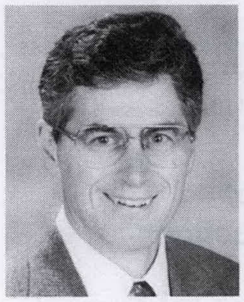

Tom Milligan
Assoc. Editor,
Antenna Designer's Notebook
8204 West Polk Place
Littleton, CO 80123 USA
Tel: +1 (303) 977 7268
Fax: +1 (303) 977 8853
E-mail: TMilligan@ieee.org

Revisiting Medium-Wave Ground-System Requirements

Benjamin F. Dawson III and Stephen S. Lockwood

Hatfield & Dawson Consulting Engineers, LLC
Seattle, WA, USA
E-mail: dawson@hatdaw.com; lockwood@hatdaw.com

Abstract

The classic 1937 paper by Brown, Lewis, and Epstein [1] outlined the necessity for a proper "imaging screen" or "ground system" for efficient operation of a vertically polarized monopole antenna. While Brown et al. showed the effects of various configurations, they did not exhaustively examine the effects of successive reductions of the number of radials, particularly in systems with radial lengths less than 90°. Furthermore, their measurements were made at 3 MHz, and were not corrected for the frequency scaling.

Recent experimental work, undertaken for a US Department of the Navy laboratory to optimize the performance of temporary medium-wave antenna installations, showed that for surface-mounted radial systems with radials 90° or shorter, both radial length and the number of radials are significant. Property availability for siting of antennas at medium-wave frequencies often results in truncation or other restrictions on radial length. The results of this study provide a guide to the practical limits on such restrictions, as well as data on the resulting efficiency reductions.

Keywords: Medium frequency antennas; monopole antennas; ground; ground plane; radial ground

1. Ground-System Function

What does the "ground system" for a vertical monopole antenna do? Its primary purpose is to provide a low-impedance return path for the displacement currents that flow between the antenna and the ground terminal of the monopole, providing a complete electric circuit and satisfying Kirchoff's Law at the antenna's input terminal (Figure 1). Because of the finite conductivity of soil (and fresh or salt water), the area where these currents are largest – close to the antenna – can be improved in conductivity. The most cost-effective way to do so is to use a radial "ground" system. As the use of systems with elevated radials shows, the radials don't actually have to be grounded to the Earth. They can be on the surface, and they can even be insulated wires, since the capacitance to the Earth of a substantial system allows significant current to flow (Figure 2).

The ground system is sometimes called an "imaging screen," but this function really occurs only for the proper operation of electrically tall vertical antennas, which are designed to produce anti-fading effects. In this situation, the combination of the antenna's current distribution and the ground-system imaging effect produces cancellation of fields at elevation angles close to

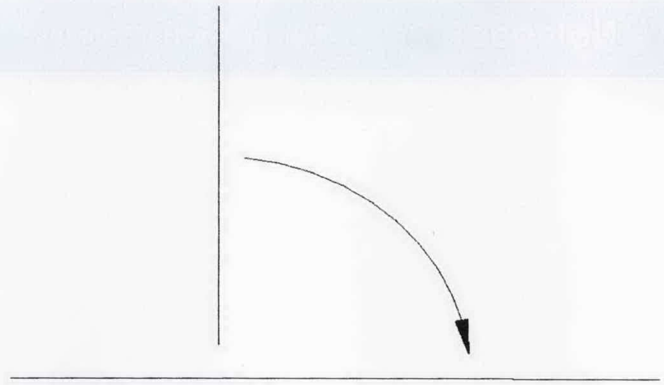

Figure 1. The termination of displacement currents by a ground system.

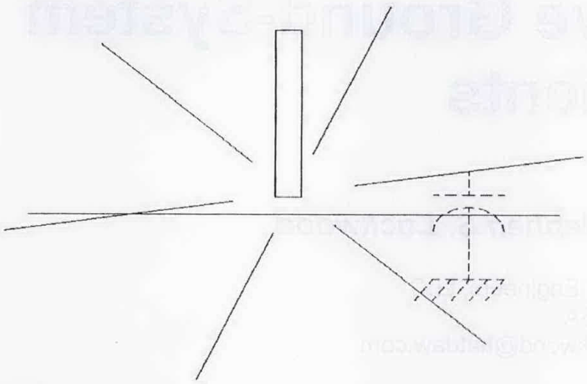

Figure 2. The capacitance to "real" ground from insulated radials or bare radials in dry or non-conducting soil.

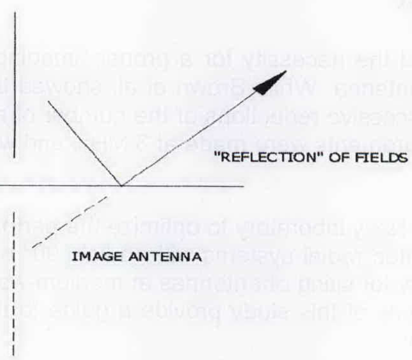

Figure 3. The ground system as an "imaging screen."

the zenith. The production of interfering skywave fields is therefore reduced at the distances from the antenna where the groundwave signal begins to diminish to minimum useful magnitude (Figure 3).

