

The Ground-Image Vertical Antenna

BY JERRY SEVICK,* W2FMI

A RECENT JOB transfer and the subsequent move into a new neighborhood permitted me to review my antenna needs in a different light. I wanted to avoid, or at least minimize, the problems and difficulties involved in reinstalling my 40-foot tower and Yagi beam antenna at the new location. Even though a beam antenna supported at the modest height of 40 feet is a compromise (a 20-meter beam should be higher to be really effective), it still can be an obstacle to good neighborly relations, at least if your neighbors don't appreciate the ecological beauty of such an installation. Moreover, even that modest sort of an installation presents quite a number of engineering problems.

This report presents the results of the first phase of my investigation to find a less conspicuous but equally effective antenna for use at the new location. I hope it will provide suggestions for those faced with a similar problem. At the least, it may be of some value to those with a general interest in the subject of antennas.

* Technical Relations Manager, Bell Telephone Laboratories, 600 Mountain Ave., Murray Hill, NJ 07974.

The first part of this article deals briefly with theoretical considerations, the second with experimental results on quarter-wavelength and five-eighths-wavelength verticals, and the third on the test equipment. It should be pointed out at the outset that the information presented here is the work of a hobby and as such cannot be exhaustive. It is hoped that others will repeat some of the experiments, extend the work, and report the effect in practice of a ground-plane system above 3 MHz. To my knowledge such practical data has not been reported.

Theoretical Considerations

A beam antenna possesses the advantage of gain and directivity. Nevertheless, its DX capability is determined primarily by its vertical radiation pattern. A large portion of the radiated energy should be directed between 5 and 25 degrees from the horizon.^{1,2} Horizontally polarized antennas yield lower angles of radiation with increase in height above the ground. This is a result of the interference pattern created by reradiation from the earth's surface. Since the earth is a somewhat conducting medium, the electric field tangential to the surface must be approximately zero. This "boundary" condition is brought about by the induced surface currents which create an electric field of opposite phase. This field then combines constructively and destructively with the initial radiation from the antenna. A model for this condition is an image antenna of opposite phase below the earth's surface at a depth equivalent to the height above the surface.³ In order to get a lobe below 15 degrees, the antenna height must exceed a wavelength. This is greater than 60 feet on 20 meters.

On the other hand, a vertical antenna, in the ideal case, possesses an image which is in phase to produce a lobe tangential to the earth's surface. Only when the antenna length is increased to a wavelength, or multiple thereof, does the tangential lobe disappear. This is true whether the antenna is on the ground or suspended in space. Therefore, a vertical beam, i.e., an array of vertical antennas coupled together with an appropriate feed system, on the surface of the earth, seemed to me to be the logical choice for my new installation

¹ Terman, *Radio Engineering*, McGraw-Hill, New York, 1947, p. 651.

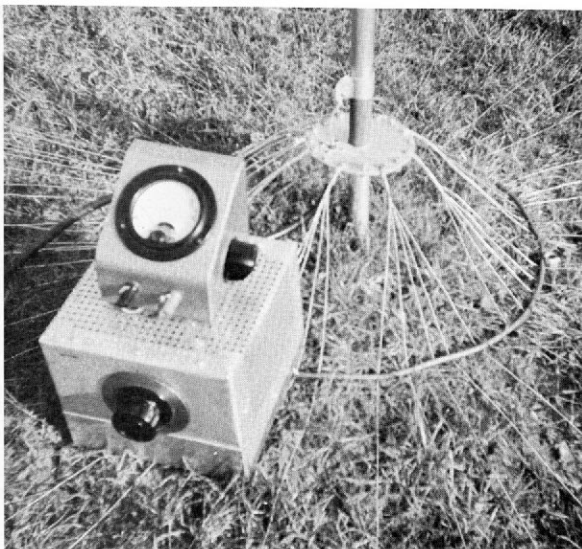
² Friis, Feldman, and Sharpless, "The Determination of the Direction of Arrival of Short Radio Waves," *Proceedings of the IRE*, Vol. 22, No. 1, January, 1934.

³ Williams, "Antenna Theory and Design," *The Electrical Design of Antennae*, Vol. 2, Second Edition, Sir Isaac Pitman and Sons Ltd., London, p. 126.



The 20-meter vertical antenna in the foreground, and the 26-foot test tower.

The base of the vertical element of the antenna and the impedance bridge. Forty radials, in bundles of 5, are fastened to the aluminum base plate, and are tied down with a ring made from copper tubing.



since it would appear to meet the following objectives: The system should

- 1) Exhibit a minimum profile.
- 2) Be easy to install and tune.
- 3) Offer a low angle of radiation.
- 4) Not require a large outlay of money.

