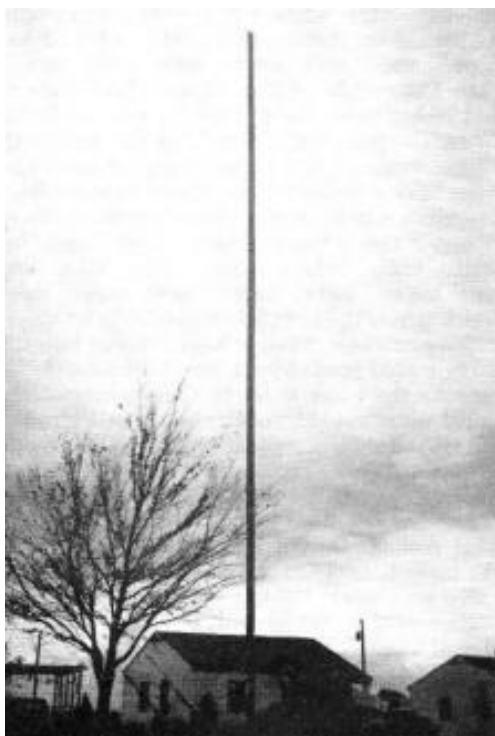


# The Truth About the Vertical Antenna

Measured and Calculated Performance  
Compared with an Ideal Horizontal Antenna  
By B. W. Griffith - W5CSU - May 1952 QST

No one antenna will do all sorts of jobs equally well, and to ask if one system is "better" than another frequently is nothing more than posing a meaningless question.

This article compares vertical and horizontal antennas for 75-meter operation and gives facts based on calculations, measurements and observation. Whether the vertical or horizontal best suits your particular objectives is something you will be able to decide after reading it.



The vertical antenna at W5CSU, constructed of 4-inch down-spouting - 40 feet high - usable on 20, 40, and 80 meters.

Many words have been written and spoken on the subject of antennas, yet the utility of the vertical antenna for the lower amateur frequencies still remains a ripe subject for argument. It is not the intent of this article to attempt to settle the controversy, but rather to provide some ammunition.

There are presented herein data, both calculated and measured, which have been accumulated during several years of actual operation of a vertical antenna in the amateur bands. It is hoped that the information will be of value to those who are interested in determining the real value of this type of antenna.

These factors which must be considered in studying an amateur antenna system:

1. Will it produce a usable signal over a large area in competition with QRM?
2. Is its appearance acceptable at your location?
3. Is the cost reasonable?
4. Is it suitable for multiband operation?
5. Is it a good receiving antenna?
6. Will it be disabled mechanically or electrically by wind or ice?
7. What is its effect regarding BCI-TVI?
8. Does it present a personal hazard?
9. Does it present a lightning hazard?
10. Is excessive space required?
11. Is it difficult to construct?
12. Are serious difficulties involved in obtaining correct adjustment?

The application of these questions to the vertical antenna is the purpose of this article. In order that the investigation of the antenna be in sufficient detail to be informative, the present discussion is limited to its performance in the 75-meter band. Some information concerning impedance matching and comments on the performance in other bands are included, but the presentation of actual data on operation in other bands is beyond the scope of this article.

### **Specific Type of Antenna Studied**

The antenna considered here is a vertical conductor whose base is at the surface of the earth. The radiator is insulated from the ground at the base, and is series excited.

In the particular antenna used at W5CSU, the radiating element consists of 40 feet of 4-inch galvanized iron down-spouting, soldered at the joints and guyed at the center and near the top. Guy wires of No. 12 copperweld, insulated at 12-foot intervals and spaced 120°, have successfully held the antenna through five years of violent Texas windstorms and winter ice.

The base of this mast rests on a Pyrex transmission-line insulator, which in turn rests on a sturdily-built copper-covered wooden pedestal about 2 inches above the ground and about 6 inches square.

