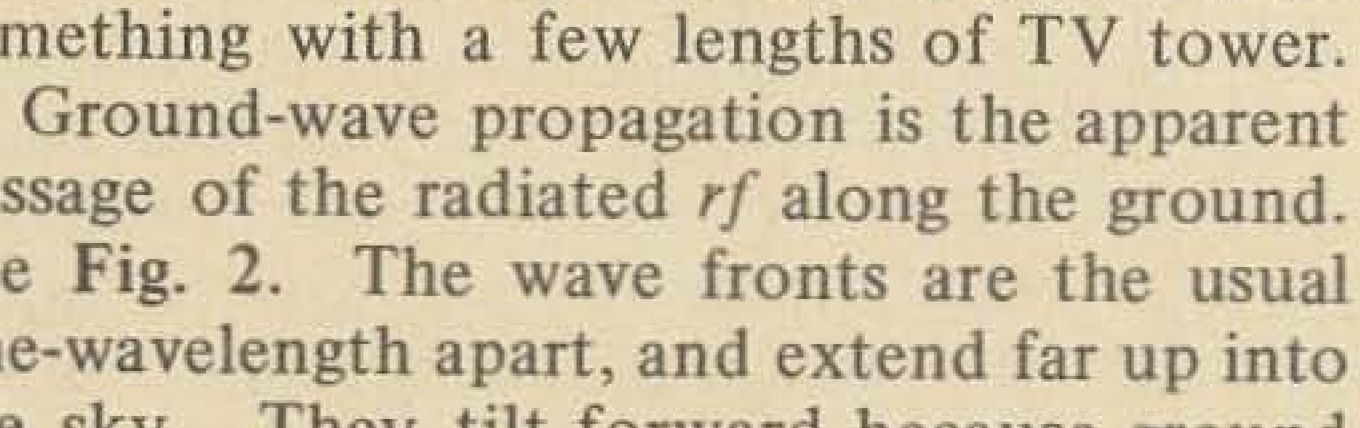
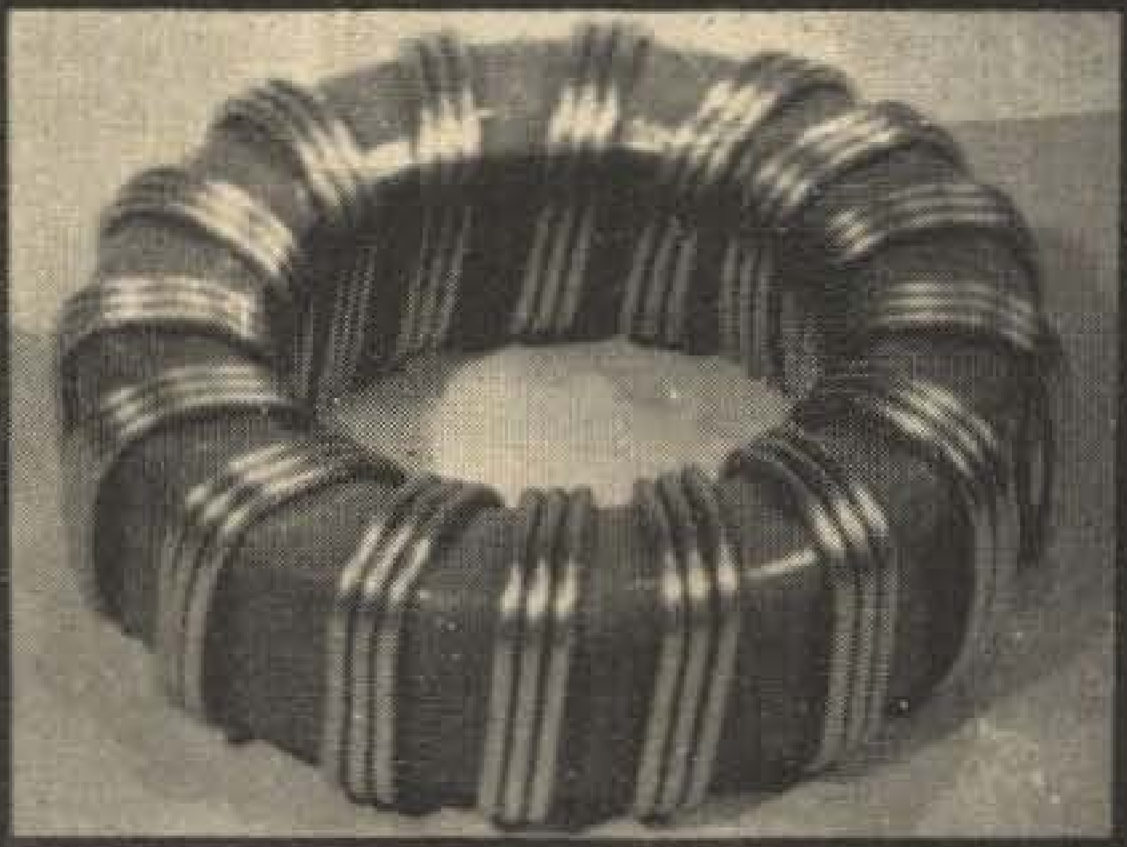


Fig. 2. Since the wave front proceeds at right angles to its surface, the tilt is an indication of the rate at which it is running into the ground. This tilt is applied by the Beverage antenna.



upon the electrical conductivity of the ground. The greatest tilt is seen over the poorest surface, which gives you the least range.

On 160 you can fairly well expect to get out to one hundred miles by ground wave, and you may do very much better than that. It depends upon the quality of the earth in your region, and upon how much competition your signal gets from electrical interference and Loran signals at the point of reception. The Loran signals can be filtered or clipped, and so electrical noise is probably the controlling factor. The situation may be surprisingly good at your site, or worse than you believe. This will have to be learned by test, but you can get some ideas from Fig. 3.

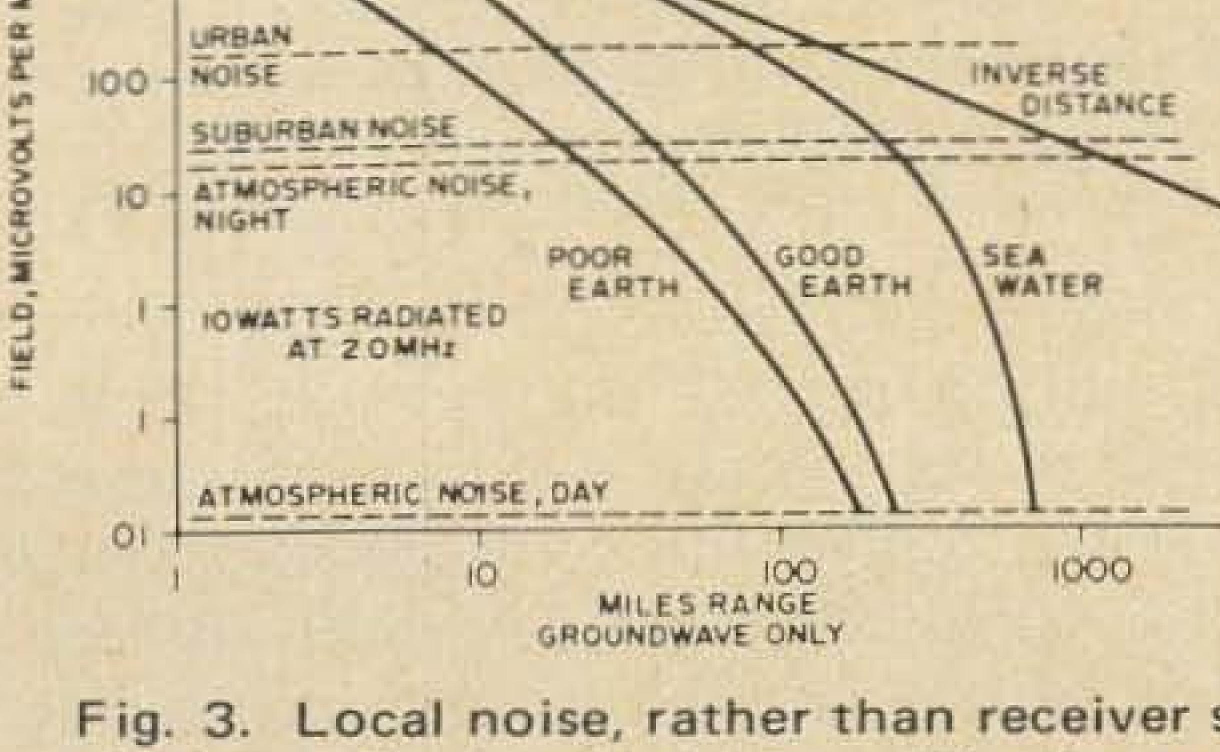


Fig. 3. Local noise, rather than receiver sensitivity, will often limit your effective range. You will not need high powers for reliable contacts if you are in a quiet area.