I proceeded, therefore, to construct an array with four vertical elements. When my tests were begun, it immediately became apparent that the simple procedures I was using were inadequate to cope with such a complex system. I had to start anew to develop a test procedure and to build some suitable test equipment. The logical step was to backtrack to a single vertical antenna and use it as a standard on which to develop some basic test standards. As discussed subsequently, I found that relatively simple equipment, e.g., a simple impedance bridge, a field-strength meter, and a test oscillator, gave me all of the data about the system that I needed.

It is important to note that a true ground-image antenna differs substantially from a ground-plane antenna system which relies merely on a few $\lambda/4$ radials above the ground. A true ground-image system results when a sufficient number of radials are used and an image of only the vertical section is sufficient to describe it. Considerable information^{4,5} is available on ground-image systems for verticals operating below 3 MHz. The results have shown that some 100 radials of $\lambda/2$ in length, buried just below the surface, provide an adequate ground system. At higher frequencies, the dielectric effect of the earth becomes important, resulting in severe discrimination of radiation or reception at very low angles.^{6,7} At low angles, the waves not only suffer by absorption, but also by a change in phase which results in destructive interference. Since little specific information was available at higher frequencies, the objective of the

present work was to measure the input impedance and vertical radiation pattern at low angles of a vertical antenna as a function of the number of radials, in order to determine the feasibility of a vertical-array system as a competitor to beams at high elevation. The results of my tests were most gratifying. I found that many of the "rules of thumb" which have developed and have been perpetuated to the point where they are practically taken for granted were more myth than truth.

Experimental Results

The classical paper on radial systems, which reports experimental results at 1 and 3 MHz, indicates that a large number of radials 0.4λ long should be used.⁸ This appeared to be a good starting point for a 20-meter vertical. Accordingly, to check the number of radials needed, I used eight bundles of wires, each 25 feet long, and each made up of five No. 18 copper wires. Each bundle was

⁸ See footnote 4.

⁴ Brown, Lewis, and Epstein, "Ground Systems as a Factor in Antenna Efficiency," *Proceedings of the IRE*, Vol. 25, No. 6, June, 1937.

⁵ Wait, "Input Resistance of L. F. Unipole Aerials," *Wireless Engineer*, May, 1955.

⁶ Feldman, "The Optical Behavior of the Ground for Short Radio Waves," *Proceedings of the IRE*, Vol. 21, No. 6, June, 1933.

⁷ Jager, "Effect of the Earth's Surface on Antenna Patterns in the Short Wave Range," *Internat Elektron Rundschau* 1970, Nr. 4.

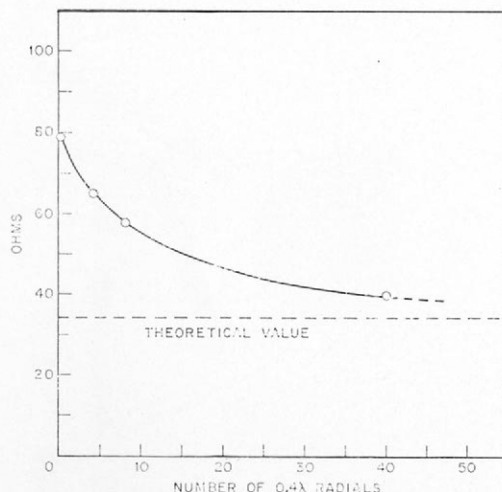


Fig. 1 — The input impedance of a 20-meter quarter-wave vertical antenna as a function of the number of radials 0.4λ -wavelength long. The 4 and 8 radials consisted of bundles of 5 wires of No. 18 gauge. The 40-radial point was obtained by fanning out the 8 bundles.

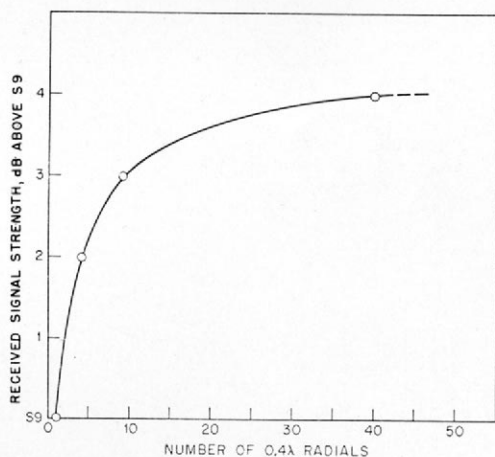


Fig. 2 — The improvement of low-angle radiation of a quarter-wavelength vertical antenna on 20 meters as a function of the number of added radials. A test oscillator was mounted on a wooden tower four wavelengths away at an elevation angle of 6 degrees from the base of the vertical.