The current flowing in the ground near such a vertical antenna will cause considerable power dissipation in the form of heat, unless ground wires are provided to reduce the resistance.

These wires must follow the lines of current flow and so must proceed radially from the tower base.

A system of wires of this type is known a "radial ground system." Broadcast-station antennas are commonly installed with 90 to 120 or more such radials extending  $1/4$  to  $1/3$  wavelength from the tower.

For amateur purposes, however, it is not necessary to go to such lengths to obtain reasonably efficient operation. The antenna at W5CSU is operated with a ground system of 16 radials varying between 25 and 40 feet in length as limited by the dimensions of the lot. It has been operated with only 8 radials with good success.

The radials are No. 14 wires buried about two inches below the surface. An axe was found to be the best tool for making the trenches. Either enameled or bare wire may be used. The wires may even be laid on the surface, as their capacitance to ground allows satisfactory operation, but this is not suitable as a permanent installation for obvious reasons. The radial ground wires are soldered to the edge of the copper sheet which covers the antenna pedestal.

**Is a pipe driven into the earth a good ground for a vertical antenna?** No. The earth losses in the absence of the radial wires would be equivalent to a loss resistance in the order of some 50 ohms, and who wants to put a 50-ohm resistor in series with his antenna?

**Does a water pipe make a good ground?** Only if it runs radially out from the tower base. Then it will be equivalent to one radial wire.

**How good is the system of 16 radials described above?** The calculated radiation resistance of this tower at 4 megacycles is 12.0 ohms. Its measured resistance is 19.6 ohms. This is taken to indicate that the ground-system resistance is in the vicinity of 7.6 ohms, so that the radiation efficiency of the antenna at 4 megacycles is about 61 per cent.

This means that the radiated signal will be 2 decibels lower than its value with a perfect ground system. It is probable that with the addition of 30' more radial wires the ground resistance could be brought to less than 3 ohms.

The choice of 40 feet for the antenna height was based mainly on the consideration of its being useful in several bands. The height chosen is approximately 0.16 wavelength in the 80-meter band, which is the shortest with which reasonable efficiency can be realized. It is 0.58 wavelength in the 20-meter band, which is the longest that can be used without wasting radiation at high vertical angles.

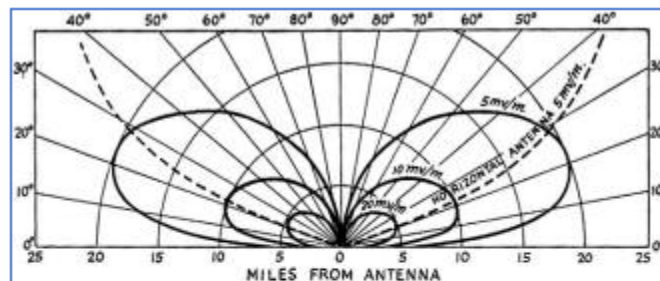
This height therefore allows efficient operation in the 80-, 40-, and 20-meter bands. The radiation efficiencies on 40 and 20 are higher than on 80.

## Comparison with Horizontal Antenna

The standard to which the vertical is compared is a half-wave horizontal antenna 1/4 wavelength above ground. Since a half-wave dipole - some 125 feet long - is a difficult thing to fit into an average city lot, and particularly hard to raise 1/4 wavelength - 62 feet or so - above ground, the average amateur antenna will not give as good results as the standard selected. The actual antenna is usually a compromise of questionable efficiency. Thus the comparison to follow is more favorable to the horizontal antenna than would be expected in practice.

The field intensity in any given direction from an antenna is proportional to the square root of the applied power. The calculated antenna patterns and coverage discussed are based on the assumption of 1000 watts input to a Class C final amplifier, with appropriate allowance for transmission losses.

Under these conditions, the theoretical vertical-plane patterns of the vertical and horizontal antennas over earth of perfect conductivity are shown in Fig. 1. The values plotted are the field intensity in millivolts per meter at a distance of 1 mile. These values assume 100 per cent efficiency - no losses - in both antennas.



