

Efficient Ground Systems for Vertical Antennas

Elevated ground systems for vertical antennas have been a bit of a mystery for the past 60 years. This report of an extensive study reveals some startling results.

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On the evening of November 27, 1923, the first two-way transatlantic radio communications took place between two Amateur Radio stations in the United States and a fellow amateur in France. One of the American stations was operated by John L. Reinartz, "the father of short-wave radio."

The antenna installation of that station was novel. The success of the Reinartz station was attributed to a new principle of antenna construction: A counterpoise was used as the second part of the balanced antenna system, rather than the capacitive ground used previously. After that night, the counterpoise (an elevated array of one or more insulated wires placed under the antenna) was used commonly in amateur and commercial antenna systems for more than 10 years. As the counterpoise was developed, its usual configuration became a symmetrical pattern of radial wires used as the "artificial ground" under electrical-ly short (one quarter wavelength or less) vertical antennas, as shown in Fig. 1.

Development of the counterpoise was, by necessity, empirical in nature, as sophisticated instrumentation and standardized antenna testing procedures were not available in those early days of radio. But after 1937 the counterpoise was almost forgotten because of a landmark

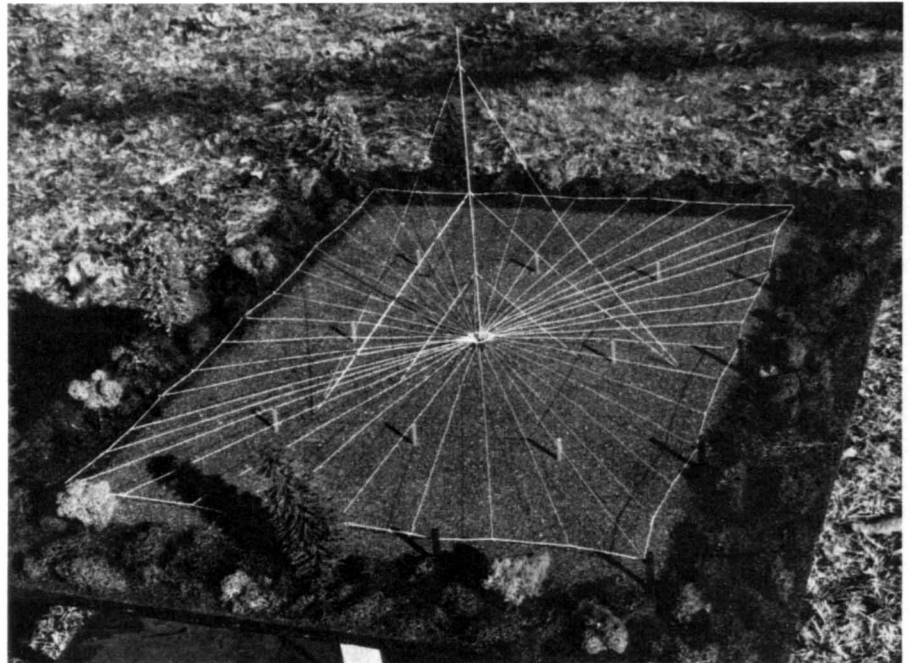


Fig. 2 — This scale model of the test antenna system was built before construction of the full-size version was undertaken. The model measures 3 by 5 feet, while the actual antenna system is 200 by 300 feet.

research program on another type of ground system — the buried radial.¹ This research, conducted by the legendary George H. Brown, was so detailed and authoritative that its results were used to develop the Federal Communications Commission's requirements for a-m broadcast stations. These requirements, which still apply today, specify that each station shall be equipped with a ground system consisting of at least 120 radials, each being at least 1/4 wavelength long.²

As is often the result of rigid regulation, interest and development of possibly superior ground systems, including the

counterpoise, has languished for the past 40 years. The same situation holds true for the "first cousin" of the counterpoise — the elevated ground screen. This is an elevated ground system that may be physically identical to the counterpoise, except that the radial wires are connected to the earth. The ground screen is little used these days, and the literature provides a very limited amount of information on its operating characteristics.

The Test Program

In 1979 a rather elaborate program was begun in Fletcher, North Carolina, to determine the effectiveness of the counterpoise and elevated ground systems. These tests were conducted at 1.8 MHz. The ver-

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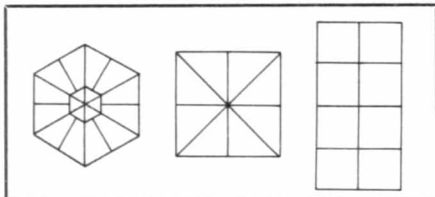


Fig. 1 — Typical arrangements of wires for counterpoise or ground-screen systems.