This chart refers to ground-wave signal strength only. We could draw a few tentative conclusions about the fading zone from this, if we knew the radiation pattern of your antenna, but that is not the purpose. Here we are seeing what 10 watts radiated power is likely to achieve against some typical noise competition. Since you will typically be radiating considerably more power than 10 watts these are probably minimum results. To adjust this chart to higher powers, correct the field strength by the square root of the change. That is, if you were radiating 1000 watts, the received signal at any given distance would be greater by a factor of ten.

Unless you are interested in 160 meter DX you will find sky-wave propagation appears largely as a source of trouble. It is not true that if a receiving antenna picks up the same transmitted signal from two directions the receiver gets twice the input signal. The receiver may not get any signal at all, if the two incoming signals are of equal amplitude but opposite phase. In that case they cancel. When incoming signals are in the general range of two or three to one in power level you have a possible signal-cancellation situation, and if one of the signals is reflected from a moving object or surface you can expect some fading. This is the effect sometimes seen on TV sets as aircraft fly across your area.

Replacing the aircraft by the ionosphere we find that under some conditions the sky wave may return to earth at a region not very different from the transmitter, and compete with the ground wave. See **Fig. 4.** This effect is more noticeable on 160 than on any other ham band, more likely at night than in the daytime. We cannot revise the ionosphere to remove the fading, but we do try to design our antennas for minimum upward radiation.

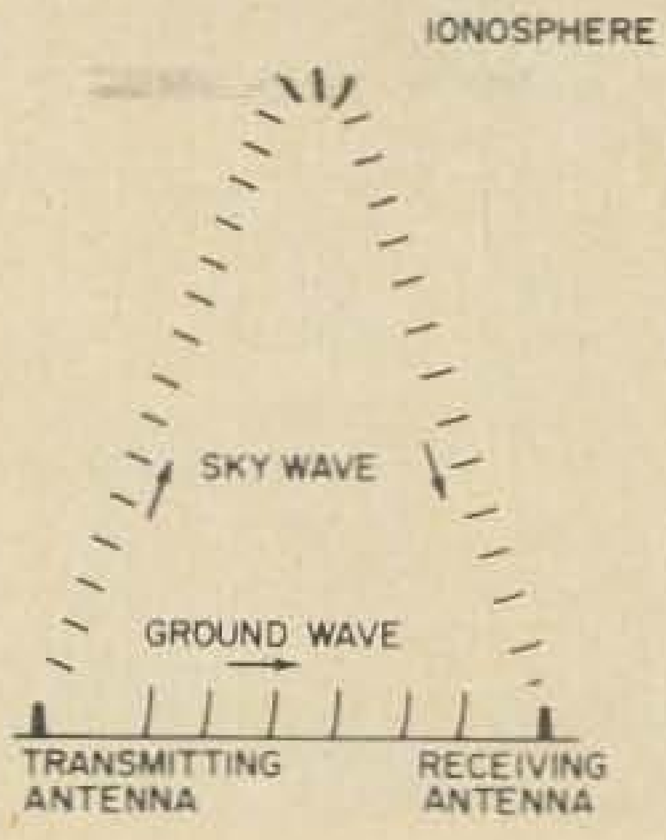


Fig. 4. If the sky and ground waves arrive at an antenna with roughly equal amplitude, a bad fading situation is likely. Good antenna design minimizes sky wave radiation.

160 Meter Antenna Principles

If you are accustomed to antenna work at 20 or even 80 meters your first thoughts about 160 meter antennas may bring a bit of a shock. The 5/8 wave vertical mentioned earlier would be 330 feet high, and the three cophased half-waves would get you up to 780 feet of tower. A mere quarter-wave vertical would be over 100 feet high! Looks like a job for a junior financier to purchase an adequate supply of building materials and a senior engineer to get them all in place without upsetting the neighbors. Fortunately, we can assemble good 160 meter antennas without forming contracting and legal partnerships. But we must understand two key ideas.

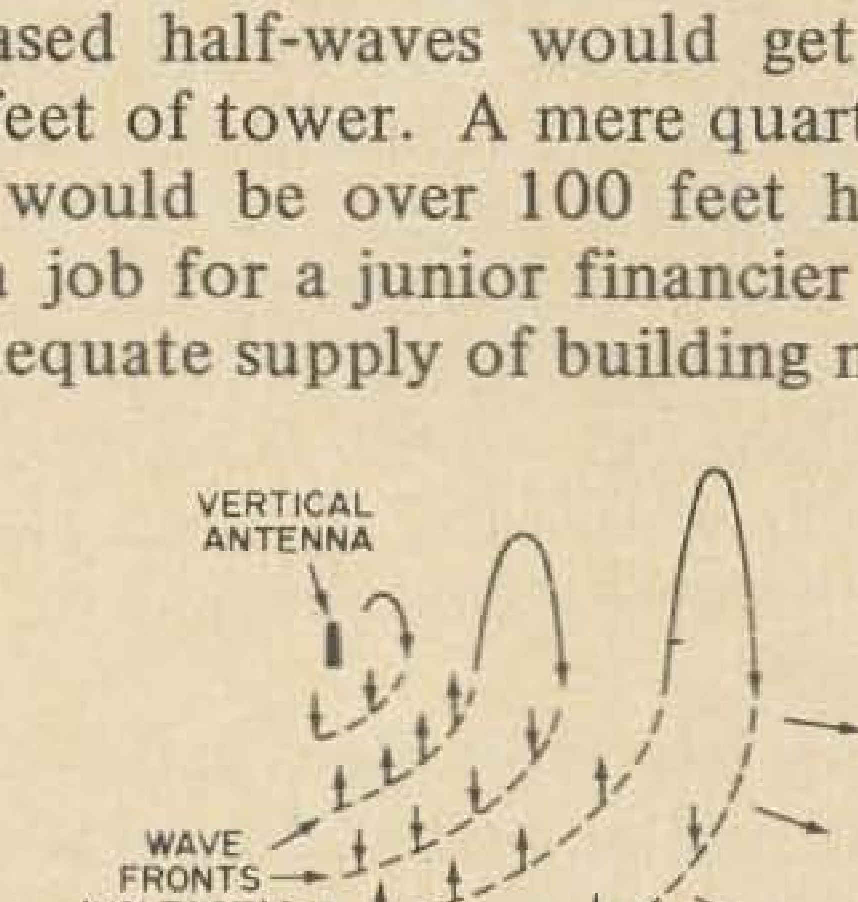


Fig. 5. Here is a partial image of the ground waves radiating outward from a vertical antenna. If the antenna were tilted its radiation pattern would include horizontally polarized components, resulting in an apparent loss of signal strength.

First, as emphasized in the section on propagation, we are concerned with which way the radiation goes, and with its polarization. It turns out these requirements do not conflict, since the vertical polarization we need is most effectively generated by the vertical antenna we can probably build. See **Fig. 5.** This same antenna ideally has zero vertical radiation and if we can only make it tall enough it radiates most effectively toward the horizon. Probably we cannot make it tall enough, but we'll just have to live with that. To see the effects of various antenna heights look at **Fig. 6.**