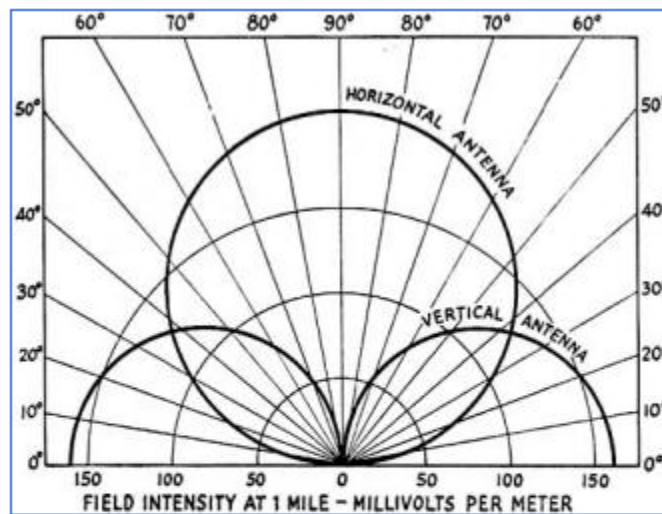
*Fig. 1 - Field intensity vs. vertical angle for lossless vertical and horizontal antennas over perfectly-conducting earth. Field intensities are calculated for 1-kw. input to Class C final amplifier. The shape of the vertical-plane pattern of the horizontal antenna will depend somewhat on the azimuthal direction, but the variations are not significant at the high angles for which this antenna is most useful at 4 Mc.*

Fig. 1 is not directly usable because the actual antennas are not 100 per cent efficient as radiators and the earth is far from a perfect conductor. However, the theoretical values form a starting point for calculating the actual behavior.

Fig. 1 shows that most of the radiation from the horizontal antenna goes out at very high angles. Only a small portion of the power is dissipated in the earth. With the vertical antenna, the preponderance of radiation is at quite low angles. This low-angle radiation - within the first few miles from the antenna - is a part of the surface wave or "ground" wave.

As this wave travels over the imperfectly-conducting earth, energy is drained away and dissipated as heat in the earth. Although this attenuates the surface wave and the radiation at very low angles, the earth cannot remove much energy from that part of the signal which is already at a great height above ground.

The vertical pattern at considerable distances from the antenna thus takes on a shape similar to that shown in Fig. 2. Here it may be seen that the maximum effective radiation from the vertical antenna occurs at an angle considerably above the horizon.



*Fig. 2 - Calculated vertical-radiation contours of the W5CSU antenna, described in the text, in comparison with a half-wave horizontal antenna one-quarter wave high; one-kilowatt input to final amplifier. The curves for the vertical antenna are based on field strengths measured along the ground.*

The rate at which the surface wave and low-angle radiation diminishes is determined by the characteristics of the soil over which the signal is traveling. The computations involved in the determination of Fig. 2 are not presented here but the method of calculating these factors will be found in an article by K. A. Norton.<sup>1</sup>

The values shown were computed for soil conditions existing in the vicinity of Dallas, Texas. Surface-wave intensity was checked by the field-intensity measurements presented in Fig. 4 and discussed later.

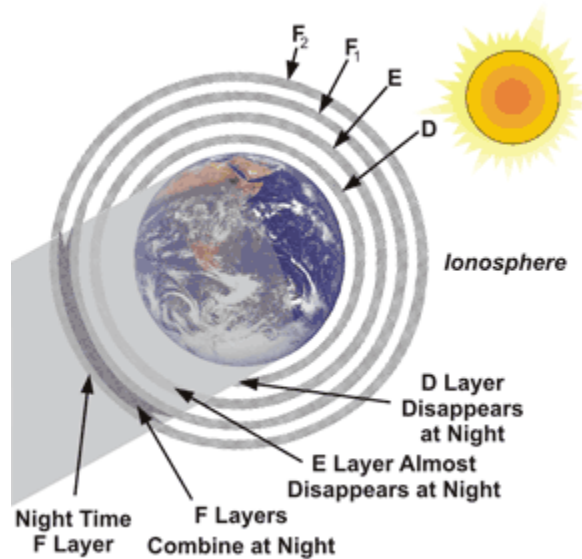
Soil conductivity varies greatly in different parts of the country. Only soil within about 15 miles of the transmitter affects appreciably the vertical-pattern characteristics of the vertical antenna.

