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ELEVATED RADIAL WIRE SYSTEMS FOR VERTICALLY POLARIZED GROUND-PLANE TYPE ANTENNAS

Part 1—Monopoles

Resonant quarter wavelength radials (electrical length at a quarter wavelength) can be used with practical elevated ground-plane type antennas and to simulate "connection" to ground for numerical modeling programs such as NEC-2, which does not allow a wire to touch lossy ground.

Introduction

From the earliest days of radio, the merits of elevated counterpoise and radial systems have been recognized because of the way in which current densities in the ground are more or less uniformly distributed over the area of the insulated counterpoise (which is, in effect, a large capacitance ground). Figure 1 shows wires running radially outwards on insulated supports without connection being made to earth plates or ground stakes at the outer ends of the system. An alternative view of the way an elevated radial system works is that it allows the collection of electromagnetic energy in the form of displacement currents, rather than conduction currents flowing through lossy earth. Certainly,
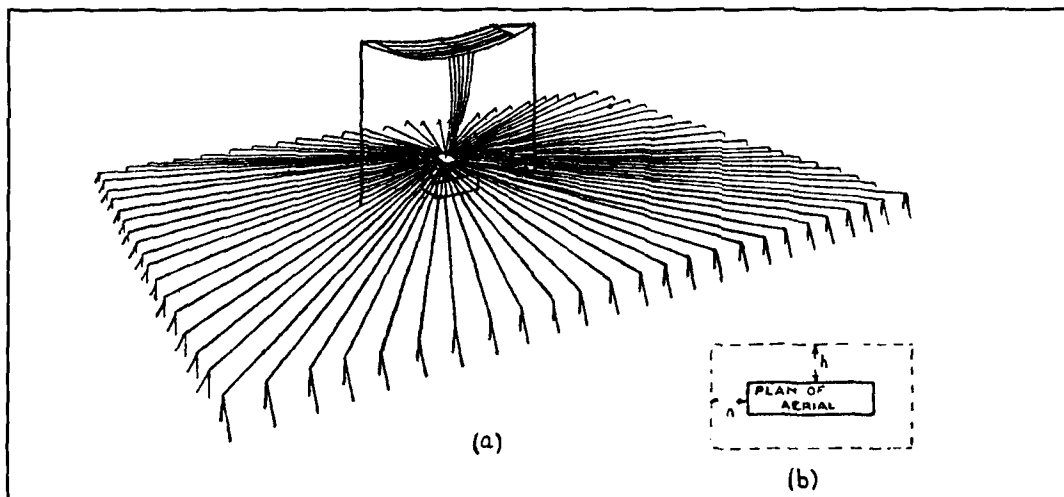

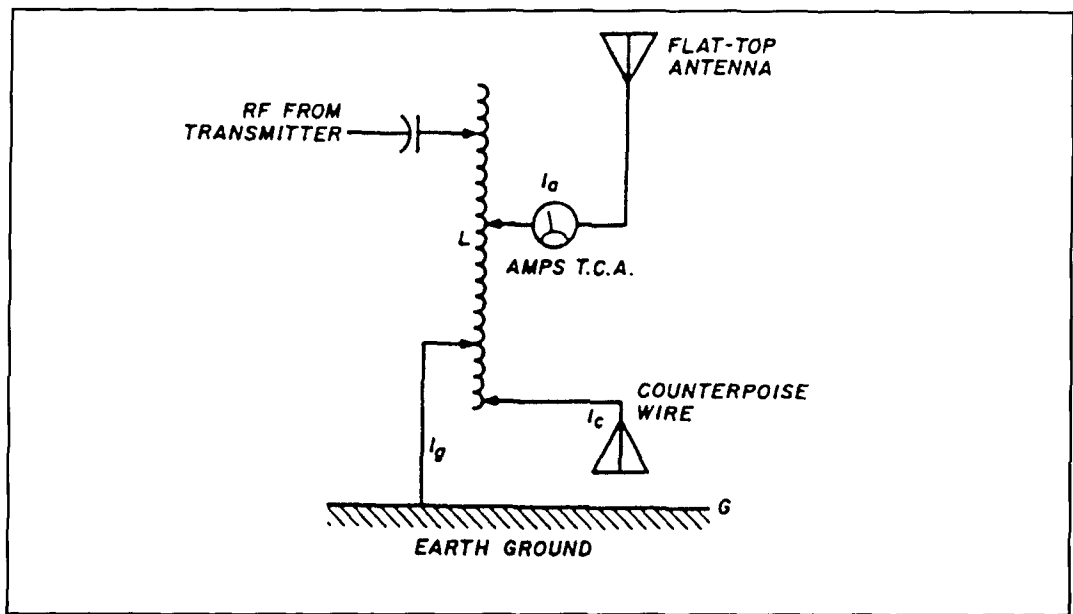Figure 1. T-antenna over a counterpoise earth [after *The Admiralty Handbook of Wireless Telegraphy*, 1938[1]].