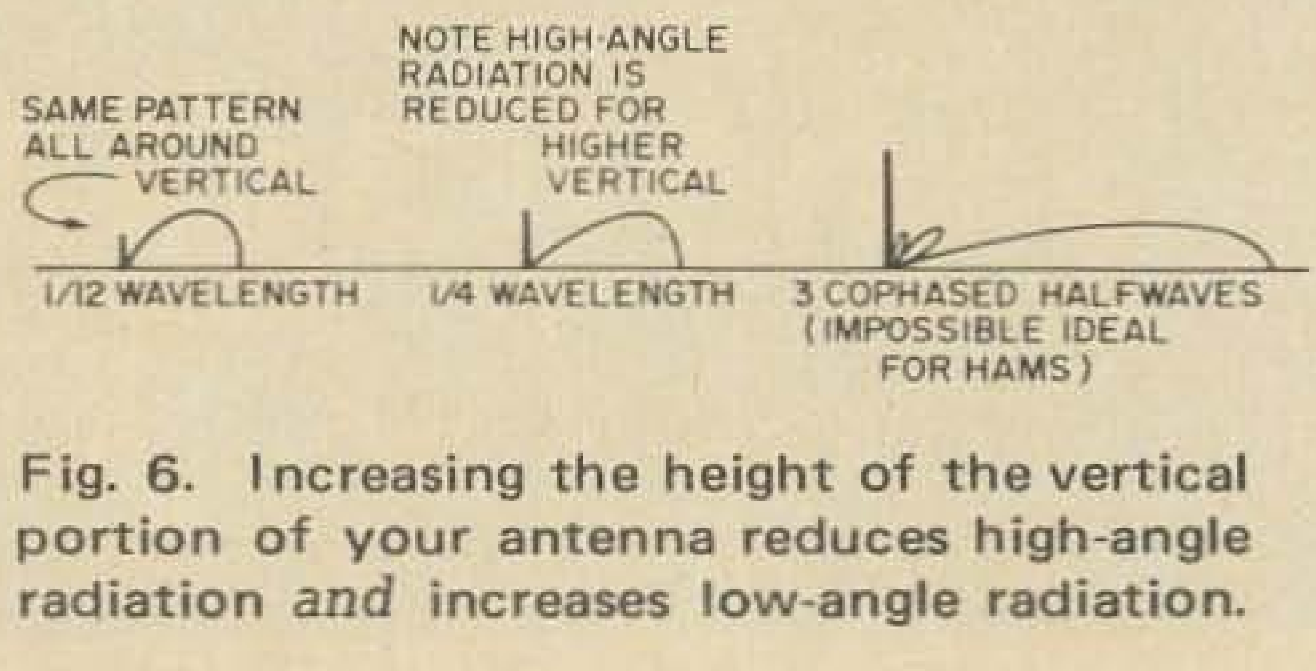


Fig. 6. Increasing the height of the vertical portion of your antenna reduces high-angle radiation *and* increases low-angle radiation.

The second key idea, but not second in importance, concerns matching power into the antenna. Hams use quarter-wave and half-wave dipole elements at the higher frequencies because these electrically special lengths guarantee convenient properties, as illustrated in **Fig. 7.** But it is not true such electrically sizable structures are good radiators *because* they are easy to feed!

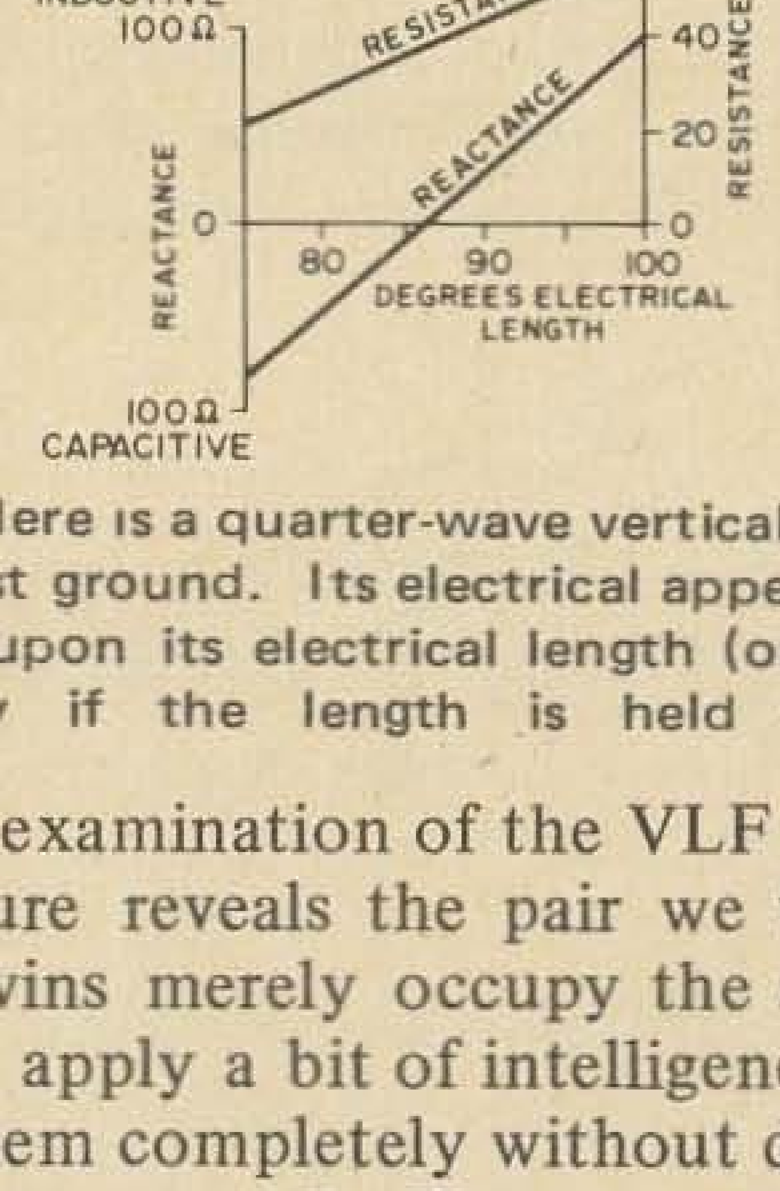


Fig. 7. Here is a quarter-wave vertical working against ground. Its electrical appearance depends upon its electrical length (or upon frequency if the length is held fixed).

A close examination of the VLF engineering literature reveals the pair we think are Siamese twins merely occupy the same cradle. If we apply a bit of intelligence we can separate them completely without disturbing Mother Nature at all. We can make electrically small structures that radiate *rf* power very effectively, if we can solve the feeding problem, and we will have excellent receiving antennas too.

Now we are concerned with the popular VLF problem of feeding electrically small structures. In good engineering style perhaps we decide to start out with an equivalent circuit. Can we draw an equivalent circuit of our antenna even before we have built it? Yes, because the variety of antennas we are likely to construct for 160 meters is not very great, and if we choose the correct equivalent circuit it will work for any antenna anyway. An appropriate circuit appears in **Fig. 8**, which shows an inductance, a capacitance, and two resistances in series. This equivalent circuit relates to our real antenna very simply.

The equivalent circuit shows a complete loop from the coax cable center terminal around to the cable's outer conductor. This is perfectly legitimate, even though we cannot see a wire connection between these terminals in many antennas. The connection is there, completed by the *rf* power that flows in the space surrounding the antenna. Maxwell used the term "displacement current." This current, a voltage, and a magnetic field may be observed in the space between capacitor plates as well as in the space around antennas. If you can accept the completeness of an ac current loop through a capacitor, you can apply the same reasoning to a real antenna in space.

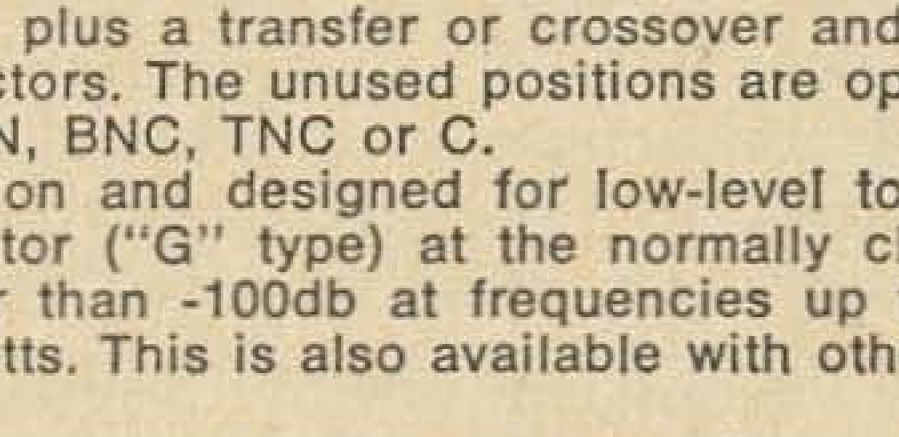


Fig. 8. An equivalent circuit that will express the characteristics of the antenna of Fig. 7, or of any other antenna, at or near a given frequency.

Next, we are concerned with the lumped capacitance, C_e, and the lumped inductance, L_e. This is an approximation of the antenna's real capacitance and inductance, which are distributed along many feet or tens of feet of physical antenna. The approximation works if we suppose we are discussing the antenna at a particular frequency or in a narrow band of frequencies. For instance, if we are thinking about a half-wave dipole fed by twinlead and operating at its resonant frequency, we ignore the capacitive and inductive reactances because at resonance they are equal and opposite in value. On 160 meters we are usually concerned about these reactances since the antenna is probably operating below its natural resonant frequency.

R_c is merely the effective resistance of all the conductors making up the antenna. That includes the very important ground resistance. If we want to achieve the best possible antenna efficiency R_c gets close attention because it sees the same feed current the real radiating part of the antenna sees, but it dissipates that power as heat rather than as *rf* field. R_c will be larger than the dc resistance of our antenna assembly because of skin effect, which confines *rf* current to the surface of the conductor.

This clues us in to a key point. Mere good ground practice is not the best we can do. We want to put up an antenna with the maximum possible amount of current-carrying surface, and that surface should be clean and shiny. We will have to protect it from our polluted and corrosive rainfall with insulation or good paint so that R_c is not gradually increased to some high value.