Wet soil is not necessarily indicative of high conductivity. The presence of water - with its high dielectric constant - materially reduces the depth to which currents penetrate in the earth,

thereby reducing the cross-sectional area through which current flows. Many dry soils exhibit higher r.f. conductivity than moist soils. Salt water marshes, however, show extremely high conductivity.

Fig. 2 assumes 1000 watts input to the final amplifier, with 61 per cent efficiency for the vertical antenna and 95 per cent efficiency for the horizontal antenna. The contours of equal signal show how the signal shapes up as it departs from the antenna, and we can guess from this its probable final form at great distances.

**Take first the horizontal antenna.** Maximum signal is radiated directly overhead, diminishing at lower angles. In the daytime, the signal fired directly up is returned by the  $F_2$  layer<sup>2</sup> arriving back at the local area of the transmitter with a field intensity of about 500 microvolts per meter after having made a 300-mile trip through the D, E and  $F_1$  layers. Owing to the vertical incidence on these layers, absorption is small and the intensity almost follows the inverse-distance law.



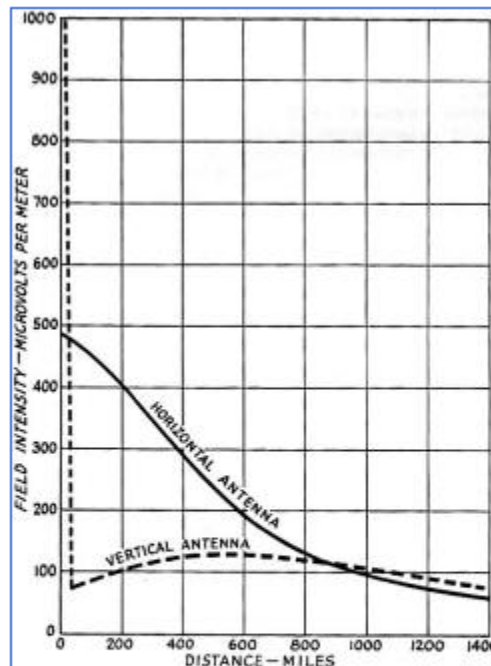
This accounts for the practically constant field intensity observed for a number of miles around the transmitter. Beyond about 30 miles, the signal decreases rapidly because of the increasing distance traveled to the ionosphere and back. The received radiation is also coming from progressively lower angles in the antenna's vertical pattern.

A particularly rapid reduction of signal strength with distance is apparent in the daytime because of the rapid increase in signal absorption by the lower ionospheric layers as the angle of incidence deviates from the vertical. At night this absorption disappears, allowing the signal to be transmitted to greater distances.

Occasionally at night, especially during sunspot minima, the ionosphere will not reflect 4-Mc. signals at near vertical incidence, thus making it impossible to produce a readable signal at a distance nearer than perhaps 150 miles. This is the "skip-distance" effect which is so disastrous to emergency communications during the night hours.

The expected nighttime signal of the horizontal antenna is shown in Fig. 3, determined by computing the root-sum-square values of signals arriving by one-hop, two-hop, three-hop, etc., transmission, assuming a loss of 3 db. due to absorption and scattering at each ground reflection.

This approximates rather well the actual condition of nighttime transmission with the F<sub>2</sub> layer reflecting the signals from a height of about 220 miles.