Figure 2. 2BML's "flat top" antenna system of 1921.

when only a few elevated radials are used, we cannot consider the counterpoise forming a large capacitance ground.

H.H. (Bev) Beverage, 2BML (now a silent key), in a 1921 publication by RCA described an aerial and counterpoise system suggested by Alexanderson and using a coupled ground wire. Details of 2BML's antenna system are shown in **Figure 2**. Having permission to operate above 200 meters, Beverage chose to tune his antenna system to 280 meters (1070 kHz). With a fair ground, his measurements showed a system resistance of around 70 ohms and 0.5 ampere antenna current. But with the elevated counterpoise attached, the system resistance dropped to 10 ohms. The ground lead tap on the inductor was adjusted to cancel the capacitive reactance of the elevated counterpoise. With both the earth and counterpoise connected, a system resistance of 4 ohms and an antenna current of 8 amperes was obtained. With 8 amperes of RF current going into the antenna, the counterpoise current (Ic) was about 6 amperes, and the earth ground current (Ig) was about 2 amperes.

It was stated that most amateurs, and many broadcast stations (KGO was one of them) were already using the counterpoise at that time. In December 1921, the amateur radio station of The Radio Club of America, 1BCG, also employed a counterpoise system containing 30 wires each 73.5 meters long (0.31 λ for an operating wavelength of 230 meters).[2]

The development of such ground systems was, by necessity, empirical in nature, as sophisticated instrumentation and standardized antenna testing procedures were not available

in the early days of radio. Unfortunately, after about 1937, the use of elevated radial systems became an almost forgotten art, because of research by Brown et. al.[3] in favor of the buried radial system. These authors carried out a very extensive measurement program to determine the impedance and radiation efficiency of a vertical monopole as a function of ground system parameters. A result of their work was their recommendation that 120 radial wires, each one about half a wavelength long, should be used to maximize radiation efficiency; 0.4 λ is a length quoted in many text books as optimum. This is a curious result (a half a wavelength?) in light of what we know today.[4]

Elevated counterpoise types of ground systems were extensively studied through experiments by Doty, Frey, and Mills.[5] The radial systems they used were not unlike that shown in c.f. **Figure 1** (except a perimeter wire joined the ends of the radial wires), i.e. the counterpoise radial wires filled a rectangular area over the ground, rather than being of equal or a resonant length. Christman, KB8I,[6] was perhaps the first to show by numerical modeling that a vertical monopole with as few as four horizontal radial wires could be at a height quite low over real ground before the radiation efficiency of the antenna was significantly degraded. Unfortunately the topic of ground mounted and elevated radials, and antennas with elevated feed, has remained clouded by controversy, e.g., posting on the Internet News Group on Radio Amateur Antenna; and, c.f. Belrose[7,8] and Hawker.[9] More recently Weber[10] has described measurements he made on systems employing elevated radials, which revealed