Finally, and here is the hero of our story, there is R_r. This is the purpose of our antenna, with L_e, C_e, and R_c appearing as unavoidable camp followers. R_r is not a loss resistance, it is the resistance that accounts for the actual radiation of useful *rf* into space. Since this energy seems to be lost from the system the transmitter and the antenna circuit see it as a resistance which dissipates watts as I^2R_r. This is the same familiar rule by which we estimate the watts dissipated by a resistor, and I is simply the current, which you can measure with an *rf* ammeter, fed into the antenna.

Now we can apply these ideas to a particular antenna. We already know our antenna should be as vertical as possible in order to maximize vertically polarized radiation, and that our antenna will be electrically short. This recipe suggests a particular type of antenna, the quarter-wave Marconi. Probably ours will be shorter than a quarter wave. What will this do to our equivalent circuit?

It will make R_c smaller since the current is flowing in less conductor, and it will reduce R_r because our coupling to space is less complete. See **Fig. 9.** The shorter current path suggests L_e will be reduced, and so will C_e, but we can see that C_e tends to predominate since the shortened antenna is approaching a capacitor configuration.

Our shortened Marconi will have reduced radiation resistance compared to a quarter-wave Marconi, and its reactance will be capacitive. We will want to put a loading coil in there somewhere, and our feed system must feed a resistance which may be much lower than the 50 to 300 ohm values we typically expect on the higher frequency bands. When we are facing up to an uncertain situation, what do we need? We need to be able to make good measurements.

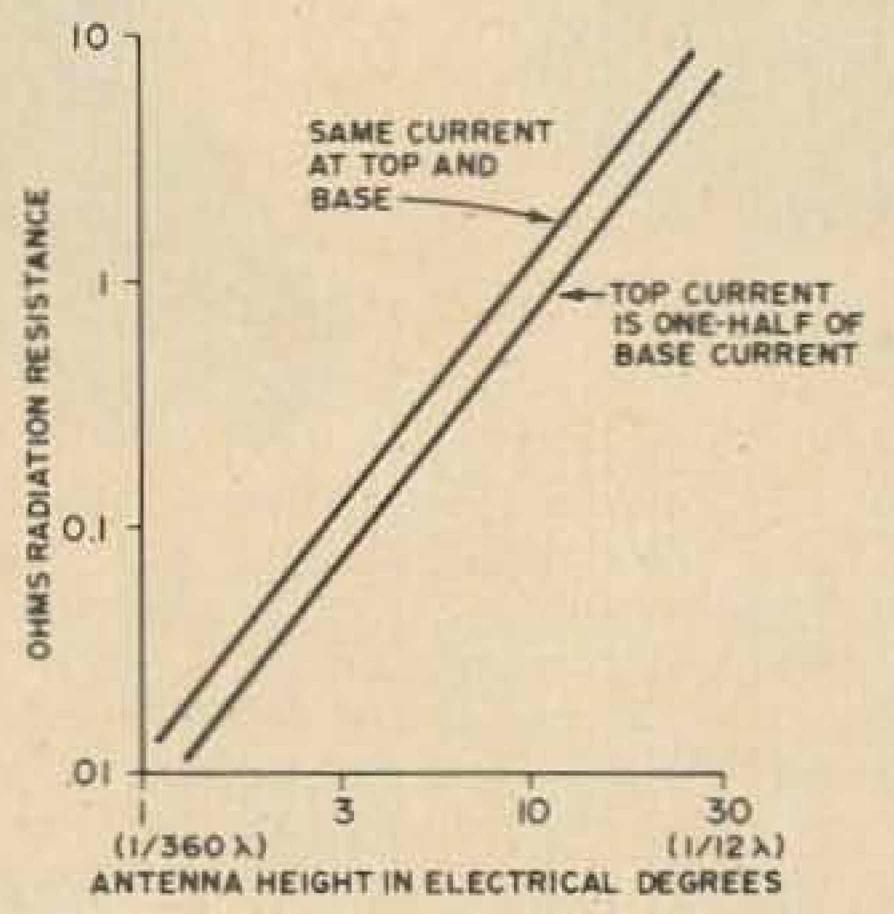


Fig. 9. Use this chart to estimate the radiation resistance of your antenna before you commence construction.

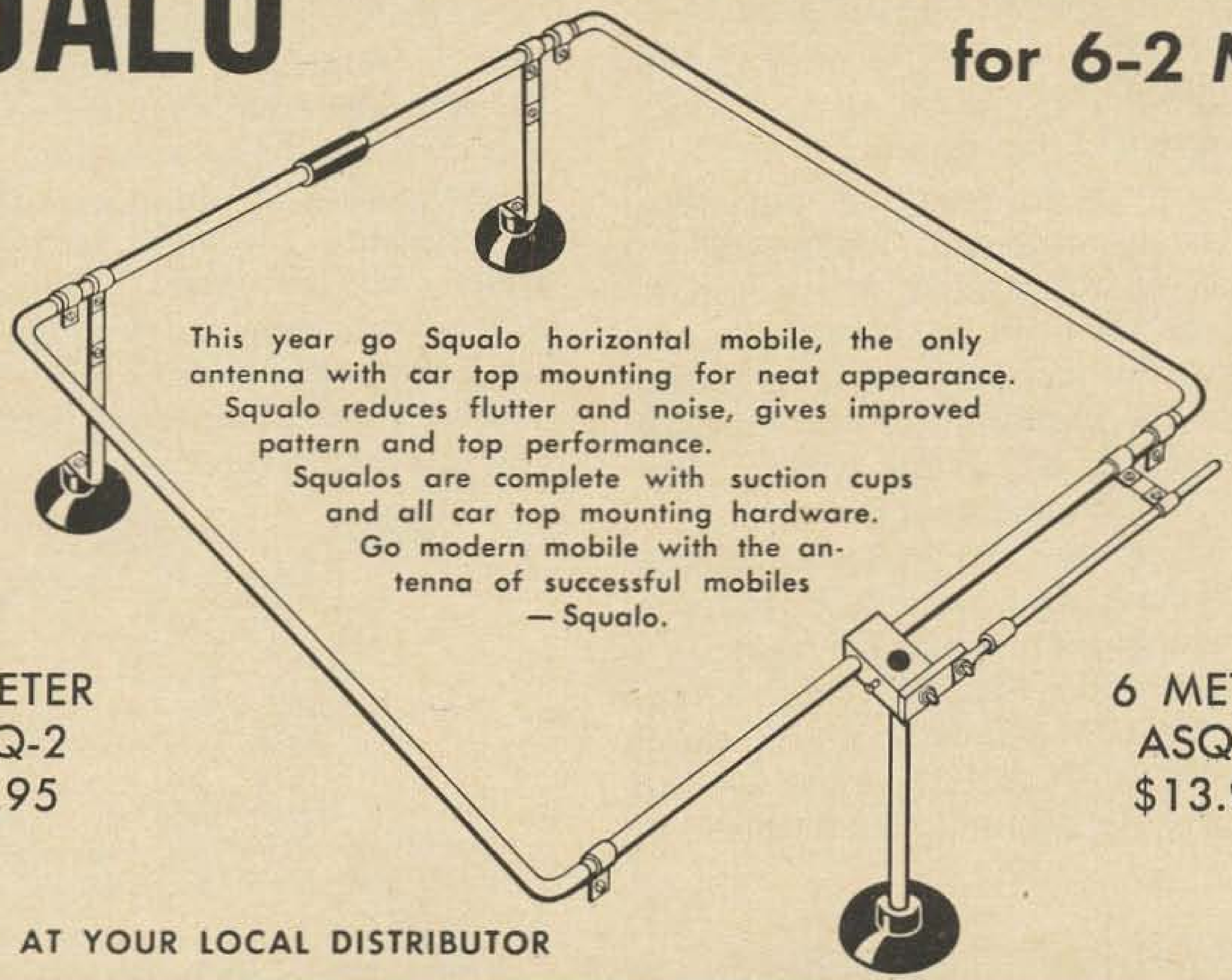
160 Meter Antenna Test Gear

On the higher frequency bands you can set up a cookbook antenna and tune your system with an SWR bridge. Perhaps you can get by on 160 using this approach but I wouldn't recommend it. What if you get a poor swr and your adjustments do not seem to be effective? Then you must proceed blindly, and that is no way to enjoy a bright Spring day. You need an SWR bridge in normal operation but until you have determined what adjustments are "normal" you should have a grid dip oscillator, and some kind of *rf* resistance bridge.

The GDO can be built, borrowed, or it may come along with direct assistance from a friend who already has one and who is interested in your 160 meter antenna project. His views will be different from yours, and this diversity of opinions can be very helpful when dealing with some knotty questions arising from antenna work. But don't tell him he is a part of the project's test gear.