*Fig. 3 - Computed field intensities of W5CSU vertical antenna and of ideal horizontal antenna, assuming F<sub>2</sub>-layer reflection (nighttime) and 3 db. loss at each earth reflection.*

**Propagation from the vertical antenna behaves in a rather different manner.** Since there is practically no radiation at angles near the vertical, the coverage within about 30 miles of the station is purely by means of the surface wave. This produces a signal of constant intensity day and night.

At about 30 miles the reflected signal from the ionosphere, when applicable, is approximately equal to the ground wave, and exceeds it at greater distances. This is because the attenuation of the ground wave is much greater than that of the nighttime sky wave.

As the distance increases, the sky wave signal remains fairly constant for some hundreds of miles, since the received signal is coming from progressively lower and therefore stronger parts of the antenna's vertical pattern.

Finally, because of the great distance and the shape of the vertical pattern, the signal drops off to unusable values. The calculated performance of the vertical antenna is plotted in Fig. 3.

It is interesting to note that in the absence of the sky wave - as in daytime or at times when high-angle radiation is not returned from the ionosphere - the ground wave is thoroughly usable out to a distance of about 100 miles, producing a signal of some 10 microvolts per meter at that distance.

This means that the vertical antenna can be relied upon to maintain emergency communications within a 100-mile radius during those late night periods when the horizontal antenna is tragically useless.

An occasional but unreliable transmission of daytime sky wave signals over distances of some 1000 miles has been observed from the vertical antenna. This effect is possibly due to reflection from the E layer, as the relatively intense radiation at low angles may make this mode of transmission possible.

Fig. 3 shows that for the normal nighttime conditions the signal from the horizontal antenna will exceed that from the vertical out to a distance of some 850 miles, with the exception of the vertical antenna's ground-wave coverage. Beyond 850 miles, the vertical antenna's signal is superior.

This presentation may be somewhat unfair to the vertical, since it is being compared with a horizontal of 95 per cent efficiency, 62 feet in the air, and in the clear. It is doubtful that many amateur antennas meet these specifications. The signal from an average amateur horizontal antenna would probably be less than shown, and thus would drop below that of the vertical at a considerably shorter distance.

The signal for the vertical has been computed from actual field-intensity measurements of the W5CSU antenna, and therefore has been reduced by the actual losses to which the antenna is subject in an average city lot.

These measurements, which determine the character of the surface wave, were made along a straight line extending out from the antenna a distance of some 22 miles as shown in Fig. 4.

Measurements of the W5CSU signal at Tulsa, Oklahoma - a distance of 236 miles - showed the median value of the signal to be from 2 to 3 times the computed value for this distance. This probably indicates that most of the signal was arriving via sporadic-E reflection, which is common during summer months.

As this low layer would propagate signals at this distance with an angle of departure of some 25 degrees, it is seen that the vertical antenna would be favored in this type of transmission.



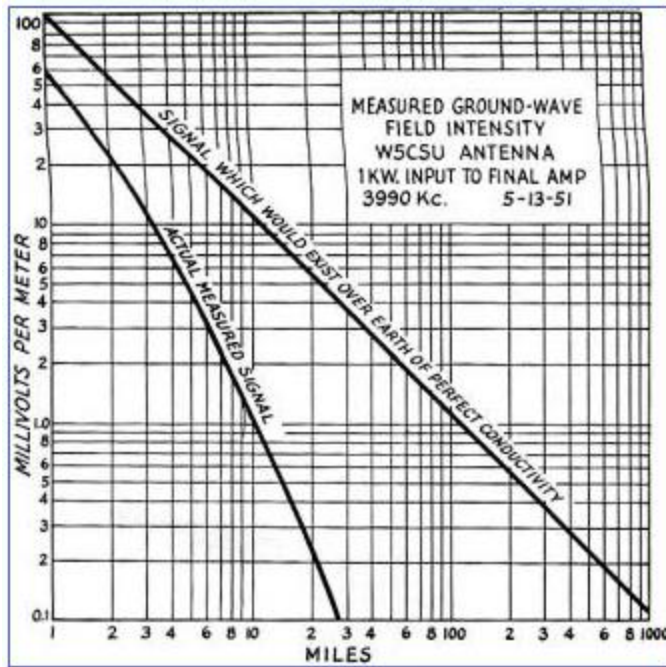


Fig. 4 - Measured ground-wave field intensity of W5CSU antenna with one-kilowatt input to final amplifier, 3990 kc.