After Chamberlain and Lodge [2] showed the desirability of the vertical monopole over a ground plane as the most efficient and cost effective MF antenna for most situations, the question of suitable "ground systems" was answered by the Brown, Lewis, and Epstein work [1]. From that study, the use of 120 radials of at least 90 electrical degrees in length became the standard. Brown further demonstrated that ground screens around the immediate base region of an antenna were not worthwhile for efficiency purposes, except for very short radiators, or where the ground system itself was very substandard. A ground screen may be useful for stability reasons for antennas that have relatively high base voltages.

The Brown, Lewis, and Epstein data was extensive, but its presentation was rather convoluted. Clearer expositions of the same basic information were given by Laport [4].

2. The Effects of Ground-System Reductions

A series of tests was conducted with a top-loaded short vertical radiator and a conventional ground system of 40 radials, which were approximately (depending upon frequency) 0.1, 0.135, or 0.25 wavelength in length. The basic antenna ground-system combination exhibited an efficiency between one-half and two-thirds that of a 90° monopole over a perfectly conducting surface. The test antenna was thus similar to the relatively inefficient medium-wave antennas often employed for US Domestic Class C Stations, or TIS service or "local" radio service in some countries. (The Class C minimum in the US is 241 mV/m at 1 km per kW. Other administrations do not appear to have minimum efficiency requirements.)

Successive tests were conducted with the radials reduced to one-half, one-quarter, or one-eighth of the total number. In each case, the input power was monitored to adjust the measurement data to a reference value for comparison. The results for the ground system of approximately 0.1λ radius are given in Table 1. The results for the ground system of approximately 0.14λ radius are given in Table 2, and Table 3 gives the results for the ground system of approximately 0.25λ radius.

Table 1. The results for the ground system of approximately 0.1λ radius.

Configuration	Efficiency
40 Radials (Full)	144 mV/m at 1 km per kW
20 Radials (1/2)	93.9 mV/m at 1 km per kW
10 Radials (1/4)	59.3 mV/m at 1 km per kW
5 Radials (1/8)	45.3 mV/m at 1 km per kW

Table 2. The results for the ground system of approximately 0.14λ radius.

Configuration	Efficiency
40 Radials (Full)	204 mV/m at 1 km per kW
20 Radials (1/2)	181 mV/m at 1 km per kW
10 Radials (1/4)	146 mV/m at 1 km per kW
5 Radials (1/8)	106 mV/m at 1 km per kW

Table 3. The results for the ground system of approximately 0.25λ radius.

Configuration	Efficiency
40 Radials (Full)	186* mV/m at 1 km per kW
20 Radials (1/2)	169* mV/m at 1 km per kW
10 Radials (1/4)	147 mV/m at 1 km per kW
5 Radials (1/8)	138 mV/m at 1 km per kW

*(some data in the 0.25 example were excluded due to unexplained scatter.)

In general, these results were consistent with the Brown et al. findings. Because the antenna itself was electrically taller for the case where the ground-system radius was approximately 0.25 wavelength, its current distribution appeared to result in proportionally greater current in the outer wires. This may have been the cause of the efficiency reduction shown for the 40 and 20 radial conditions, compared to the case where the antenna and the radials were substantially electrically shorter. The useful result that these data provide is that any significant reduction in the number of radials for a buried or surface radial system is significantly damaging to efficiency, even with one-quarter-wavelength radials.

3. The Limitations of Brown's Study

Griffith [3] supplied an analysis that showed the reason for the relatively good performance of the short antenna with only a 0.1 wavelength ground radial system. The surface resistivity of the Earth follows the skin-effect rule: that is, it varies as the square root of frequency. Thus, in a radial system, the length of the radials needs to be proportional to the square root of the wavelength. Another way of stating this is that the ground-system's area needs to be inversely proportional to frequency for a constant value of ground-system's resistance (Figure 4).

Griffith's calculations have been confirmed by analysis using *NEC-4*, for moderate (6-10 mS/m) values of conductivity. This seems to contradict Brown et al. In fact, it doesn't, because Brown's measurements were conducted at 3 MHz, where a 1 ohm loss system needs to have radials just over $\lambda/4$! This means that for many situations, ground systems for medium-wave antennas can be constructed with considerable truncation or other size and shape compromises, without significant effect on performance.

4. Reduction of Ground Systems

It is not at all unusual for property limitations to impose restrictions on the desired full length of buried radial ground systems (Figures 5 and 6). *NEC-4* analysis showed that for a substantial truncation, or even for an interior area that is removed from a ground system, the resulting losses are negligible: on the order of 1% or 2% of the field. Furthermore, such truncation has no effect on radiation-pattern shape. As the figures show, if property boundaries permit a "makeup" in total area, it is often economical, but of limited benefit.