Since *rf* resistance bridges are quite rare you can expect to build your own. It can get its *rf* power from the GDO. The circuit of **Fig. 10** is discussed in detail in "How To Hang a Dipole," in the May 1968 issue of 73 Magazine, and so it gets pretty light treatment here. The present version is optimized for 160 meter antenna work, where resistances will typically be quite low.

Basically, this is a Wheatstone bridge, or a resistance comparison bridge. You will get some meter reading when applying *rf* to the



input loop, and the reading falls to zero when the LH side and the RH side act as resistive voltage dividers reducing the applied *rf* voltage in the same ratio.

This situation arises when the antenna terminals present a purely resistive connection, since the adjustable resistance has negligible inductance or capacitance, and when the variable resistance is adjusted to the same value.

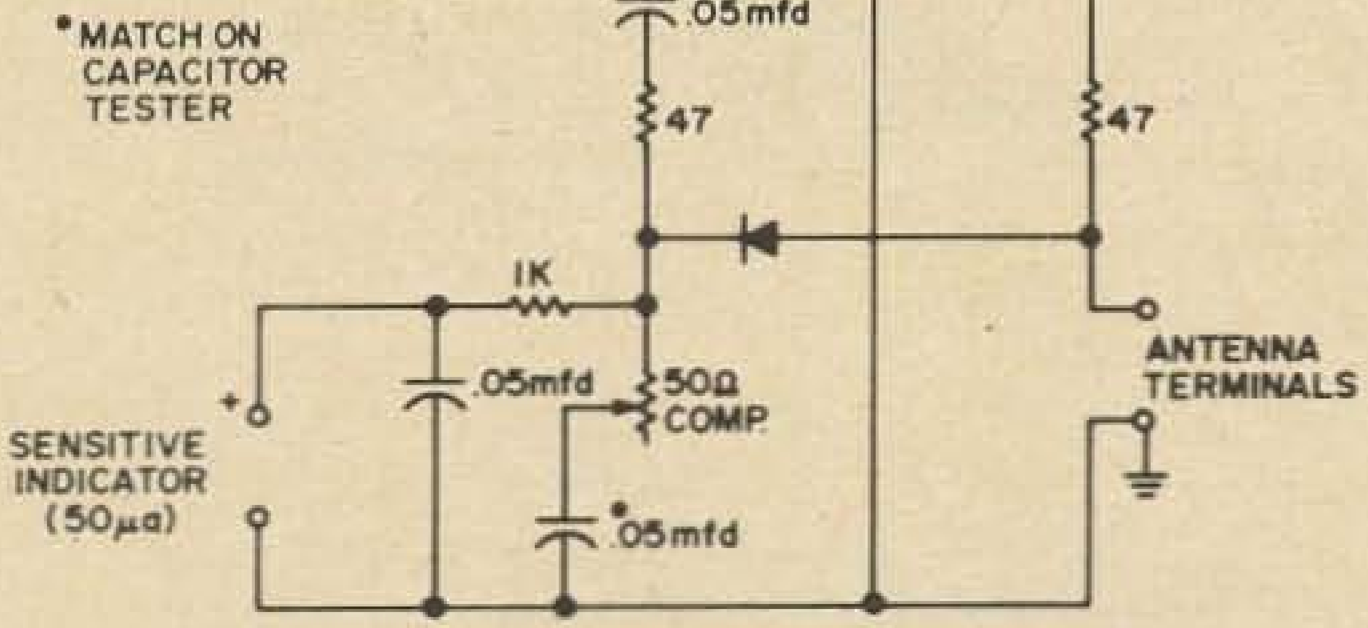


Fig. 10. This simple bridge circuit will measure antenna input resistance at resonance. Remember tolerances on capacitors are commonly very loose. A capacitor checker can do an adequate job of matching.

If you want to put this into a box it makes a handy item, once each year or so. A breadboard assembly, or simply soldering all connections and moving things gently will get you by, and to determine the result of your test you unhook the pot, after nulling, and measure its resistance with a low-range ohmmeter.

Your procedure in applying this gear is suggested by the equivalent circuit of Fig. 8. The best approach goes in two steps. First, you determine the antenna's resonant frequency by dipping it at a high-current point to discover its resonant frequency. Probably you merely add a couple of turns of wire for a coupling loop at the input terminals, and couple in the GDO to this loop. If antenna tuning is indicated, you bring the resonant frequency up or down by appropriate loading coil or capacitance adjustments. And then you apply the bridge to measure the antenna's input resistance, *at the same frequency.*

Since the antenna may have a very low input resistance, you may change its design or use a transformer matching system to increase the input resistance. In this case the *rf* bridge comes into play again to establish that your work has had the intended results. If a certain arrangement was supposed to increase a five ohm input resistance to 60 ohms, and you get a good null with a 60 ohm bridge setting then you know you have achieved your goal. You will be using your antenna while the fellow with only an SWR bridge is still running around with wires, insulators, pulleys, etc.

160 Meter Antenna Construction

Now we are about ready to put up a shortened Marconi antenna. Where will we put it? Since we can place it wherever convenient, it does not need to be very close to the transmitter. In fact, we want it at least a few feet from the building to reduce energy wasted by coupling into house wiring. The possibility of TVI is reduced too.

Having chosen our site and identified a few places where we can attach the top portions of the system, we might make up a sketch something like **Fig. 11**. There is very little detail since we already know about what is available to work with. First we turn our attention to the ground connection.

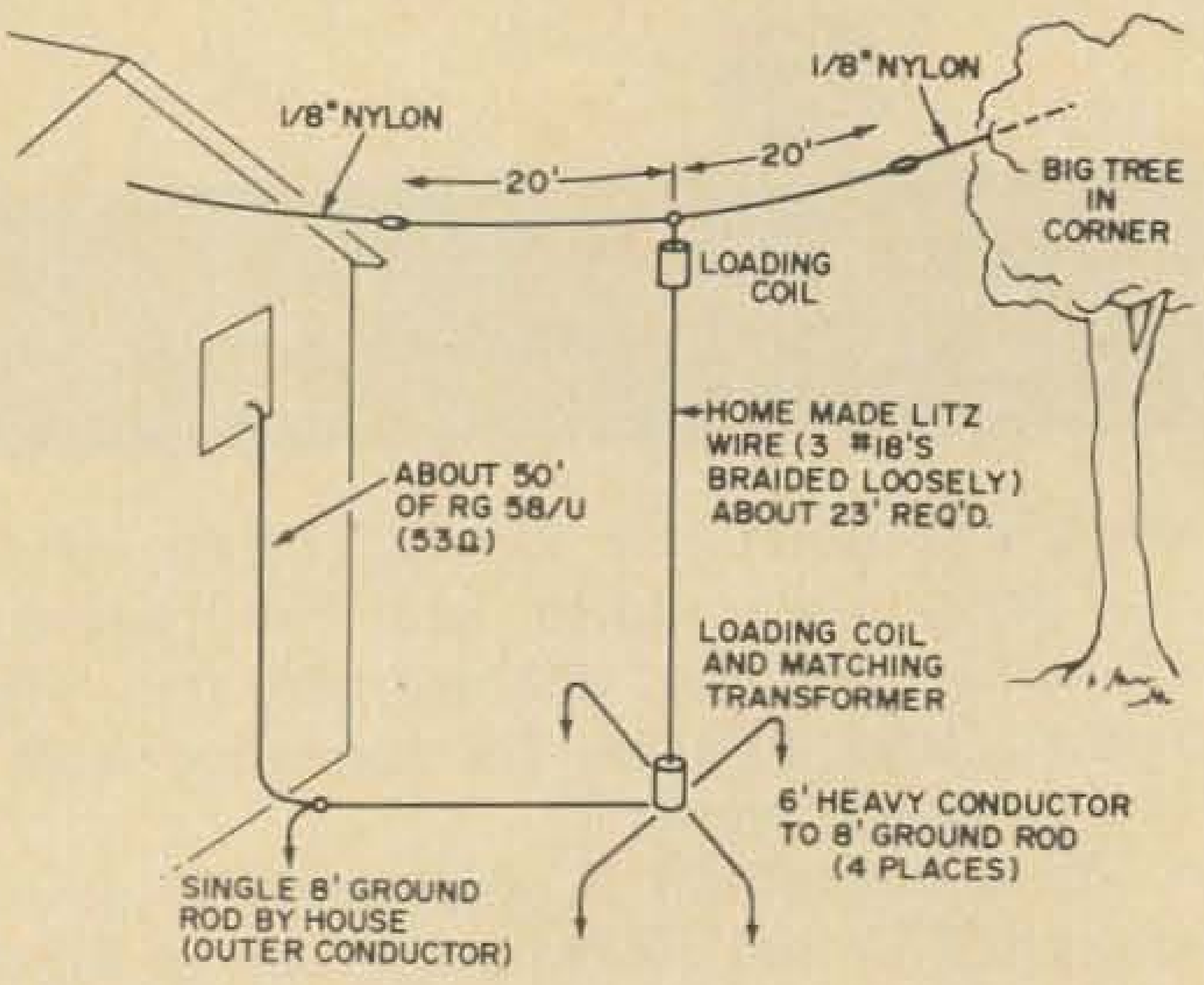


Fig. 11. Ballpark estimate of a real antenna somebody might construct for 160 meters. Note generous grounding.