Figure 3(A). Wire model and current on the wires for a 20.2-meter vertical wire antenna with one resonant radial (length 19.184 meters for a height of 2.5 meters over average ground; (B) vertical radiation pattern; and (C) principle plain azimuthal pattern (resonant frequency 3.75 MHz).
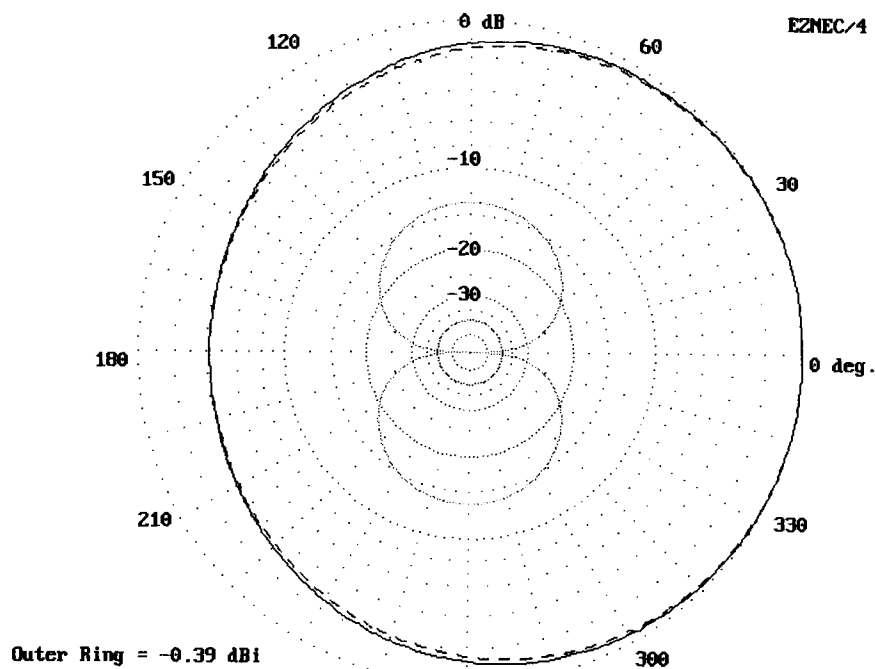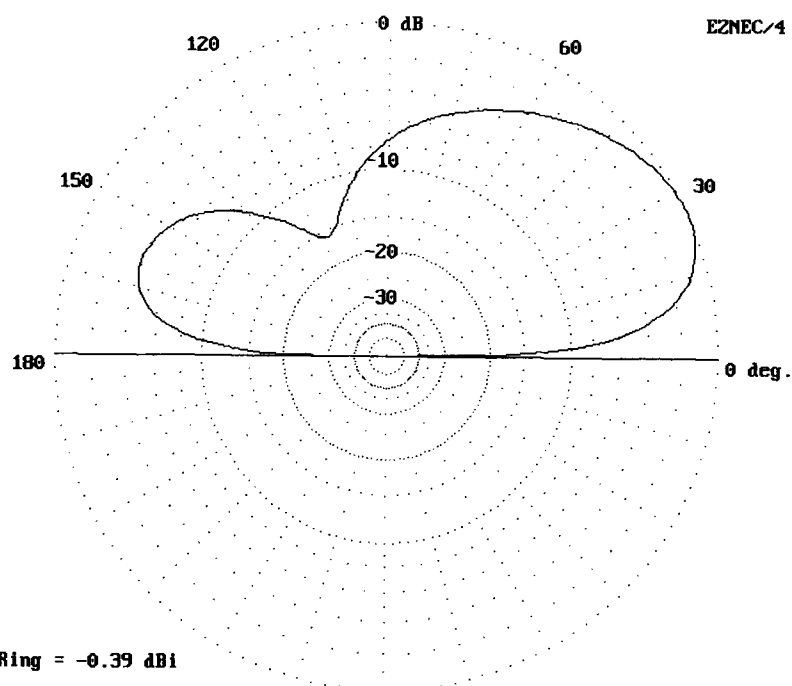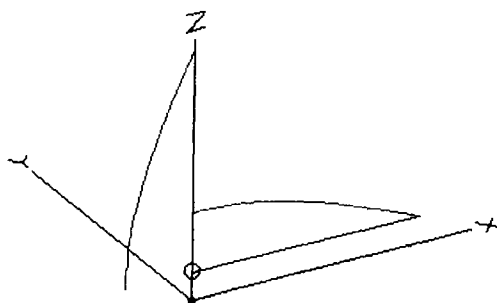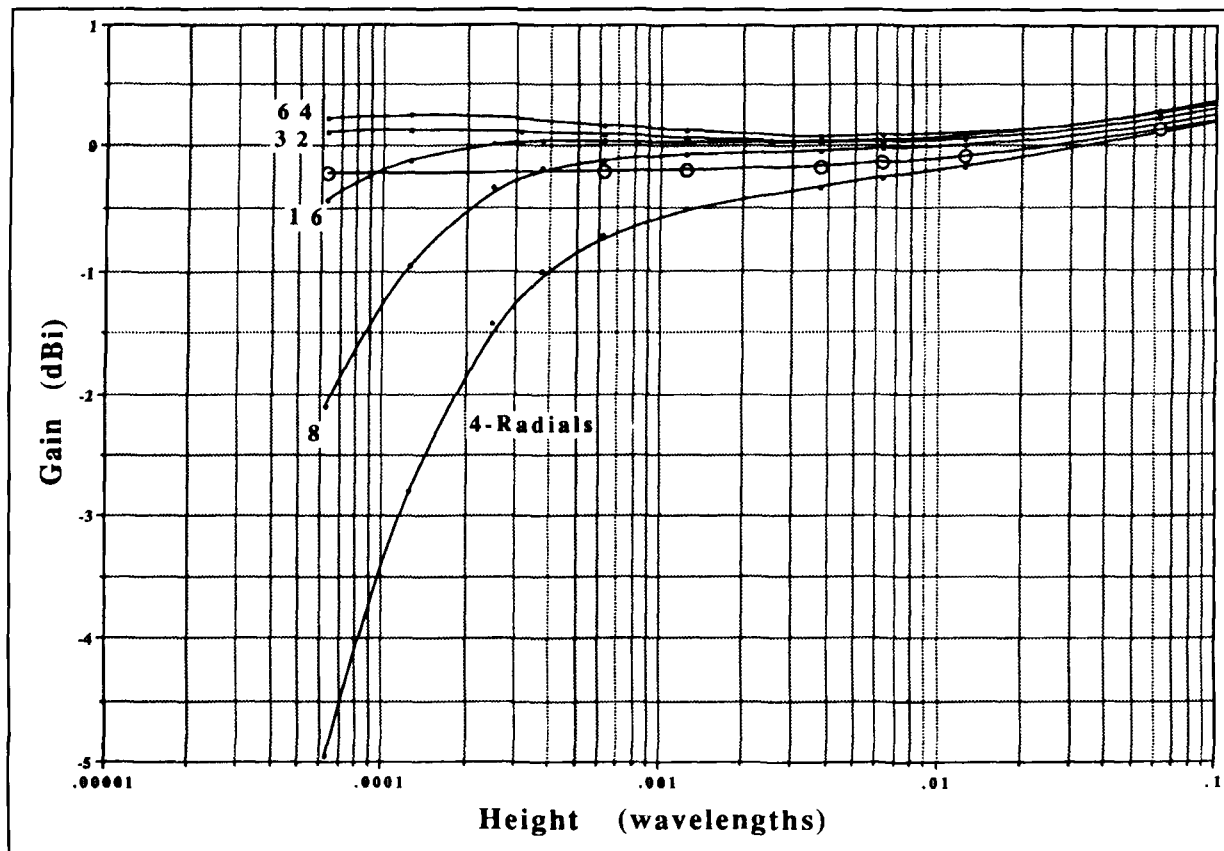
Figure 4. Predicted gain for a 20-meter monopole versus number of 20-meter radials and height in wavelengths of radials over average ground; and for a vertical half-wave dipole for reference, where height is the lower end height of the dipole. Frequency is 3.75 MHz.