¹Notes appear on page 25.

tical antenna used for the portion of the test program reported here was a 45-degree (about 65-foot) top-loaded section of tower.³ The base of this antenna was 4 feet above the ground and was insulated from the earth. The antenna was deliberately offset slightly from the center of the radial system so that no two radials would be of exactly the same length. The radial wire system used in the tests covers an area of 200 × 300 feet (slightly less than 1.4 acres). This system was used first as a counterpoise and then, after it had been grounded at several locations, as a ground screen. The longer dimension was selected on the assumption that the optimum radial lengths determined by Brown for buried radials would also be correct for a counterpoise and an elevated ground screen (a correct assumption, as it turned out!).⁴ The smaller dimension was selected to be less than the optimum length found by Brown.

Tests were conducted with 6, 12, 18, 24, 36, 40 and 48 radials in place. Total lengths of wire in the various systems tested were from 1821 feet to 7386 feet. The radial wires are from 6 to 8 feet above ground. Before construction of the antenna system was undertaken, the 3- × 5-foot scale model shown in Fig. 2 was made and evaluated for mechanical considerations.

Ground Conductivity

Antenna literature is full of references to the importance of ground conductivity to the efficient operation of vertical antennas. Our first chore, therefore, was to determine the ground conductivity of the test site. There have been few mentions in the literature of actual measurements of conductivity, and no convenient system for such measurements was offered until recently. In the Fletcher test program, ground conductivity was measured directly by the relatively simple method described by Sevick.⁵ At first we experienced trouble from ground currents. Thus, we modified Sevick's circuit by adding an isolation transformer, and that cleared up the problem. Fig. 3 shows the results of four months of daily tests of the ground conductivity at a "standard" fixed location adjacent to the base of the antenna. As is shown by this data, the conductivity varied by a factor of approximately 2:1 over the period covered.

Data has now been accumulated for a total of 16 months, and conductivity has remained within the limits shown. The long-term variations in conductivity correlated, as expected, with the variations in temperature and rainfall. In addition, however, severe variations in conductivity were found at different locations in the test site. As illustrated in Fig. 4, ground conductivity varied by a factor of 7.5:1 within less than 10 feet.

In theoretical analyses of vertical antenna radiation patterns, previous literature

indicates that the ground conductivity was assumed to be homogeneous throughout the area covered by the antenna ground system (usually buried radial wires). Our tests indicate that it should *not* be assumed that the ground conductivity will be homogeneous. Past usage of an area (such as agricultural, where fertilizers or chemicals have been applied), past conditions (as on cleared land previously covered with brush or trees, which could accumulate salts or other chemicals in their root systems), and microtopography (smaller ruts or lower areas that may contain electrolytes washed from higher areas) can be expected to produce con-

siderable local variations in ground conductivity. If you have built a vertical antenna and have found that its radiation pattern is unusual in any respect, perhaps the ground conductivity under it was the reason!

RF Current Measurements

The tests reported here (and those conducted subsequently) required the taking of literally thousands of rf current measurements. Currents were repeatedly measured in each radial wire at various distances from the antenna, for the various test conditions. As soon as the earliest measurements were made in the

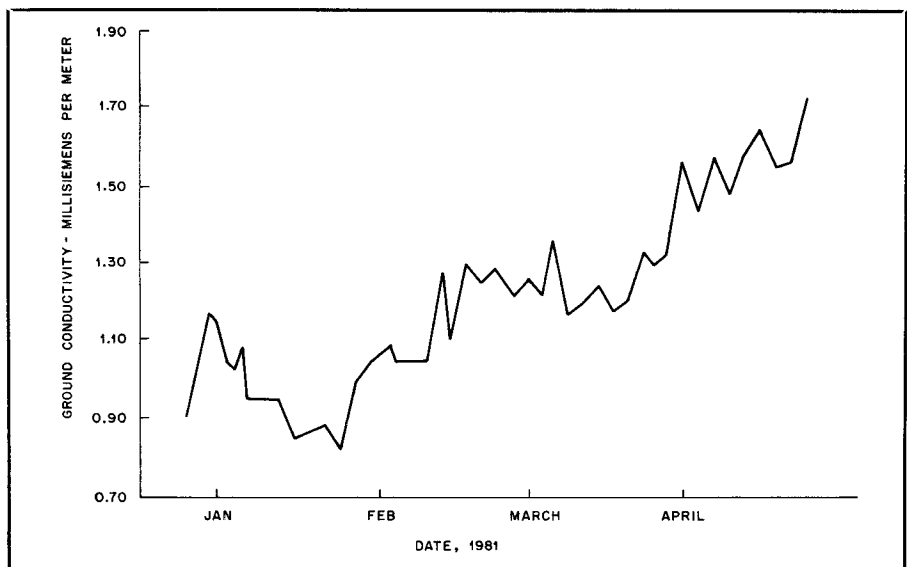


Fig. 3 — Ground conductivity at one fixed location in the test site at Fletcher, North Carolina. Measurements, taken daily, are shown here for the first four months of 1981.