## Impedance Matching

For operation in the 75-, 40-, and 20-meter bands, the coil L should be 8 turns of 1/4-inch copper tubing, 6 inches in diameter and 6 inches long, with the taps placed approximately 3 turns from each end. The capacitor C for 40-meter operation should be 200 or 250  $\mu\text{fd.}$ , and should be able to carry 5 amp. r.f. for operation at 1 kilowatt.

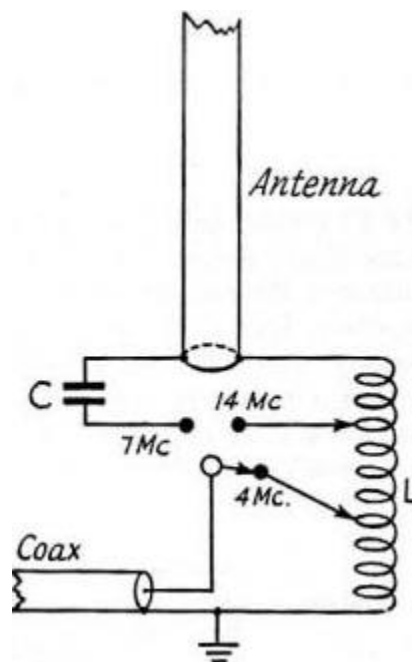


Fig. 5. Method of matching to 52-ohm coax

It is possible, with only a slight compromise in match, to find a single tap position that provides satisfactory coupling for both the 75- and 20-meter bands, thus making it unnecessary to visit the base of the tower in changing frequency between these two bands.

For the lower-frequency part of the 80-meter band, the coil should be increased to 9 turns, with the other adjustments unaffected. Provision for either using or not using one or two turns of the coil will provide the greatest range of frequencies in the 75-80-meter band.

For operation in the 160-meter band, the coil should consist of approximately 21 turns of wire, 6 inches in diameter and 7 inches long, or some other inductor having an inductance of about 40 microhenrys.

The center conductor of the coaxial line is tapped only one or two turns from the ground end. The coil will have to carry some 8 amperes for 1-kw. operation, so should be wound of No. 8 wire or equivalent. Operation in the 40-meter band may be accomplished with the 160-meter coil connected, using the capacitor as before. 20-meter operation is not advisable.

It must be pointed out that the impedance and matching information given here apply only to a cylindrical tower 4 inches in diameter and installed as was previously described. Towers of other dimensions would not be expected to have the same impedance characteristics.

### **Utility of the Vertical Antenna**

From the standpoint of appearance, the vertical antenna is difficult to surpass. With the transmission line and ground system buried, the complete absence of overhead leads except for the mast and its guy wires provides an exceptionally neat installation. These same characteristics also make this antenna virtually proof against weather hazards.

The antenna at W5CSU has withstood high winds and heavy icing without damage and with only negligible change in operating impedance. Previous operation in Minnesota has shown that deep snow does not appreciably affect its operating characteristics.

Since the "hot" end of the antenna is high in the air instead of extending near your neighbors' houses, the most intense part of the electric field is usually farther away than with the horizontal antenna. A few cases of blanketing of broadcast receivers have been encountered within 100 yards of the antenna.