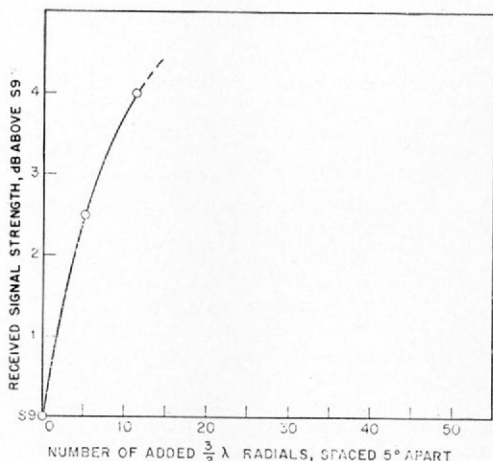


Fig. 3 — The result of interlacing $\frac{3}{2}$ -wavelength radials in a particular direction. Data were obtained by using a test oscillator on a wooden tower eight wavelengths away, at an elevation angle of 3 degrees from the base of the vertical. The results indicate the advantage of longer wires and the possibility of directional properties of a nonsymmetrical radial system.

bolted to a $5 \times 1/4$ -inch aluminum plate as shown in the photograph. I was then able to use each bundle as a radial, measure the input impedance of the system, and then separate the bundles, wire by wire, to increase the number of radials in the system.

Fig. 1 shows the input impedance as a function of the number of radials used. Measurements were made with a simple impedance bridge. (Its construction is discussed later.) The antenna was resonated before each measurement was made, and the difference between the 40-radial system and the 8-radial system resulted only by fanning out the bundles of wires. This technique points out another important feature of ground systems and refutes one of the old myths: since the current carried by the radial system is equally divided among n radial elements, each radial is required to

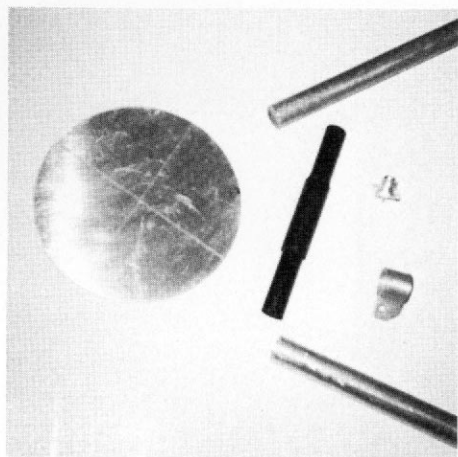
carry only $1/n$ of the total current. This means that relatively small diameter wire is perfectly adequate.

Moreover, it was found that at the higher frequencies it is best to keep the radials near the surface of the ground. Radials buried more than a few feet become less effective! Thus, you should not rely on the old admonition that radials should be six feet down to be effective. I found that burying the wires slightly below the surface is the best way of installing the system. Mechanically the radials can be nailed down, electrically they are most effective, and esthetically they provide little interference to a healthy stand of grass.

It will be seen from Fig. 1 that the input impedance for a vertical antenna is drastically affected by the number of radials. Many radial wires are necessary to prevent an excessive loss of power and to provide a convenient input impedance. Fig. 1 also shows the theoretical impedance limit for an antenna having an effective height-to-radius ratio of 300.⁹

Fig. 2 shows the effect on low-angle radiation as a function of the number of radials. These data were obtained by placing a test oscillator on a wooden tower, four wavelengths away. A photograph shows the 20-meter vertical and the 26-foot wooden test tower.

⁹ King and Harrison, "The Impedance of Short, Long, and Capacitively Loaded Antennas with a Critical Discussion of the Antenna Problem," *Journal of Applied Physics*, Vol. 15, February, 1944.



Base hardware for the antennas being tested. The insulator was made from 1-inch maple dowel, turned down to accept the $7/8$ -inch inside diameter of the ground and antenna tubing.

The effect of using longer radials in a particular direction is shown in Fig. 3. Radials of No. 18 wire $3/2$ wavelengths long, were put down between the existing 40 radials. The spacing between the longer wires was 5 degrees. The considerable improvement indicates the need for longer wires and the directional properties a ground plane could give.