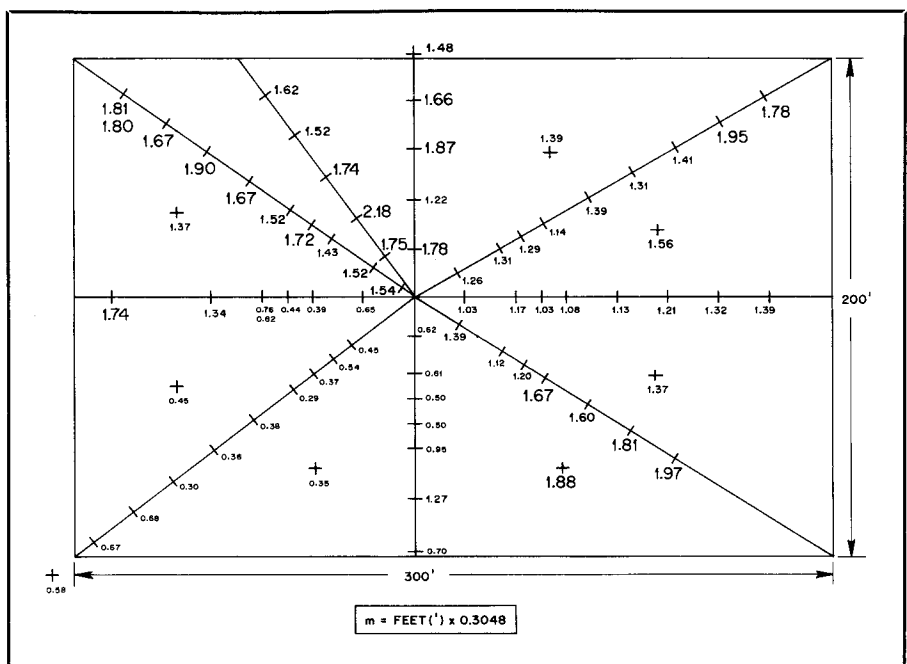


Fig. 4 — Ground conductivity along different radials at the test site. Note that there is a difference ratio of as much as 7.5:1 within a distance of 10 feet.

test program, it was evident that the most sensitive rf ammeter commonly available (0-100 mA) would not be satisfactory. Readings of less than 1 mA were commonplace at the power level that we wished to feed to the antenna. Accordingly, a magnetometer of the design published by Carr was constructed and used throughout the test program, Fig. 5.⁶

Although it is not evident in Fig. 5, two pieces of sheet plastic, spaced 1/8 in. apart, are mounted on the top of the magnetometer. The radial to be measured was placed in the slot between the pieces of plastic, thus locating the wire precisely. It was found that the meter was capable of reproducible measurements of rf currents of less than 10 microamperes, and of indicating the presence of levels in the area of 1 to 3 microamperes. The magnetometer was calibrated by averaging readings from a number of sensitive thermocouple-type instruments. The extreme sensitivity

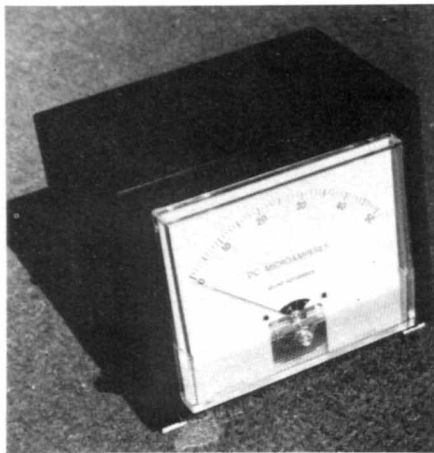


Fig. 5 — The magnetometer used for rf current measurements, after Carr.⁶ The basic meter movement is a 5-inch, 50- μ A instrument, selected for its sensitivity and readability.

of the meter allowed it to indicate clearly the presence of a small aluminum ladder 5 feet from a radial!

In use, the instrument was placed against the radial wire and positioned so the wire would “snap” into place in the slot between the plastic sheets. This enabled repeatable measurements to be taken rapidly. In other tests, rf currents were measured in buried radials by cutting small rectangular holes in the earth beyond the depth of the radials. This permitted inserting the magnetometer into the holes with the buried wires positioned in the slot.

Current Distribution in Counterpoise Radials

No record has been found in past literature of specific data on the the distribution of current in the wires comprising any type of artificial ground system — buried radials, counterpoise or ground screen. What data is available indicates that there is uniform distribution of current in the radial wires of such systems. The thousands of measurements made in the Fletcher tests clearly indicate lack of uniformity of current distribution in the radial wires of a counterpoise. Fig. 6, showing the result of 800 data points, illustrates the wide variation of current flow found in the radial wires of a 48-radial counterpoise.