unequal radial currents, and he employed numerical modeling to aid his understanding of the subject (see also comment by Severns[11] and **Appendix 1** of the present article).

To continue, if four elevated radials can be used to realize performance for a monopole comparable with many buried radials, then elevated radials can be used for real antennas and to simulate ground "connection" for numerical modeling programs like NEC-2, which does not permit a wire to connect to lossy ground.

This article is an overview of the subject of elevated radials.

Initial Experience

NEC-2 is currently enjoying wide application by radio amateurs using PC based programs such as EZNEC, available from Roy Lewallen, W7EL,[12] and EZNEC/4 pro for those registered for NEC-4. The ability of the NEC codes to accurately treat the air-ground interface (based on the Sommerfeld-integral formulation) is assumed to be validated by the developers of the program[3].

About 20 years ago, while conducting experiments to determine the efficiency of electrically short antennas, I noticed that a vertical antenna with one radial exhibited a marked directional effect. The direction of maximum gain (maximum groundwave field strength) was the direction toward which the radial ran. A front/back ratio of 10 dB was observed for a short center-loaded whip with a quarter wavelength insulated radial lying on the ground.

This discovery lead to the development of a simple transportable antenna, dubbed, by Christman,[6] the "VE2CV Field Day Special" antenna. This antenna was simply a quarter wavelength vertical wire with a tree support (or a pipe mast for 40 meters and down), with one radial elevated above head height (2.5 meters) directed toward the azimuth of principle interest. The directional pattern can be changed by installing more than one radial and selecting the appropriate radial by connect/disconnect relays.