Because the antenna's radiation resistance will be low, we must have an excellent ground. That could be the subject for another article, but it's basically simple and is well treated in many handbooks. The key points when making a good low-resistance ground are lots of surface contact, and possibly some assistance from chemicals. Remember salt and copper sulfate are plant poisons and may be carried out by ground water to do damage some distance away.

Now, with the ground established, we are ready to start setting up our antenna. The flat top goes up and pulls the vertical portion with it. There is no loading coil, yet. With everything in approximately its finished location we really have a full-scale mockup of our antenna and we are ready for some cut-and-try adjustments. Careful notes and records will help.

Probably the system resonates at too high a frequency. After determining what the resonant frequency actually is, we let the top down and add a loading coil of, say, 20 microhenries. Pulling everything up again, we measure the new resonant frequency, which will be lower. This gives us two points on a graph of frequency versus loading inductance, and we plot this variation assuming a straight-line relationship to choose a new inductance.

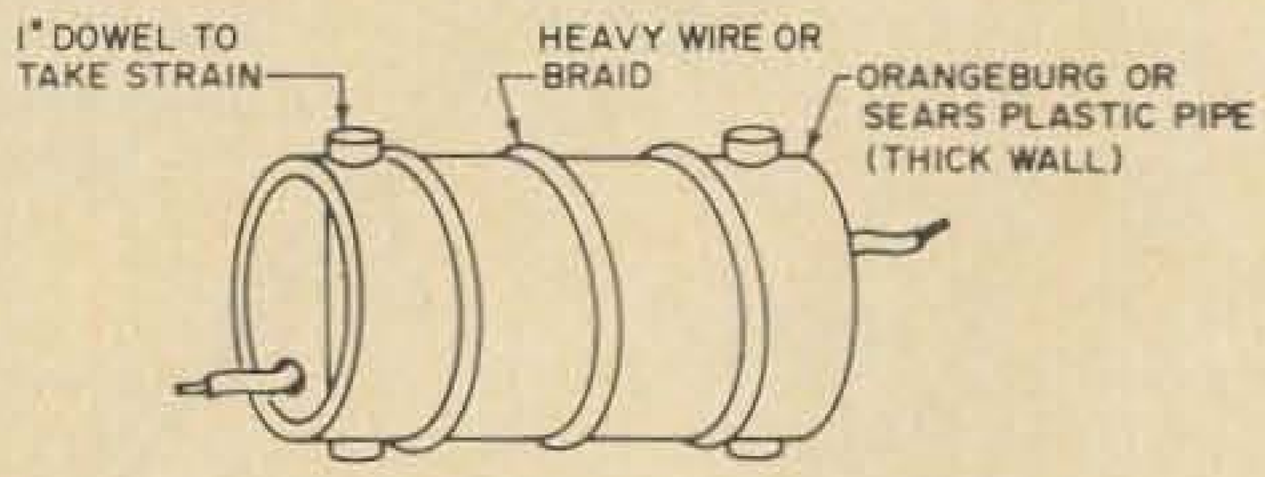


Fig. 12. Sizable loading inductances can be assembled easily from materials available around the house, from Sears, or an Agway farm store.

These three tests should give us an excellent idea of the loading inductance required to bring the resonant frequency down to 2 MHz. Ideally, we want to resonate the system to the top of the 160 meter band, or slightly above that, since we can make final adjustments at the bottom of the antenna without appreciably reducing its effectiveness. We make up appropriate rugged transmitting type inductances, perhaps from #16 vinyl-insulated Sears-Roebuck wire on a piece of Sears plastic sewer pipe as suggested in **Fig. 12**, and assemble the finished antenna.

A final test establishes that we have done the job in a sound workmanlike way, and we wind up with a finished antenna that looks something like **Fig. 13**.

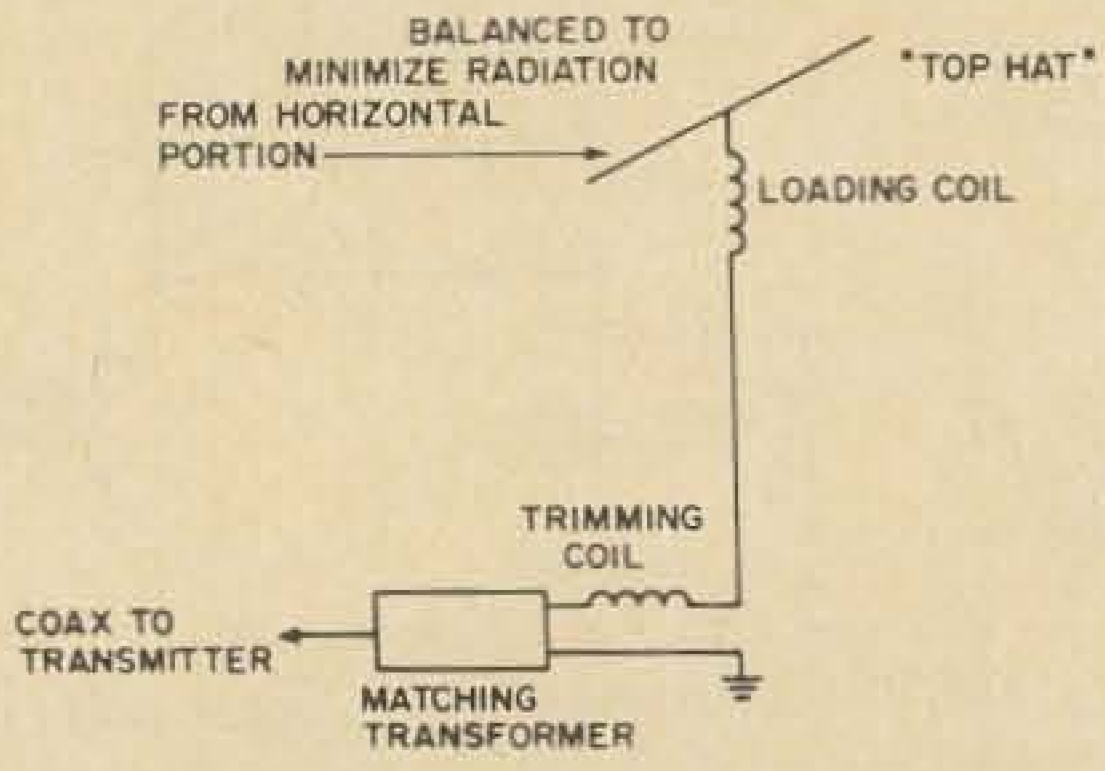


Fig. 13. Electrical appearance of the finished antenna.

Try your understanding of the principles on the two other antenna designs of **Fig. 14** and **Fig. 15**. These are borrowed from the Radio Handbook where their operation is