The distribution shown was a considerable surprise. Every indication found in the literature of the past 60 years⁷⁻¹¹, and in modern commentary by experts in the field, indicates that the counterpoise was thought to act as one plate of a large capacitor. The earth was thought to act as the second plate. It was believed that the return currents flowing back to the base of the antenna through the radials should be better distributed than with buried radials. It was also believed that the cur-

rents should show some concentration (as the result of the “edge effect” of a capacitor) along the periphery of the counterpoise system, rather than being concentrated near the base of the antenna, as is found with buried radial systems. The Fletcher tests showed an entirely different distribution of current flow in the radials of a counterpoise from that predicted in the literature.

A number of tests at the inception of the program indicated that there was a direct relationship between the level of current in the counterpoise radials and the conductivity of the ground under them. The most striking illustration of this correlation comes from comparing Fig. 4, which shows the conductivity of the ground at the test site, and Fig. 6, showing the currents in the radials. The comparison of these two illustrations offers an intriguing possibility. Shouldn't it be possible to modify the current pattern in the radials, and thus the radiation pattern of the antenna, by artificially modifying the conductivity of the ground under the radials? Preliminary tests by the authors indicates that this is definitely possible!

As radials were added to the counterpoise, a record was kept of the current supplied to the antenna, and the return current collected by the radials. The results are given in Table 1. This data indicates that an elevated counterpoise of less than 50 radial wires provides a very efficient ground system. Previous tests have indicated that more than 100 radials are required to provide the same level of performance if buried radials are used.

As previously mentioned, it has been thought that an elevated counterpoise acts in conjunction with the earth as a giant capacitor, with the counterpoise radials being one “plate” and the earth the other. The Fletcher tests clearly indicate that a counterpoise operates in a more complex

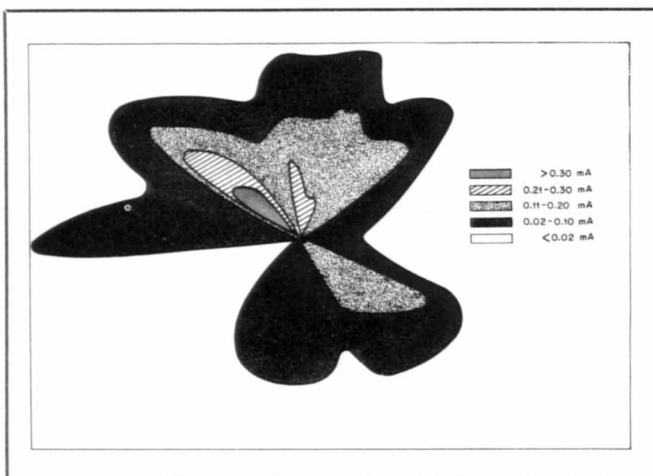


Fig. 6 — The range of current distribution in the wires of a 48-radial counterpoise is shown over the area of the test site. This drawing is based on approximately 800 data points. As one would assume, the current tends to be greatest at the base of the vertical radiator. But the surprising fact emerged that the current was nowhere near being equal from one radial wire to another.

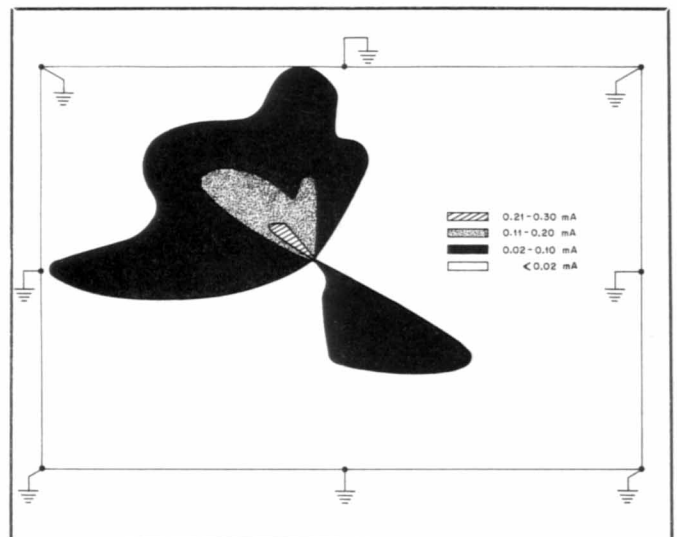


Fig. 7 — The range of current distribution in the wires of a 48-radial elevated ground screen. The wires were grounded at the center, and at eight points on the periphery of the system.

Table 1
Current Flowing in the Antenna and in the Radials of a Counterpoise

No. of Radials	Antenna Current, mA	Return Current, mA of Ant. Curr.	Return as % of Ant. Curr.
6	350	220	63
12	390	260	66
20	495	445	90
28	495	450	91
36	495	455	92
40	495	490	99
48	495	495	100

manner than has been thought for the past 60 or so years, and that the wires in a counterpoise system definitely do not operate in concert as the plate of a large capacitor of the type usually considered. Rather, the counterpoise appears to operate efficiently as the result of a number of factors, including those itemized below.

1) Each radial of a counterpoise is individually capacitively coupled to the earth under that radial.

