the vertical radiator

A discussion of the operating characteristics of simple vertical antennas for 40, 80 and 160

John R. True, W4OQ, 10322 Georgetown Pike, Great Falls, Virginia 22066

On the 40-, 80- and 160-meter amateur bands, a vertical radiator is superior to the horizontally-oriented dipole. It gives omni-directional coverage with extremely low radiation angles when anchored in the earth, which will provide excellent long-range communication and good signal strengths at short range.[1] Further, if properly constructed, it will provide full band, low vswr coverage over the three amateur bands.

balanced horizontal radiator

The balanced horizontal radiator system is one of the most common systems in use. If a half-wave dipole antenna is horizontally oriented in space, free of all other objects, the radiation pattern is like a doughnut at right angles to the axis of the dipole wire. However, if the dipole is situated near the earth (quarter wavelength or less), the ground reflected ray cancels most of the direct ray of radiation at lower vertical angles. Only the higher angles are propagated with appreciable amplitude under these circumstances.

If the dipole is oriented about a half wavelength above the earth, the radiation pattern has two fairly broad major lobes at right angles to the wire in the vicinity of 25-35° above the horizontal. To reduce the major lobe to 10-20° the dipole has to be elevated to approximately one wavelength above the ground. Dipoles have little radiation below 15° in any direction if less than one wavelength above poor earth.

A typical half-wave dipole for 80 meters would be about 125 feet long. If it were made of no. 10 wire (0.1-inch diameter) it would have an extremely high characteristic impedance (over 2000 ohms). This would make an efficient radiator at resonance; however, due to its high characteristic impedance, it would have a very narrow operating bandwidth.

If the two halves of the dipole could be made into a multiwire cage about one foot in diameter, the characteristic impedance would be approximately halved and the bandwidth increased proportionally.

unbalanced vertical radiator

If, instead of a balanced dipole, an unbalanced system fed by unbalanced coaxial cable were used, and further, if the outer conductors of the coaxial cable were unbraided into a plane at right angles to the center conductor, an unbalanced radiator would result. This form of radiator is known as a monopole or unipole. If the center conductor is vertically anchored in the earth it becomes known as a vertical monopole, for obvious reasons. If the length of the center conductor is made an electrical quarter-wavelength long and the plane of outer conductors is also made one-quarter wavelength, it becomes a very efficient omnidirectional radiator at low vertical angles.

When the center conductor is about one-quarter wavelength, the vertical pattern is quite broad and extends from near 10° to about 50° at the half power points with the peak radiation at about 25° above the horizontal. When the length approaches 1/2 wave, the vertical pattern is concentrated between 30° and near 5°, with the peak of radiation near 15° above the horizontal. At 5/8-wavelength, the lobe is concentrated between zero and 20° with the peak radiation about 8° above the horizontal. Additionally, at this height there is a small high-angle lobe near 60°.

At lengths in excess of 5/8 wavelength the low-angle lobe diminishes in amplitude and the high-angle lobe increases until, at a height of one wavelength, the low-angle lobe disappears altogether and the high-angle lobe is at a maximum. See **figs. 1** and **2** for a comparison of the vertical pattern of a typical vertical radiator and a horizontal dipole.

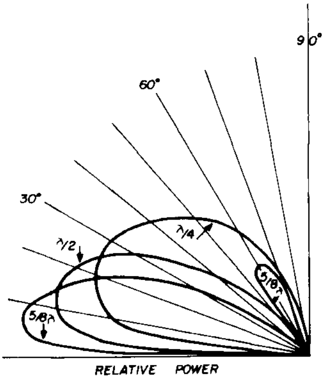


fig. 1. Radiation pattern of the vertical monopole antenna. The pattern is omnidirectional for heights of 1/4, 1/2 and 5/8 wavelength when an adequate ground plane is used.

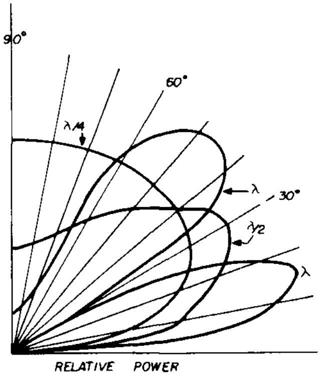
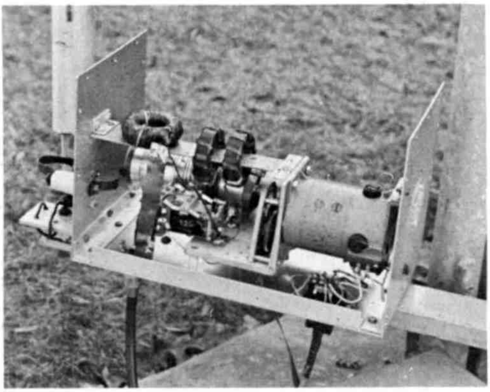


fig. 2. Radiation pattern of the horizontal dipole antenna. Pattern at right angles to the wire for heights of 1/4, 1/2 and 1 wavelength over a good ground.