Figures 3A through C show the patterns for such a simple antenna over average ground (ITU-R definition of average ground, viz. $\sigma = 3$ mS/m; $\varepsilon = 13$). The patterns are for a frequency of 3.75 MHz, quarter wavelength vertical (resonant length 20.2 meters), with a single resonant radial (length 19.184 meters) for a radial height of 2.5 meters over average ground. The input impedance according to NEC-4 is a good match
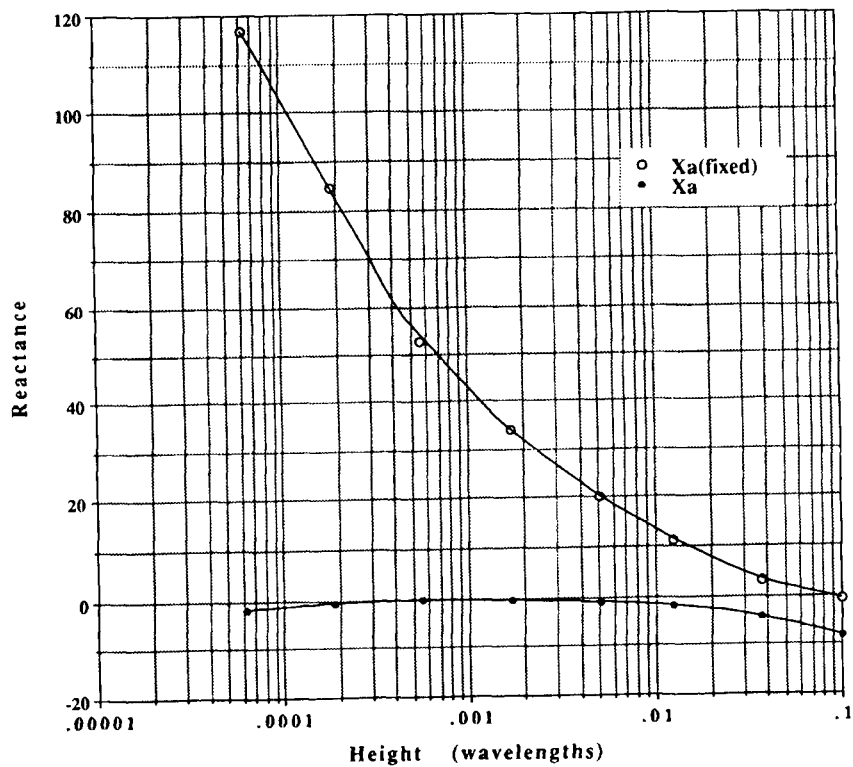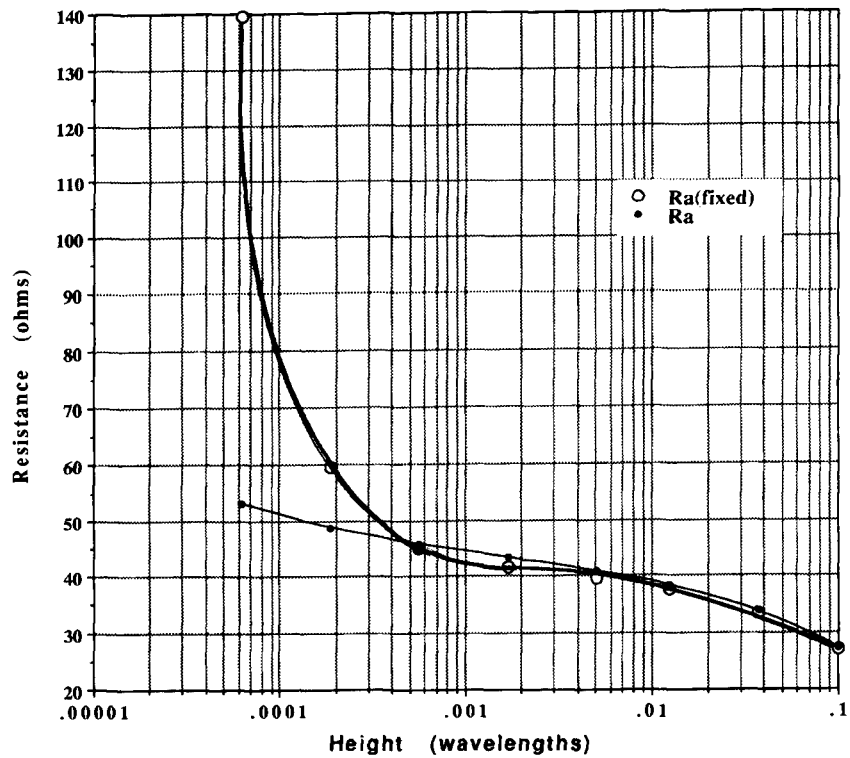