2) The magnitude of the currents carried by the radials of a counterpoise vary as the conductivity of the ground under the radials — the higher the conductivity, the higher the current. Current distribution in counterpoise radials is *not* similar to that found in buried radial systems.¹²

3) The counterpoise provides an efficient, low-loss path for antenna return currents, as do buried radial systems. The small amount of current in the counterpoise radials which is not directly induced from the antenna is in the form of displacement currents flowing from the earth as "charge-discharge" currents. However, the return currents in a buried radial must flow through high-resistance, high-loss earth to get to those radials. What this means in practice is that a counterpoise operates more efficiently — with less loss — in collecting return currents and guiding them to the base of the antenna than does a buried radial ground system.

The Elevated Ground Screen

The elevated ground screen used in the tests was the same physical array of radial wires as that for the counterpoise tests. For the ground screen tests, however, the radials were grounded at the center of the "spiderweb," and at eight locations around the peripheral wire that connected the far ends of the radials. Previous literature provides no specific data as to what distribution of current might be expected in the radial wires of an elevated ground screen. The only information we could uncover indicates the belief that the currents in the radials of a buried ground system should be equal from radial to radial. The measurements made at Fletcher leave no doubt that there was a pronounced lack of uniformity of current

distribution in the radials of the ground screen tested. Fig. 7, which portrays several hundred data points, illustrates the wide variation of current flow found.

The radial wires in the ground screen vary in length from 96 feet to 173 feet. Each radial is grounded at its end near the antenna, and through the grounded peripheral wire at its far end. The various current levels in the radials are not related to the radial lengths. No rational explanation could be found for the unexpected, uneven, current pattern until the ground conductivity factor, discussed above in relation to the counterpoise, was discovered.

From the test data, a direct correlation was found between the level of current flow in the radials and the conductivity of the ground under those radials. Fig. 4 shows the ground conductivity at numerous locations of the test site, and Fig. 7 shows the level of the return currents in the radials of a 48-wire elevated ground screen over that ground. A comparison illustrates this correlation.

Additional testing showed that the correlation holds true even if a radial is placed on the surface of the ground, and connected to ground stakes every 20 feet. This was verified by testing a radial laid on the ground at two different locations, one having higher ground conductivity, and the other lower conductivity. Fig. 8 shows the considerable difference in radial current found. As shown, the current was substantially higher when the radial was on the ground with higher conductivity.

As each set of radials was added to the ground screen, a record was made of the current being supplied to the antenna, and the return current collected by the radials. The results are given in Table 2. As was also found in the case of the counterpoise, it appears that a ground system of fewer

Table 2
Current Flowing in the Antenna and Radials of Elevated Ground Screen

No. of Radials	Antenna Current, mA	Return Current, mA	Return as % of Ant. Curr.
0*	440	380	86
6	415	370	89
12	380	330	87
20	410	370	90
28	490	450	92
36	495	470	95
40	495	490	98
48	495	493	99

*Two 8-foot ground rods at base of antenna used to collect this data.

than 50 elevated radials may be as efficient as more than 100 buried radials.

The lack of research data in the past literature on the operational characteristics of the counterpoise extends to the ground screen. The ground screen is described in some detail by Laport¹³ and others, and its use is recommended in conjunction with buried-radial-wire ground systems to reduce ohmic losses near the base of a vertical antenna — losses caused by the concentration of return currents in that area (i.e., I²R losses). There is, however, no specific data on elevated ground screens operating alone, without additional buried radials. It can only be deduced that the ground screen has been considered to be identical in its operating characteristics, regardless of whether the radial wires were buried or elevated.

The Fletcher tests indicate that an elevated ground screen operates with excellent efficiency as the result of a number of factors.

1) The ground screen operates as a low-resistance, low-loss path for return currents.

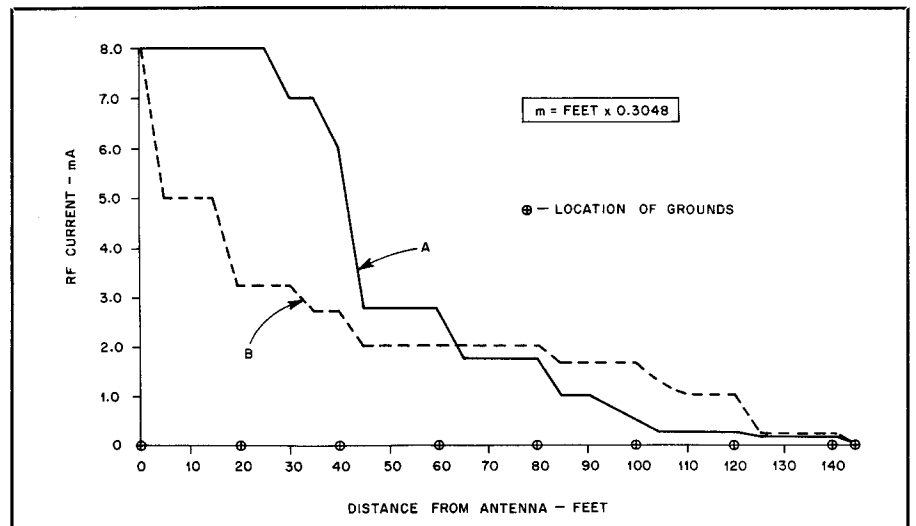


Fig. 8 — This drawing shows how ground conductivity affects the current flowing in a radial wire placed on the surface of the earth. Both wires were grounded every 20 feet. The wire of curve A was placed over soil with conductivity averaging 1.66 mS/m, while that under curve B averaged 1.17 mS/m.