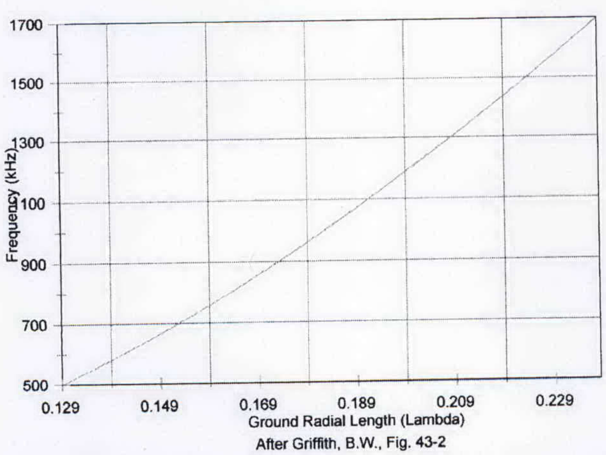

Figure 4. The ground radial length required to maintain 1 ohm ground loss.

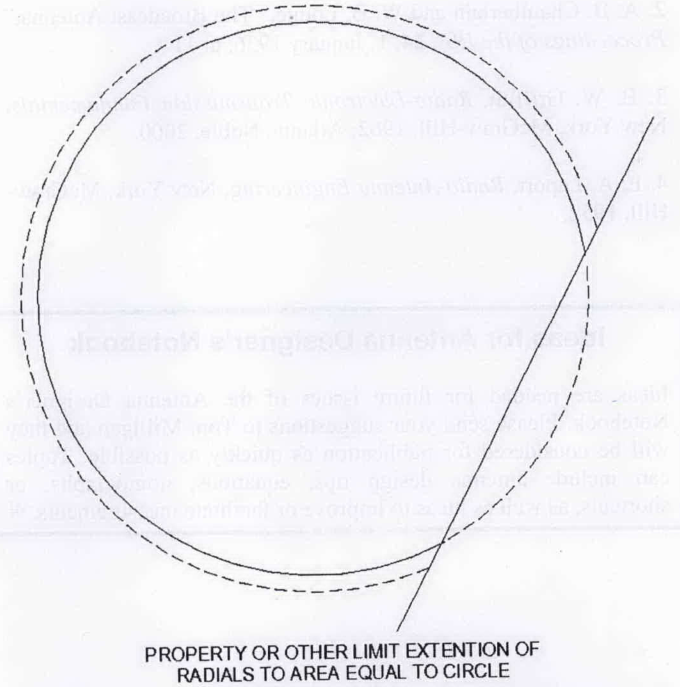

Figure 5. The extension of radials to an area equal to the circle in the presence of a property or other limitation.

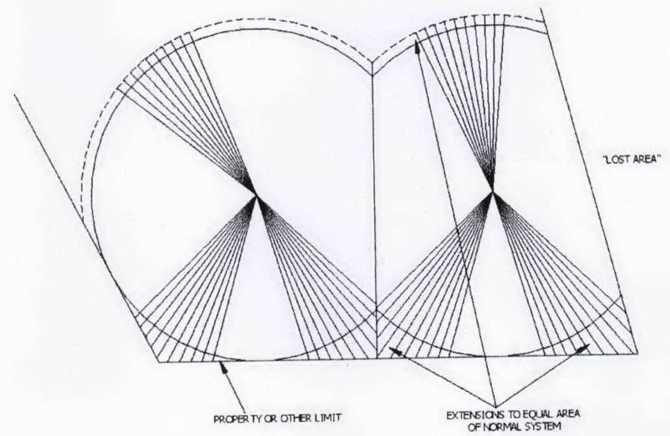

Figure 6. Extensions to equal the area of a normal system in the presence of a property or other limitation.

5. Conclusion

The conventional ground system of 120 radials 90° in length in many instances is a very conservative design. Particularly at the lower frequencies in the MF broadcast band and in the MF navaid band, smaller systems will produce acceptable performance.

6. References

1. G. H. Brown, R. F. Lewis, and J. Epstein, "Ground Systems as a Factor in Antenna Efficiency," *Proceedings of the IRE*, **25**, 6, June 1937, p. 753.

2. A. B. Chamberlain and W. B. Lodge, "The Broadcast Antenna," *Proceedings of the IRE*, **24**, 1, January 1936, p. 11.

3. B. W. Griffith, *Radio-Electronic Transmission Fundamentals*, New York, McGraw-Hill, 1962; Atlanta, Noble, 2000.

4. E. A. Laport, *Radio Antenna Engineering*, New York, McGraw-Hill, 1952.

Ideas for Antenna Designer's Notebook

Ideas are needed for future issues of the Antenna Designer's Notebook. Please send your suggestions to Tom Milligan and they will be considered for publication as quickly as possible. Topics can include antenna design tips, equations, nomographs, or shortcuts, as well as ideas to improve or facilitate measurements.