Figure 5. Predicted impedance (resistance and reactance) for a quarter wavelength, 20-meter, 3.75-MHz monopole versus radial height over average ground, for four fixed-length (20-meter) radials and for four resonant radials.
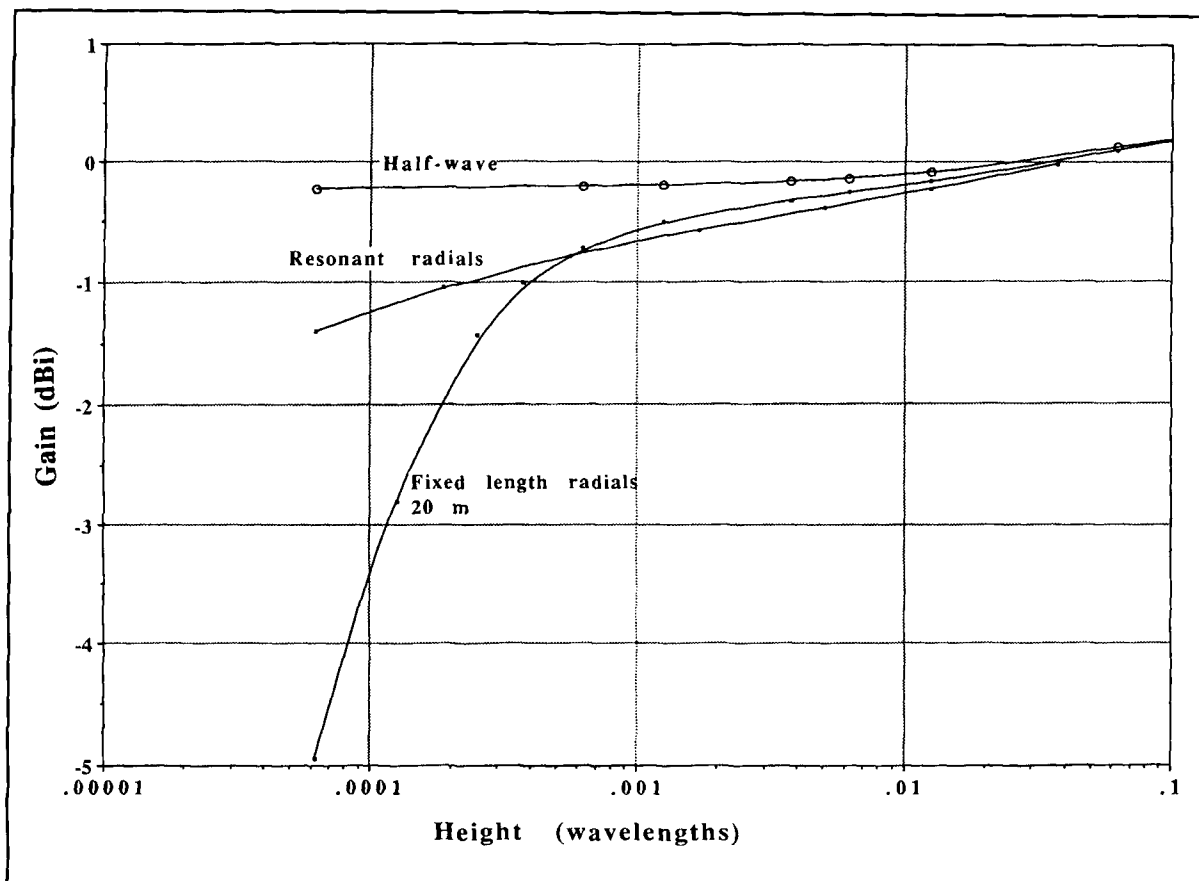
Figure 6. Predicted gain for a quarter wavelength monopole with four quarter wavelength radials and with resonant radials versus height (wavelengths) of radials over average grounds; and for a half-wave dipole where height is the height of the lower end of the dipole. Frequency is 3.75 MHz.