2) Even though it is grounded at each end, each radial of the ground screen tested was capacitively coupled to the ground beneath it.

3) Return currents carried by the radials of an elevated ground screen vary with the conductivity of the ground under the individual radials — the higher the conductivity, the higher the current.

Summary of Findings

Our findings may be summarized briefly as follows: (a) There can be large variations in surface ground conductivity within the area covered by the ground system of a vertical antenna. (b) If there are variations in ground conductivity in the area occupied by a radial system, there will be corresponding variations in the magnitude of the currents in the various radials. These variations will persist regardless of whether the radials are elevated and insulated, as in a counterpoise, or grounded, as in a ground screen. (c) Elevated ground systems — counterpoise or ground screen — will collect return currents primarily as displacement currents induced directly by the field of the antenna. Currents will also be collected as charge-discharge currents induced from the ground below.

The majority of the return currents carried by elevated ground-system radials are collected directly from the antenna, or from the ground through an air dielectric. There is no necessity for these currents to pass for any considerable distance through high-resistance earth (as is the case when buried radials are used). As a result, these systems are highly efficient. Initial indications (i.e., a comparison of the data presented here with Brown's very thorough research on buried radials¹⁴) are that elevated "ground" systems used with electrically short vertical antennas may require substantially fewer radials than needed by a buried wire system of equal efficiency. (These indications have not yet been confirmed by direct comparison.)

Future Research

The research project described in this article was designed to help fill the gap of technical knowledge about the counterpoise and the elevated ground screen. Our findings, to a considerable degree, do not agree with the technical writings of the past 60 years, and they may therefore be controversial. In this regard we would like to point out that in the 45 years since the last comprehensive work was done on radial-current measurements, there have been great advances in instrumentation and techniques for measuring both ground conductivity and rf currents in wires. Thus, today's researcher, using relatively simple equipment, can make infinitely more accurate measurements than could be done in the past with a whole laboratory full of instrumentation.

We hope this research will encourage

others to continue the investigations we have started, and that Amateur Radio operators, who have always led the way in the area of practical experimentation, will obtain operational evaluation of counterpoises and ground screens from on-the-air tests. To assist efforts in this direction, we have examined the results of our research and have designed a "Minipoise" ground system that can be constructed in almost any backyard. As shown in Figs. 9 and 10, this antenna system comprises a 30-foot-high vertical antenna and a 100- × 100-foot counterpoise.

You might think the 30-foot vertical is short for use on 160 meters. However, a check of the literature shows us that "... an antenna of infinitesimal length, subject to no losses, yields a field strength which is only 4.25 percent less than the field from a quarter-wave antenna."¹⁵ This makes a 30-foot-high antenna, if used with a really efficient ground system, begin to look more attractive!

The 100- × 100-foot radial system, again based on past practice with buried radials, might seem too small to fill the requirement of a "really efficient ground system" for a 1.8-MHz antenna. But a

look at Fig. 6 shows that by far the majority of the return currents in the radial wires of a counterpoise are collected within 100 feet of the base of the antenna. And if this is so, why should the radials be longer?

At present, we are testing an extensively instrumented version of the system shown in Fig. 9, and have designed a rigorous test program to check its characteristics. We are making our design widely available, in the hope that others will join us in operational testing of this antenna. If impetus is required to get others interested, we might mention that our original antenna has been providing some rather remarkable results. From our location in the mountains of North Carolina — 400 miles inland — we have, with no difficulty at all, worked all continents on 160 meters. Our contacts included ZL, 4X4, OA, LZ, ZS, many European countries and all 50 states. And 99% of these contacts have been on ssb! We hope that many amateurs will join us in further testing of the counterpoise or ground screen systems.

Acknowledgments

From the inception of our test program

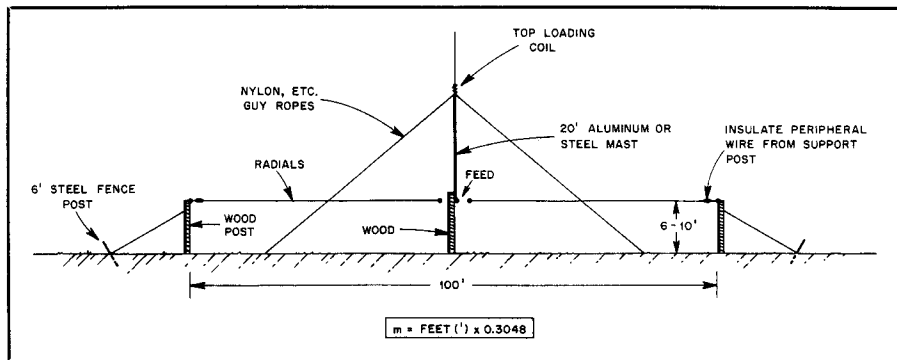


Fig. 9 — The Minipoise antenna system with a short, top-loaded vertical radiator, for 160-meter operation. See text.