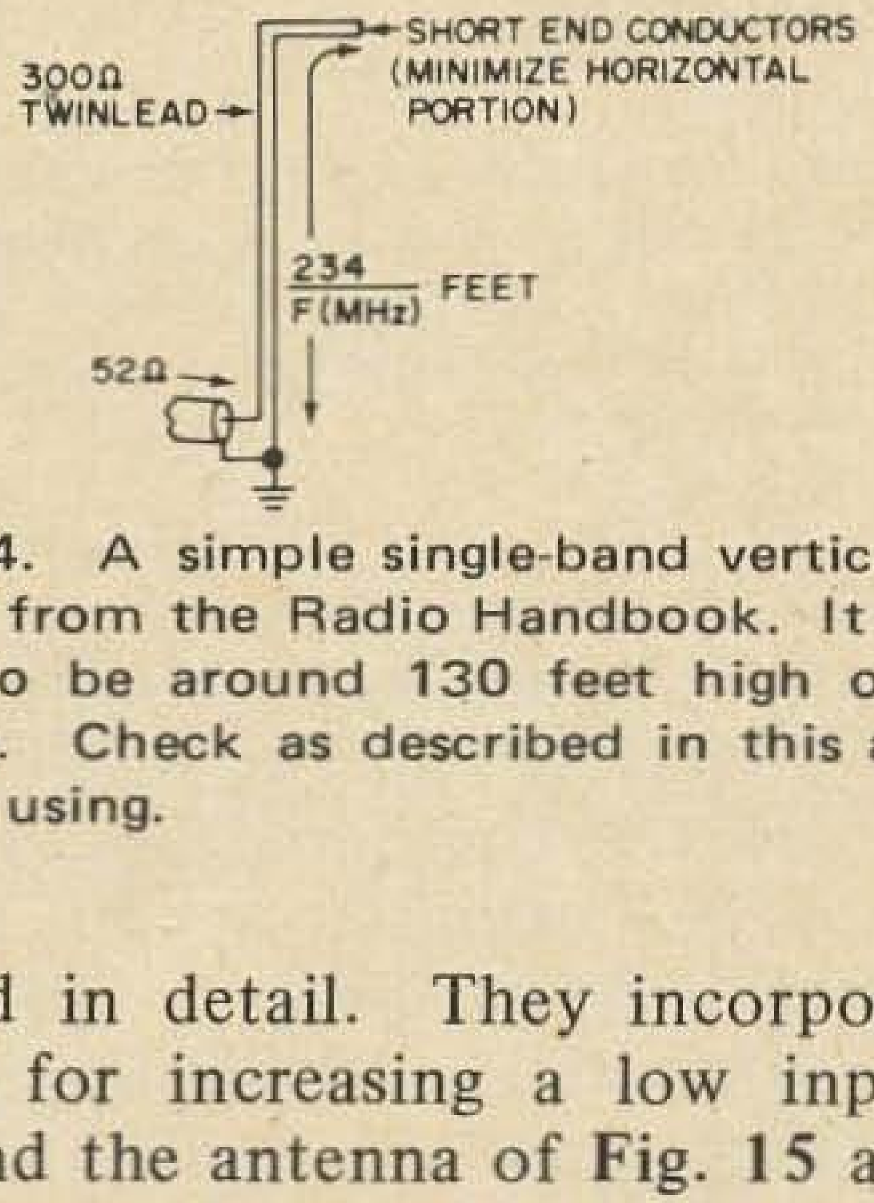


Fig. 14. A simple single-band vertical borrowed from the Radio Handbook. It would have to be around 130 feet high on 160 meters. Check as described in this article, before using.

described in detail. They incorporate two schemes for increasing a low input resistance, and the antenna of Fig. 15 also has a top-loading effect which operates to resonate the system on the lower frequency band.

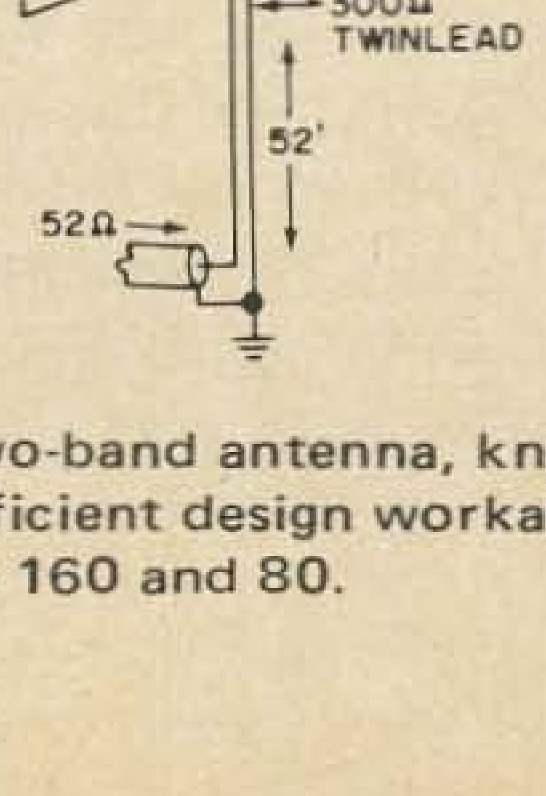


Fig. 15. A two-band antenna, known as the "Multee." Efficient design workable on two bands, such as 160 and 80.

Matching Into 160 Meter Antennas

A 50 or 75 ohm coaxial cable is said to be properly terminated if it feeds a 50 or 75 ohm resistive load. Referring to Fig. 8 again, we see that if the inductive and capacitive reactances are equal the load must be resistive. We guarantee this by checking and adjusting our antenna to resonance at our intended operating frequency. But, looking at Fig. 9 we see our shortened Marconi will probably have a radiation resistance considerably lower than appropriate for the kind of system we would like to use for feeding it. What can we do to improve matching?

A trivial answer is that a series resistor will make up the difference. A 5 ohm R_C plus R_T with an added series 47 ohm resistor

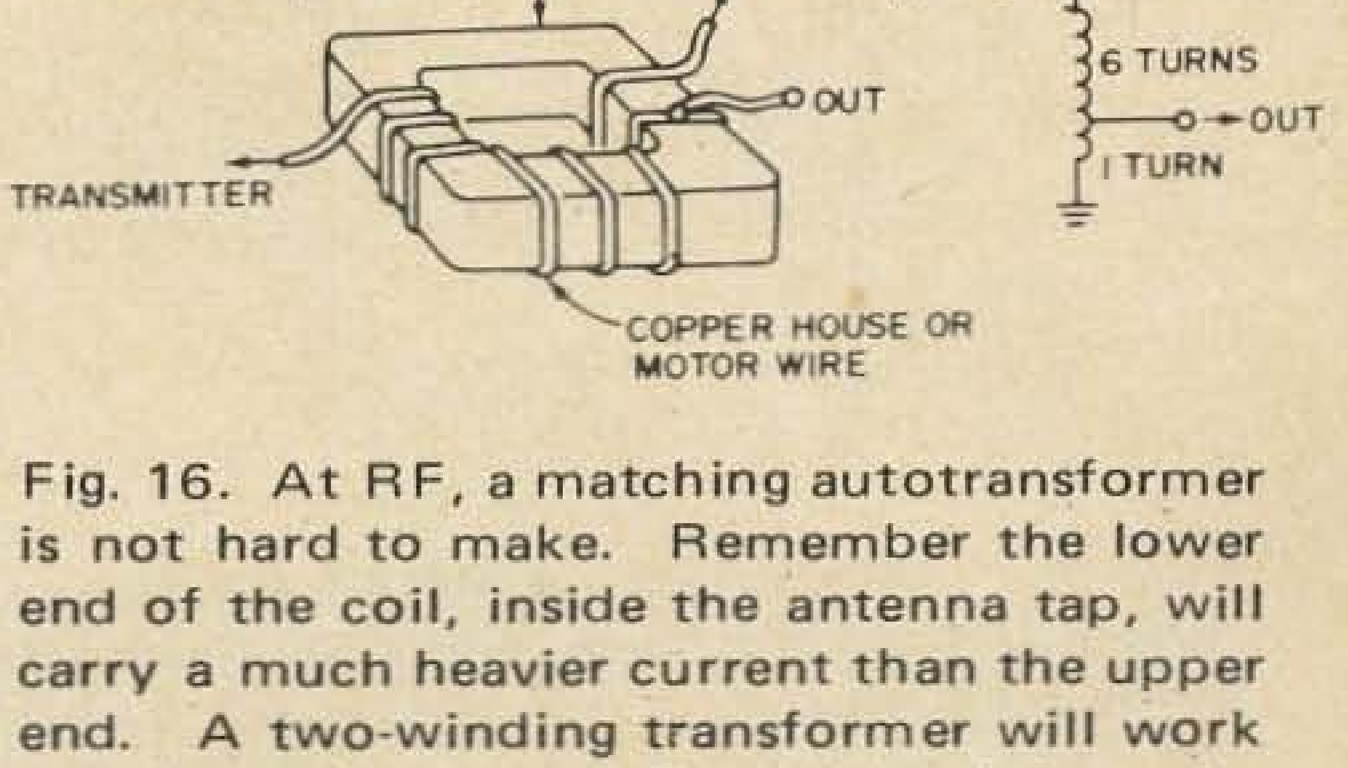


Fig. 16. At RF, a matching autotransformer is not hard to make. Remember the lower end of the coil, inside the antenna tap, will carry a much heavier current than the upper end. A two-winding transformer will work equally well and could avoid mixing wire sizes on the same winding.

makes up 52 ohms, just right for feeding by a standard coax cable. We'll have a matched system, and it won't be worth peanuts.

We can do much better with a nonresonant matching transformer. If you can do it at audio why not *rf*? Imagine we want to match a radiation resistance of 1 ohm up to a 50 ohm cable. We see how to do this in **Fig. 16.** A 7:1 turns ratio will achieve a 49:1 resistance conversion, just what is required. And if we apply a few simple facts about transformers we can determine that our system actually performs as intended.

Our key to sensible tests is that if the transformer is doing its job it will transform a short into a short. That is, our antenna should act the same with its input shorted as with the transformer input shorted. Checking the system's resonant frequency under these two conditions will establish this point.