for 50-ohm coax (57 ohms), but a current balun should be used.

Note that **Figure 3C** shows the vertical, horizontal, and total fields—dashed, dotted, and continuous lines—since there has been some discussion about the horizontal field not canceling when there are fewer than three radials (three radials is the minimum number that can be arranged symmetrically about the monopole).

A detailed study

For the case studies to be reported here, I chose to model a 3.75-MHz monopole over a radial wire system where all elements were #10 copper wire, and where all wires, monopole height, and radials were 20 meters long (0.25 λ long for a wavelength of 80 meters).

Tom Rauch, W8JI[13], conducted a series of experiments with a 3.7-MHz quarter wavelength vertical wire antenna using elevated and ground-mounted radials. His measured relative field strengths for the ground mounted radial systems changed as the number of radials

changed in a way closely predicted by NEC-4. For four, eight, and 16 radials on the ground, his measured gain differences, referenced to the relative field strength measured for 60 radials on the ground, were -5.5 dB, -2.7 dB, and -1.3 dB.

Since NEC-4 does not allow a wire to touch lossy ground in more than one place (NEC-2 does not allow a wire to touch the ground at all), I modeled a radial on the ground by assuming an insulated radial system with radials 5 millimeters high. With four, eight, 16, 32, and 64 quarter-wavelength radials, EZNEC/4 predicts gains for an antenna over average ground of -4.66 dBi, -2.16 dBi, -0.6 dBi, +0.03 dBi, and +0.23 dBi.

Note: the spacewave gain of our monopole with perfect ground beneath the antenna (equivalent to, say, an infinite number of radials), but with average ground in front of the antenna (MININEC analysis), is 0.18 dBi.

Now let us see how gain changes as a function of height (height of radials) and number of radials (**Figure 4**). For reference, the gain of a half wave dipole is shown (large open circles), where height is the height of the lower end of

the dipole. Note that the lowest height, 6.25 x 10^{-5} λ, corresponds to the 5 millimeter height referenced above; and a height above head height (2.5 meters) corresponds to 0.031 λ at the reference frequency of 3.75 MHz (wavelength 80 meters).

All experiments that I am aware of have used radials of a fixed length (quarter wavelength) as the height of the radial system was changed. But a radial wire at a low height over finitely conducting ground needs to be increasingly shortened as its height is lowered in order to realize and maintain resonance. The length for the ground mounted radial case study described above was for a fixed length radial (quarter wavelength long). The resonant length of a radial wire 5 millimeters above average ground is 0.138 λ, and so clearly the radials were not resonant. The impedance at 3.75 MHz, according to NEC-4, for our 20-meter high vertical wire antenna with four radials, 20 meters long, is $Z_a = 130 + j\,114$ ohms (which is certainly not a resonant monopole), and the gain is -4.66 dBi. But, if four resonant radials, 11.1 meters long (quarter wavelength electrical length for a radial height of 5 millimeters over average ground), are used, the antenna is more or less resonant at $Z_a = 52.3 - j\,0.9$ ohms, and the gain is -1.45 dBi.

In **Figure 5**, I have plotted the monopole resistance and reactance versus height of the antenna for four fixed-length (20 meters) radials (open circles). For resonant radials (closed circles), length is a function of height and ground conductivity, which for this graph is average ground. Notice in **Figure 5A** the sudden break between the two curves for heights less than 4 x 10^{-4} λ (4.8 centimeters).

In **Figure 6**, I have plotted the predicted gain for a 20-meter-high vertical wire antenna versus height in wavelengths for four radials a quarter wavelength long (20 meters); for radials of resonant length; and the gain of a vertical half wave dipole, for reference, where height is the lower end height of the dipole. Again, notice the sudden break between the two curves for heights less than 6 x 10^{-4} λ.

Note: the curves on **Figures 4, 5**, and **6** have been computed by NEC-2 (earlier work by the author[14]), but NEC-4 gives very similar results.