If the vertical (center) conductor is small in diameter with respect to its length, its characteristic impedance would be a high value. Typically, a quarter-wave vertical conductor at 80 meters, made of 63 feet of no. 10 wire, would exhibit a characteristic impedance of over 1000 ohms. On the other hand, if the vertical conductor were to be made of a metal pole, 1 foot in diameter (30-inch diameter triangular tubing tower is the equivalent), it would have a characteristic impedance near 500 ohms. (This is about one-fourth the characteristic impedance of a thin dipole.) This would result in a much broader bandwidth characteristic and allow the use of the radiator throughout an amateur band without appreciable variation in its electrical characteristics. The bandwidth available for efficient operation is proportional to the radiating conductor's diameter to length radio.

ground plane

Other factors which affect the efficient operation of a radiator are the ohmic (rf) resistance of the system and dielectric losses induced by material of lossy characteristics between the two halves of the radiator. No one in his right mind would erect a dipole and then surround one of the two elements with several inches of lossy material such as grass, soil or clay! Ridiculous? Not at all! For years the designers of vertical radiators have been burying the outer conductor extension of the unbalanced vertical system in the earth "to get a good ground."



Control box located at bottom of the tower. The geared motor on the right drives the voltage-variable capacitor which is nearly hidden by the two toroid inductors. The circuit for the control box is shown in fig. 3.

A good *ground* we do not want. A large plane of highly conductive material that the vertical radiating member can see without intervening lossy dielectric *is* what is needed! The current must flow between the two halves of the system without lossy material in the intervening space, and charge the medium that will carry the signal outward. The *ideal* outer conductor extension would be a continuous plane, at least one-quarter wave long of metal of high conductivity that would completely hide the earth in the near field (most model studies are made this way). Since this approach results in rather poor economics at the lower amateur frequencies a mat of mesh wire and/or a radial wire system, extending outward one-quarter wavelength in as many directions as the budget and available space will allow, will provide an adequate outer conductor extension of the unbalanced system. However, the mesh/wire should *not* be buried deeply.

Since the typical amateur's backyard location of an antenna system must be available for other purposes, as a compromise the radials may be placed into the sod of the grass, as shallow as is possible. They should not present an obstacle course, nor should they be buried so deeply that part of that expensive antenna power is used in warming the back yard.

How extensive should the outer-conductor extension plane be made? First, let's review the things not to do. It should *not* be made by merely connecting the bottom of the vertical member to several rods driven into the earth to get a good ground. Five ground rods 6-feet long (or three ground rods 10-feet long) connected to the tower base is good lightning insurance, however.

The extension plane need not be made one-quarter wavelength long in all 360° directions of the radial system. If an omnidirectional pattern is a requirement it should be about $\lambda/4$ in all directions but this is not mandatory if some pattern distortion is permissible or desirable. The individual wires need not be of large diameter if there are enough of them to satisfy the area and conductivity requirements indicated below.

Now, let's think of some of the things that should be done. The outer conductor extension place of the unbalanced vertical radiator should be made of material that has high conductivity. Also, between the base of the vertical and the extension plane the connecting conductors should be made of many large cross-section wires to reduce the chance of losses in this high-current part of the system.

The extension plane should have an area (total) approximately equal to the area of the vertical member. To build a capacitor with several square units of area on one plate and a single square unit of area on the other would not be good practice. A radiator is an L-C circuit; the length of its elements provide the inductance and the area of its members provide the capacity. Therefore, they should be roughly equal in area and length. If necessary, use wire matting (fence wire) near the tower base (10 to 15 feet out) to augment the radial wires.