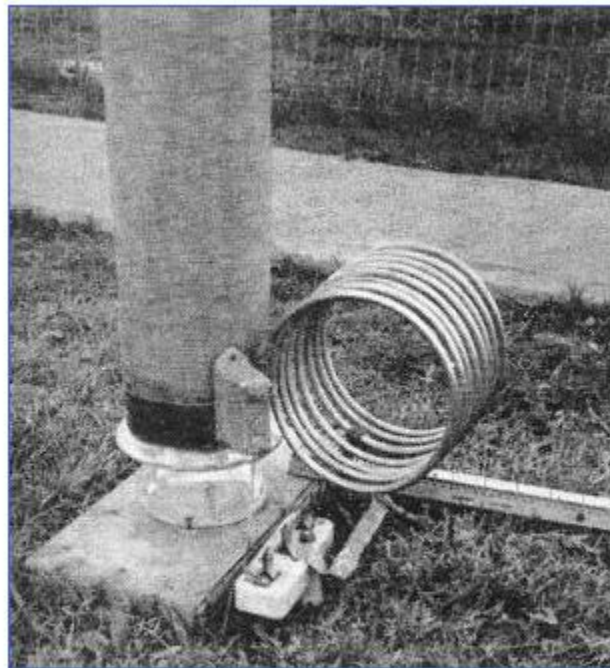
Since this is principally caused by currents induced in power wires, etc., all these cases have been cured by by-passing the a.c. line to the chassis of the receiver, and occasionally by including a small by-pass condenser from the audio amplifier grid to the chassis.

These are moreover vertically-polarized and therefore are at right angles to the receiving antenna polarization. Any high-order harmonic content of the signal delivered to the vertical antenna is thus directed into space at very high angles where it can do no damage.

Any antenna of appreciable height presents a target for lightning. This vertical antenna, with its base resting near an excellent ground system and being connected to the ground through heavy conductors in the tuning equipment at its base, probably gives less danger from lightning or accidental contact with power wires than other types of antennas.

Although there is no d.c. shock hazard from a properly-fed vertical antenna, the operating r.f. potential - which may be several hundred volts on some bands - does cause danger of minor burns. The antenna should be protected in some way from accidental contact with persons.

Among the virtues of the vertical antenna is its ability to provide satisfactory operation over several bands. This antenna will operate well on 20, 40, and 80 meter bands. Even on 160-meters, it has high efficiency compared to the short poorly grounded verticals used in 75-meter mobile operation. It is not suitable for operation on 10 meters.



*Coupling network at the base of the antenna. The feed line is coax buried in the ground.*

No difficulties have been experienced in using the vertical antenna for receiving. It appears to be somewhat less subject to the disturbances propagated along power lines than the horizontal antenna, but somewhat more subject to ignition noise in the 20-meter band than the horizontal.

In the 75-meter band, the discrimination it provides is against strong signals arriving at high vertical angles from near-by stations. This relieves part the problem of intense QRM, making it much less difficult to copy stations at the greater distances.

## Conclusions

The results of this study indicate that the vertical antenna is a very practical antenna system for an amateur station. It can be erected in a relatively small space, and can be used successfully on four bands. It is difficult to install because of the requirement of the radial ground system.

After being installed, a vertical requires little maintenance because it can be made extremely weatherproof. With the exception of the ground-wave coverage - 35 miles or so, the 75-meter nighttime signal within 500 miles is somewhat inferior to a good horizontal antenna. Beyond about 800 miles, a vertical is definitely superior.

Experience has shown that the vertical usually produces an excellent daytime signal within a radius of 300 miles or so - probably by means of E-layer reflection. This daytime signal is somewhat better than that from a horizontal antenna.

- 1 Norton, "The Calculation of Ground-Wave Field Intensity Over a Finitely Conducting Spherical Earth," Proc. I.R.E., December, 1941.
- 2 The actual reflection may occur at the E, F<sub>1</sub> or F<sub>2</sub> layer, depending on the ionization, which in turn depends on latitude and the sunspot cycle.