A $5/8$ -wavelength vertical was also constructed and tested. It consisted of a 40-ft telescoping aluminum pole and a loading coil of 8 turns of No. 12 wire with a diameter of 2.5 inches. The comparison in low-angle radiation at a distance of 7.5 wavelengths is presented in Table I. A field-strength meter was mounted at different heights on the 26-foot tower. The ground plane for these data consisted of the forty 0.4λ radials plus the eleven $3/2\lambda$ ones. Measurements were taken in the direction of the added longer radials. The results show the improvement in low angle radiation offered by the $5/8\lambda$ vertical. The input impedance of this longer antenna was found to be 76 ohms.

On-The-Air Checks

From these experiments and measurements I decided to settle on a $1/4\lambda$ antenna with approximately 40 radials. My installation is shown in the photograph. I then proceeded to make on-the-air tests to compare its effectiveness with an inverted-V antenna having its apex at 0.4 wavelength, and with a $5/8\lambda$ vertical using the same ground system. Surprisingly, the $1/4\lambda$ vertical seemed to perform just as well as the much taller $5/8\lambda$ vertical. This could result from the fact that most signals arrive after several hops and the optimum lobe angle is probably as high as 15 to 20 degrees.¹⁰ At that angle, the $\lambda/4$ antenna actually enjoys an advantage. With practically all DX contacts, the verticals had a 6- to 8-dB improvement over the inverted V! The only exceptions were at intermediate distances and for local contacts. At about 500 or 600 miles, the inverted V with its higher angle of radiation gave better results. Locally, the verticals gave far superior performance. Improvements of 10 to 15 dB were recorded. A triband trap vertical antenna was also tested on 20 meters and found to be practically the same in impedance and performance. This antenna had an overall height of only 12.5 feet!

Test Equipment

A most interesting aspect of antenna measurements is that the equipment can be rather simple and in many cases constructed from items most

¹⁰ See footnote 2.

Shown here is the triband trap vertical antenna which has an overall height of only 12.5 feet. With the system of 40 radials, performance of this antenna on 20 meters was about the same as that of the quarter- and $5/8$ -wavelength vertical elements.

TABLE I

Comparison of responses of quarter-wavelength and $5/8$ -wavelength vertical antennas at low radiation angles. Data were taken by field-strength meter mounted on a wooden tower at a distance of 7.5 wavelengths at 14.25 MHz. Field strength (E) is normalized to maximum value obtained with $5/8$ -wavelength case.

θ	$E(\lambda/4)$	$E(5/8\lambda)$	GAIN OF $5/8\lambda$ ANTENNA
0.1°	0	.58	∞
0.4°	0	.62	∞
0.75°	.62	.80	3.4 dB
1.1°	.69	1.0	3.2 dB
1.5°	.62	.92	3.4 dB
2.25°	.48	.80	4.3 dB
3°	.41	.69	4.5 dB

amateurs have in their junk boxes. All that is really needed is some standard to compare with, such as a wattmeter or an S meter that is known to have reasonable accuracy. I have used both — the wattmeter in my Drake L-4B linear amplifier and the S meter in my R-4B receiver.

The impedance bridge shown in the photograph was patterned after the one shown in the ARRL *Handbook*. Care was taken in shielding the input and output circuits. The meter was mounted externally in order to minimize stray pickup. A calibration curve was obtained at 14.25 MHz by using many carbon resistors of known values as the load.

The field-strength meter is a simple diode detector and dc amplifier. The instrument was constructed to cover the 10-, 15-, and 20-meter bands. Its meter was also mounted externally. The antenna length for the field-strength meter was determined by the strength of the available field. In addition to these pieces of test equipment, a 20-meter transistorized crystal oscillator was used for many of the tests.

(Continued on page 22)



Vertical Antenna

(Continued from page 19)

Conclusion

The performance of a vertical antenna on the ground is highly dependent upon a good ground system, and, properly installed, the antenna can be a very good performer indeed for DX and local contacts. This is particularly true at the higher frequencies where the dielectric property of the earth plays a major role. Forty radials of No. 18 wire, 0.4λ long, will increase the total radiated power by about 3 dB. Radials can be thin if a sufficient number is used. The thought of using thick wires buried deeply, probably a carry-over from lightning grounds, is not valid at higher frequencies. The idea of using only four buried radials, as commonly recommended, is a serious error, and if this article does nothing more than eliminate that misconception, I will be satisfied. Since the electric field only penetrates the ground for a foot or two at the higher frequencies, the radial wires need be buried only as deep as necessary to escape children's feet and the lawn mower. Finally, these results from the single vertical antenna indicate that a vertical array could be a competitor to the more elaborate horizontal beams and warrants further investigation.