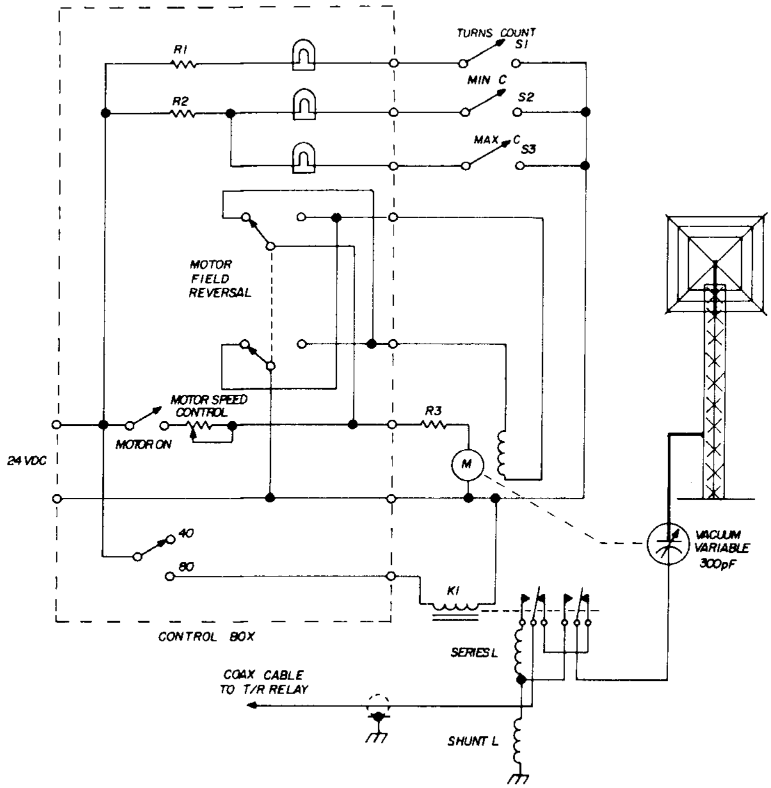
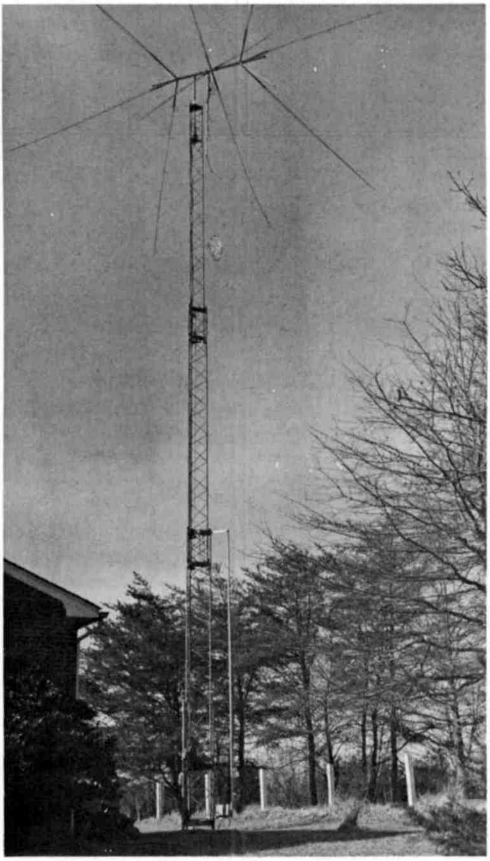


fig. 3. Electrical control system for the 40- and 80-meter vertical antenna. Microswitches S1, S2 and S3 are limit switches actuated by the motor system, which control the pilot lamps. R1 and R2 are pilot-lamp current-limiting resistors. R3 controls maximum motor speed. The motor is a 24-volt unit geared down to drive the vacuum variable capacitor.

If the radial wires are spaced not more than 0.1 wavelength at a distance of λ/4, they will intercept about 95% of the energy (16 radials meets this requirement). This is not a perfect design but will provide a good extension plane for the outer conductor. If the mesh mat is made of fence wire of the type that has each crosswire welded to the longitudinal wires it will provide a high capacitance at the base of the vertical radiator.

If some directivity is desired it may be concentrated in one direction both in length and spacing. Do not overdo the length, however. There is a point of diminishing returns beyond 3/8-wavelengths long.[1]

Excellent results can be obtained by using multielement, multiband, rotatable beams on 20 meters and above, especially if they are mounted on top of a tower that gets them far enough above the earth for low angle radiation (50 to 60 feet). They can be purchased or constructed at a nominal price. Also, they can be made rugged enough to withstand rather heavy weather.



The W4OQ vertical-tower antenna system that covers all bands, 80 through 10 meters.

For the lower frequencies it is nearly impossible to get a large enough beam, with rugged characteristics, up a full wavelength in height for low-angle radiation, without excessive expenditure of funds and effort.