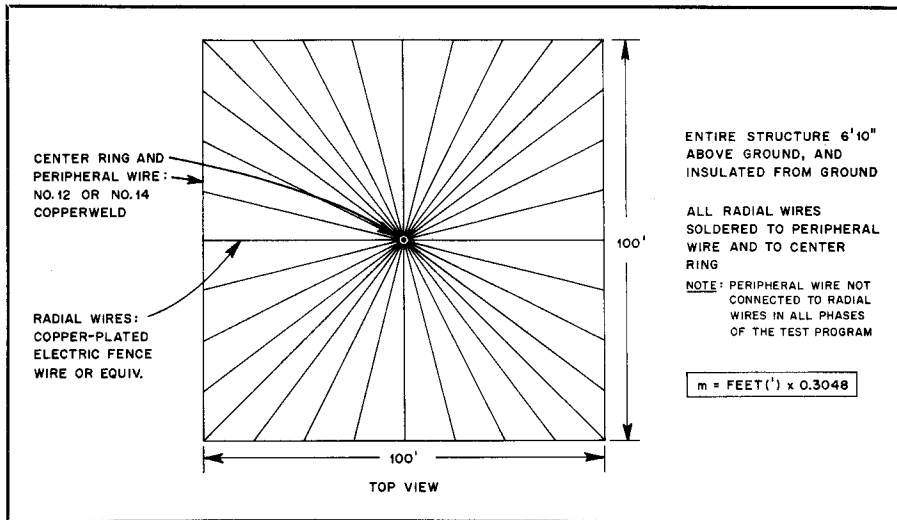



Fig. 10 — The Minipoise (miniature counterpoise) radial system is 100 feet square. This antenna was developed to promote interest in furthering the tests begun by the authors.

New Books

we have had a great amount of help, suggestions and encouragement from a number of our friends. Thus, we would like to express our very sincere thanks to those who gave their personal time to help this project: to Edmund A. Laport, without whose encouragement this project would never have been finished; to Barry A. Boothe, W9UCW, Earl W. Cunningham, K6SE, Paul R. Engle, K9QLL, and Richard B. Frey, K4XU, for their incisive and expert editing of the full technical report, from which this article was excerpted.

The complete (75-page) report of the full (15,000-measurement) test program includes the results of extensive additional tests not reported here. These included investigation of (a) capacitance of elevated radial wires to ground, (b) dielectric anomalies in the test area, (c) radial current vs. number of radials, and (d) effect of artificial modification of ground conductivity on radial current. Also, 27 references, in addition to those appended, were used in the design of the test program. The authors will be glad to share this material with anyone planning to undertake a definitive test program on the counterpoise or the ground screen. 

Notes

- ¹G. H. Brown, R. F. Lewis, and J. Epstein, "Ground Systems As A Factor in Antenna Efficiency," *Proceedings of the IRE*, June 1937, pp. 753-787.
- ²FCC Rules and Regulations, Part 73, Subpart A, 1972.
- ³Meters = ft \times 0.3048.
- ⁴See note 1.
- ⁵J. Sevicik, "Measuring Soil Conductivity," *QST*, March 1981, pp. 38-39.
- ⁶K. F. Carr, "Ground Currents Measuring," *Ham Radio*, June 1979, pp. 46-47.
- ⁷K. Henny, *Principles of Radio*, 3rd ed. (New York: John Wiley and Son, 1938), p. 461.
- ⁸S. A. Schelkunoff and H. T. Friis, *Antennas, Theory and Practice* (New York: John Wiley and Son, 1952).
- ⁹A. R. Nilson and J. L. Hornung, *Practical Radio Communication* (New York: McGraw-Hill, 1935).
- ¹⁰*Antennas and Radio Propagation*, Dept. of the Army, 1935.
- ¹¹Schure, *Antennas* (New York: John R. Rider, 1957), pp. 23, 73.
- ¹²E. A. Laport, *Radio Antenna Engineering* (New York: McGraw-Hill, 1952), pp. 48-54, 115-117, 187.
- ¹³See note 12.
- ¹⁴See note 1.
- ¹⁵See note 1.

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- Spencer, L., "John L. Reinartz," *Ham Radio*, Aug. 1981, pp. 10-18.
- The ARRL Antenna Book*, ARRL, 1968, pp. 200, 201.