Once we know the transformer is transforming, we check the system input resistance, looking at it through the transformer to establish that our input is really resistive. Finally, an on-the-air test shows the transformer does not get very warm, indicating core losses are not excessive. Just to make sure, perhaps we check for harmonics or observe the transformer's operation with a scope to discover if the core is going into saturation and generating interference. This is very unlikely. Once we have performed all these tests we have about covered the field, and if we have done mechanically sound work our system will be reliable.

To understand another way of matching the antenna's low radiation resistance, let's suppose we have a vertical antenna that accepts 1 ampere at 20 volts, at resonance. See **Fig. 17.** Now, we split this antenna in two, and feed only one side of it. Since each side carries half the current we feed only one-half ampere into it. But then we will have to double the input voltage, in order to radiate the same power. The effective input resistance, E_{in}/I_{in}, has increased by a factor of four. If we split the antenna three ways we could step up the effective input resistance by a factor of 9.

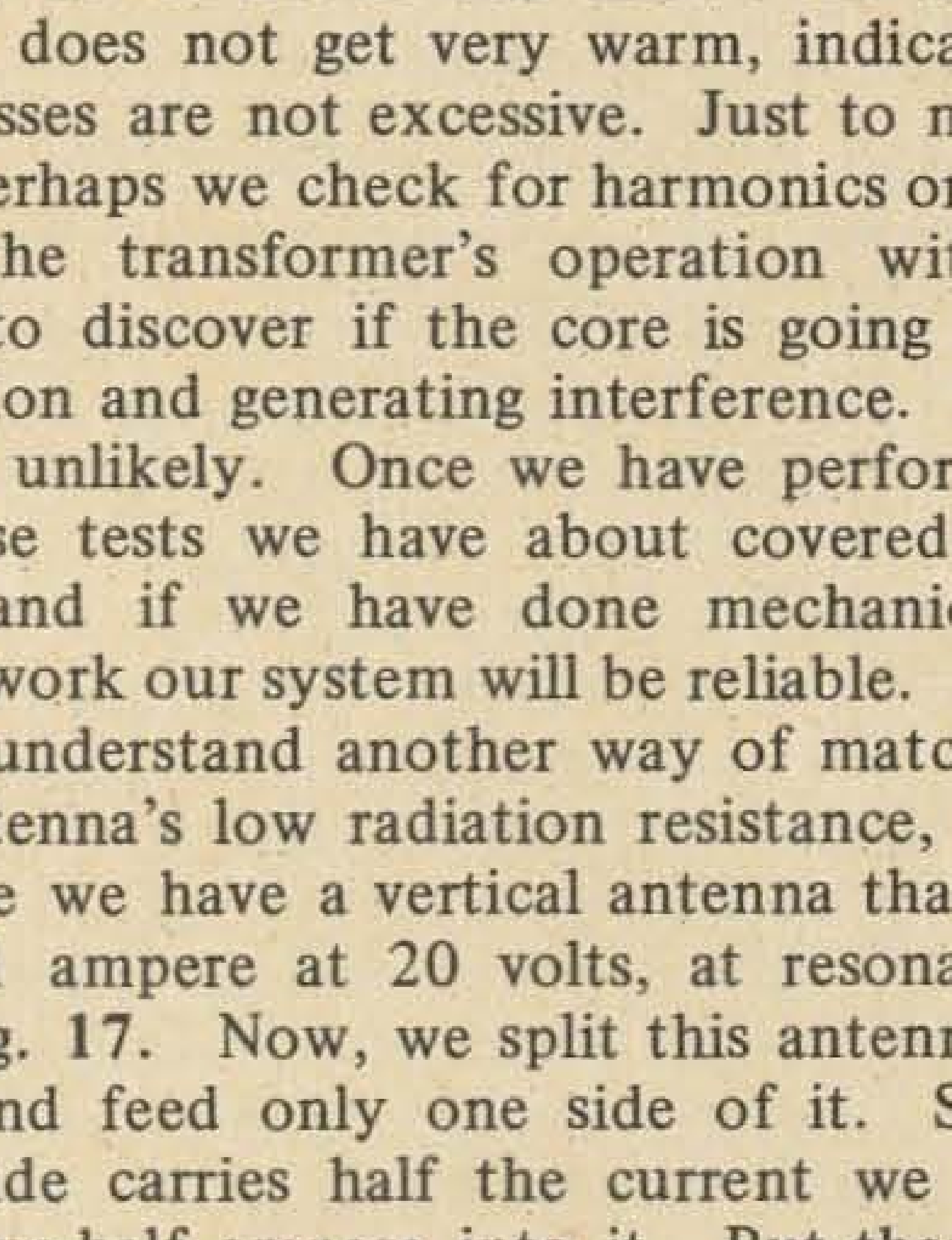


Fig. 17. How to get something for almost nothing. Splitting the vertical increases the input resistance by a factor of four. This is the idea behind the antenna of Fig. 14.

Perhaps that seems strange. But this is the same system used on the higher frequency bands, where a dipole may be divided into two parallel conductors of unequal size, and only one is fed. You see this in Yagi construction. The unequal size acts in the same way as the uneven division of fed and unfed conductors. This arrangement serves in the Radio Handbook antennas shown in **Figs. 14 and 15.**

Finally, we can go to the VLF engineer's trick of using several downleads. This works in the same way as the split-conductor method, but it is more elaborate. See **Fig. 18.**

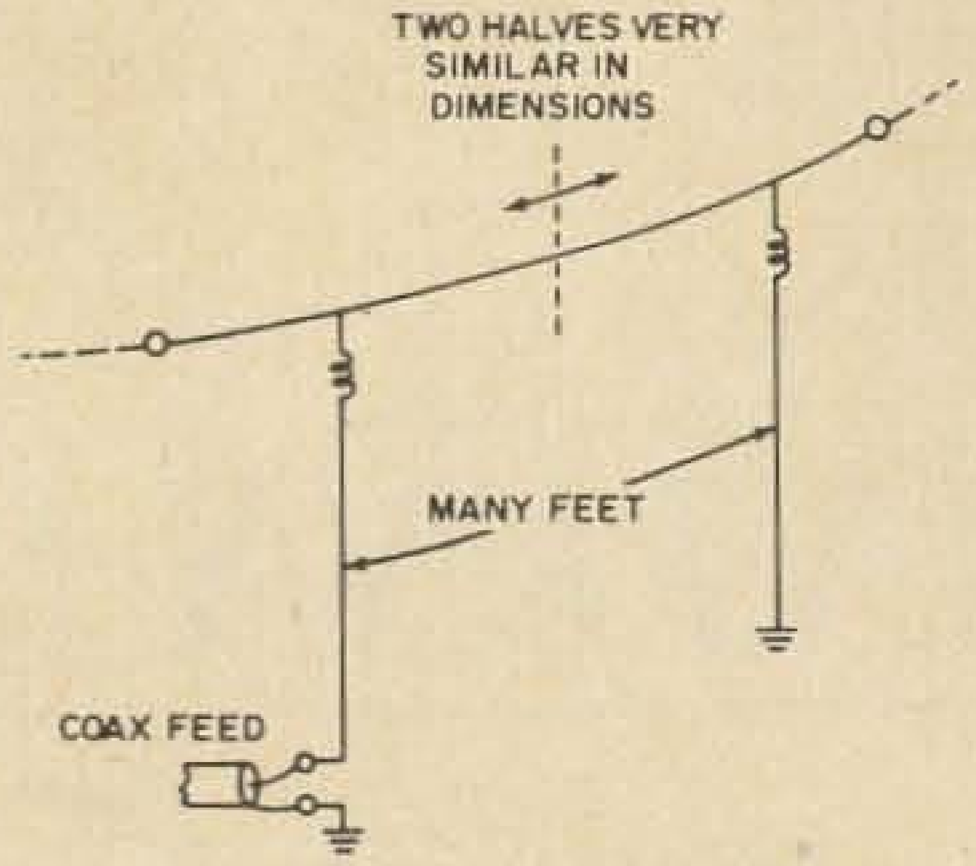


Fig. 18. The idea of Fig. 17 can be used very practically in a more extreme form. Testing and adjustment is more difficult, but this is the way the Navy builds its huge VLF antennas.

Here we have two "downleads", for an apparent radiation resistance stepup by a factor of 4. Since each downlead carries half the capacitive current surging between ground and the horizontal top conductors, ground is less critical. To tune this one imagine each downlead gets half the available top capacitance. Then the inductance per downlead must be twice that of a single downlead, with equal inductance for each downlead. Imagine a commercial engineer setting up a hugh VLF system with several downleads, if you like. I'd rather not! But it is a way to get efficiency from a system that would ordinarily offer high losses.

VLF engineers can get workable efficiencies from antennas for wavelengths in the order of a million feet. Now that mere 530 feet doesn't look so bad after all, does it? So get out there and enjoy that Summer weather while you get your new antenna established.

...W1EZT