These are the reasons that this article is directed toward the use of the vertical radiator on 40 meters and lower. Further, the use of a beam supporting tower for the vertical member of the radiator is recommended as a bonus with minimum additional expenditure.

base impedance

There are many charts which show the characteristic impedance, as well as the resistive and reactive components, for the *ungrounded* vertical radiator when fed at the base. However, there are several reasons why the ungrounded vertical radiator is impractical for use by the radio amateur. For one thing, any static level and/or lightning strokes in the vicinity would channel this collected energy directly to the equipment to which it is connected. Also, any use of the tower for other purposes, such as for mounting hf or vhf beams, would require all the cables to be routed through a decoupling device at the base so that these cables would not short out the base insulators. The tower would almost certainly have to be guyed in order that too much stress will not be placed on the base insulators.

Whether the tower is ungrounded or grounded, towers that require guys should be insulated from metallic guys. These guys must be broken up with egg insulators into non-resonant lengths to reduce pattern distortion. Non-conductive guys of polypropalene are relatively invisible to rf at high frequencies and are reputed to be quite strong and inexpensive. Nylon stretches too much to be considered for use in tower guying.

Also, whether the tower is guyed or unguyed, any rf and control cables from the beams down to the base, should be routed inside the tower structure all the way to the bottom to reduce pattern distortion. Additionally, they should be routed underground a few inches from the tower base to the operating position. Here is a good place to use that lossy earth. It will attenuate any rf on the outside of the cables. This will also assist in TVI reduction.

There are few charts available for feed impedance versus tower heights for the grounded tower vertical radiator. Although there are too many variables in such a system to make an accurate prediction of the feed impedance some generalities can be stated.

A grounded-base tower can be easily shunt fed by the use of either the delta-or the gamma-type feed system. The delta system will radiate a little and distort the radiation pattern. Therefore, it is not considered practical. The gamma system is an excellent choice for shunt feeding the grounded radiator. Its feed impedance can be adjusted by changing the length of the vertical member. It can also be adjusted a small amount by changing the diameter and spacing of the gamma rod. In all cases where the gamma rod is less than one-quarter wavelength long, it will show inductive reactance. This reactance can be cancelled by a series variable capacitor. Typical R ± jX readings for various lengths of gamma rod and vertical antenna heights are given in **table 1**.

table 1. Typical resistance and reactance values for various lengths of gamma rods and vertical antennas.

tower height (wavelengths)	gamma length (wavelengths)	resistance (ohms)	reactance (+j ohms)
0.25	0.1	5-10	200-300
0.5	0.2	40-80	700-1000
0.5	0.25	over 500	over 1000'

note: The above readings were made with a fence-wire ground mat (two lengths, 100-feet long by 3-feet wide). The tower height was varied from 22 to 54 feet (a 3-element tri-band quad mounted on top). Another tower, ground plane or beam setup will have a different feed-point impedance but it should be near those figures isted above.

From **table 1** it becomes obvious that a gamma length too near one-quarter wavelength is to be avoided, especially if the vertical radiator is near one-half wave. At the other extreme, if the gamma rod is much shorter than 0.1 wavelength and the tower is well below one-quarter wave high, the feed-point resistive component may be so low that transformation to the coaxial-line impedance may be difficult.

If all three lower frequencies available to the amateur are to be used on one vertical antenna, it is recommended that the two higher frequencies be used with one gamma rod, and that a second gamma system be provided on the opposite (physical) side of the tower to reduce reaction between them. This second gamma system can be made physically longer on the tower than the other one which will increase the resistive component.

measurements and matching

After the gamma matching system has been installed the measurement of feed point reactance and resistive components can be accomplished by use of a commercial or home-made rf impedance bridge.[2] Once the electrical characteristics on each amateur band have been determined, the design of the reactance cancellation and resistance matching transformation to the coaxial feed impedance can be solved by the use of a graphical technique.[3] This technique requires no more exotic tools than a straight edge, a compass and graph paper. The mathematics required will not exceed simple arithmatic. Every amateur interested in antenna work should add this valuable set of tools to his experience and knowledge.

Next month I will present some practical solutions to the construction of the vertical radiator and its ground plane. The use of the rf impedance bridge and solution of impedance matching by use of the graphical method will also be shown. A practical control system using a motor-driven vacuum-variable capacitor to cancel the reactance will be explained. Additionally, a switching system that will allow complete remote control of one vertical radiator over the 40- and 80-meter amateur bands will be illustrated.

references

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2. J. 'Hall, K1PLP, J. Kaufmann, WA1VQW, "The Macromatcher," *QST*, January, 1972, page 14.

3. I.L. McNally, W1NCK, H.S. Keen, W2CTK, "Graphical Solution of Impedance-Matching Problems," *ham radio*, December, 1969, page 26.

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