□ *Amateur Radio Operating Manual*, R. J. Eckersley, G4FTJ, editor, published by the Radio Society of Great Britain, London; second edition, 1982. 204 pages, soft-cover, 7-1/4 \times 9-3/4 in., \$10. Available from ARRL Hq. or your radio book counter.

There are lots of new books on Amateur Radio subjects floating around these days, many of them with inflated price tags and few of them worth the asking price. Shelling out upwards of \$10 for a poorly researched and sloppily edited publication appears to be what some publishers expect radio amateurs to do these days.

One book that definitely is worth the money, if you're at all interested in viewing on-the-air operating from a fresh perspective, is the *Amateur Radio Operating Manual*, published by the Radio Society of Great Britain. In the brand-new second edition of this popular publication, editor R. J. Eckersley, G4FTJ, combines the efforts of some 50 contributors into a highly informative volume of more than 200 pages. Much of this material is original and unique to this publication; you probably won't find it anywhere else on this side of the Atlantic.

While written primarily for the British amateur and shortwave listener, most of its contents are of universal interest. Just about all aspects of Amateur Radio operating are covered in sufficient depth to be instructive to the old-timer but the text is written at a level that should appeal to the newcomer. In fact, a non-radio enthusiast could pick it up, read the opening chapter defining the Amateur Radio Service, and continue from there, developing a pretty good (although vicarious) working knowledge of what Amateur Radio is all about. This is in contrast to most other Amateur Radio literature, which seems to presuppose a large amount of "inbreeding."

The 10 chapters and 7 appendices include 11 pages on how to set up a station, 17 pages on operating practices, 52 pages of information on DXing (at hf and vhf/uhf), 10 pages on amateur satellites and 19 pages on contesting (did you know that most contesters drink Coke, Pepsi, black coffee or tea?), and so forth. The book is lavishly illustrated throughout, with high-quality charts and graphs, diagrams and very detailed maps. Of particular interest, for both the armchair traveler and the DXpeditioner, are the individual call area maps for each country that has been assigned an ITU call sign block, along with the addresses of the licensing administration and the national Amateur Radio society in each country.

I have the utmost admiration for Editor Eckersley and his associates for the painstaking work involved in compiling all the information that appears in the RSGB *Amateur Radio Operating Manual*. However, I would comment that the *ARRL Operating Manual*, although not nearly as comprehensive, may be more readable to amateurs on this side of the pond, owing to its somewhat more informal prose style. Between the two of them, no questions about Amateur Radio operating — one of life's spirited adventures — will be left unanswered. — *Robert Halprin, K1XA*

□ *EMP Engineering And Design Principles*, by Bell Laboratories, copyright 1975, second printing. Soft-bound, 8-1/2 \times 11 in., 151 pp., \$14.95 plus \$2 shipping. Available from Clayton Survival Services, P.O. Box 1411 Mariposa, CA 95338.

In the August 1981 issue of *QST*, a major article featured the subject of EMP — electromagnetic pulses generated by a high-altitude detonation of a nuclear device. A 250-mile-high nuclear detonation over the central USA would create an intense pulse of tens of kilovolts within nanoseconds over a frequency range from a few cycles into vhf. The radius of this pulse would cover the entire continental USA. Consequently, EMP represents a potential threat to the integrity of all solid-state devices in general, and to Amateur Radio equipment in particular.

This book, although written at the engineering level, is an excellent source that enables amateurs to better understand EMP and take precautionary measures against it. The book is directed toward telephone company buildings, installations and equipment. However, most of the information is applicable to radio communications.

An opening chapter covers EMP generation and characteristics in detail, and is excellent in providing for an understanding of the EMP phenomenon.

A chapter on coupling to exterior structures deals with EMP conduction by power lines, cables, towers, waveguides and other metallic objects into the interior of a building.

The chapter on shielding is of limited interest to amateurs, since it mostly involves shielding an entire building from EMP by means of reinforcing steel rod loops installed during the construction of concrete buildings.

Coupling inside the building is the subject of a chapter that deals with methods of preventing EMP from reaching sensitive devices, principally by multiple bonding and grounding outer shields of conductors, but also through the use of EMP-effective lightning arrestors.

Component susceptibility and electrical devices for EMP mitigation are two chapters of real interest and practical value to radio amateurs — particularly to designers and builders of solid-state equipment. Detailed factual data is given on various types of component vulnerability to EMP, and various methods are outlined on how to protect these components.

The final two chapters concern EMP testing and personal safety. This information is interesting, but few (if any) hams have this kind of high-voltage testing capability.

EMP Engineering And Design Principles is one of the few available sources of detailed information on EMP. I highly recommend it for reading and application by all radio amateurs, and designers of Amateur Radio equipment.

With new Amateur Radio equipment now virtually 100% solid-state, our hobby, which serves in the public interest, can ill afford to fall behind the state of the art with regard to EMP. We must be able to provide radio communications in the event of a nuclear emergency situation. — *Fred Huntley, W6RNC* 