The reason for the marked difference between radials having a physical length of a quarter wavelength and radials having an electrical length of a quarter wavelength can be seen in **Figure 7**, where I show the wire models for these two antenna systems and the current distribution on the wires for a radial height of 5 millimeters. Since a ground system is one side of a GP antenna, its purpose is to provide a low impedance against which the antenna can be driven. Ideally this impedance should have a
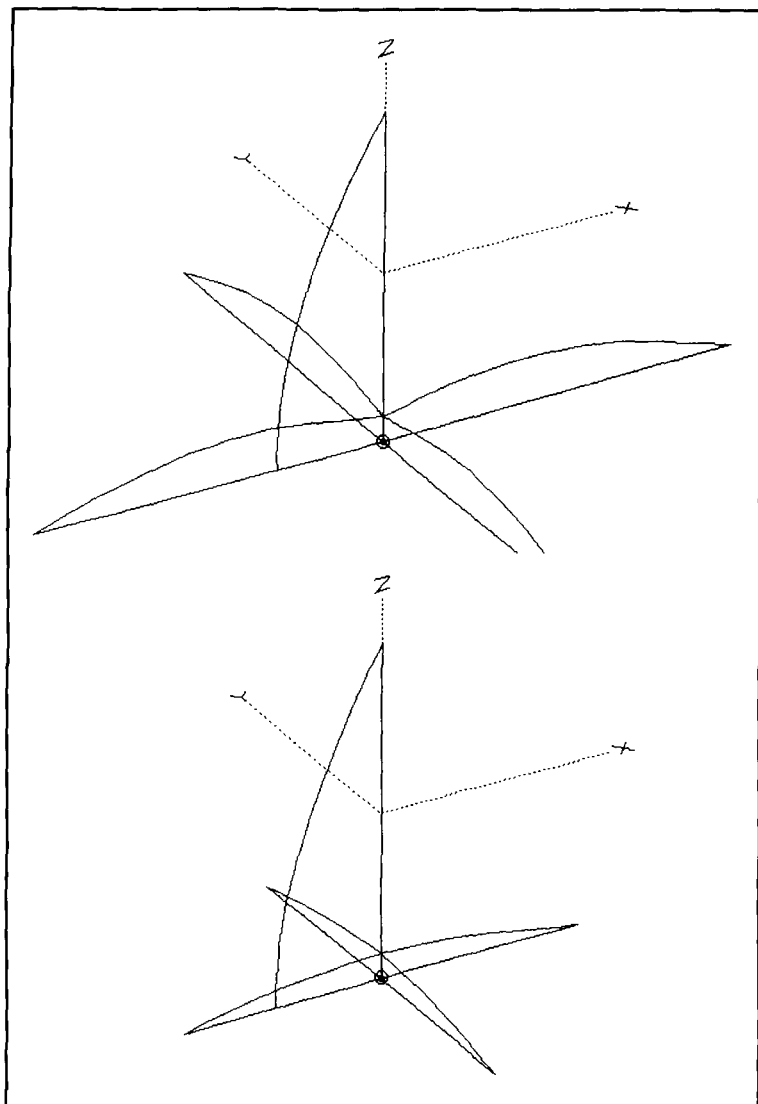

Figure 7. Wire models and current on the wires for a 20-meter vertical wire antenna with four 20-meter long radials; and with four resonant radials (length 11.1 meters) 5 millimeters above average ground.
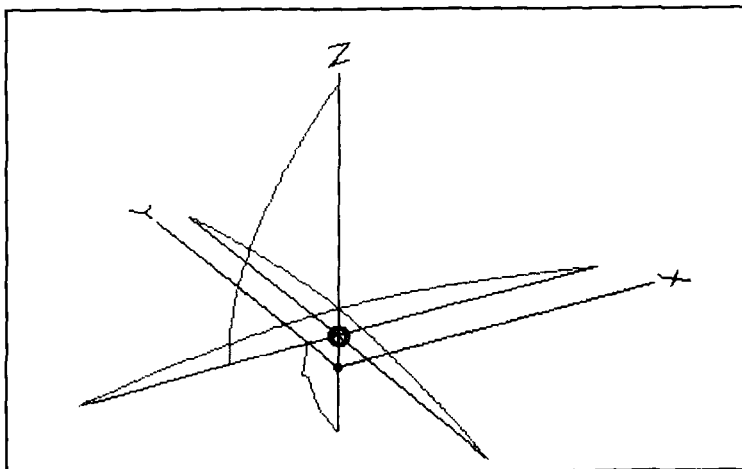

Figure 8. Model and current on the antenna system for a grounded tower (ground is a ground rod) with elevated radials, see text for details.

low resistance and only a small reactance since we want to maximize the current on the antenna. Clearly, the longer radials, shown in **Figure 7A**, do not well fulfill the requirement for a resonant radial. And, since the radials are not a resonant length, the impedance of the monopole is changed. Furthermore, since the current on the source end of the radial wires is not the maximum current on the wires, the radial system couples more current, and hence more power loss, to the ground beneath then does the shorter resonant radial system (see **Figure B**).

Comparison with measurements

There are only a few measured results to compare with predicted performance. Christman[15] measured groundwave field strengths at three distances for an 8-MHz vertical monopole with various ground systems. He made measurements with four quarter wavelength long elevated radials for three heights, 1 meter, 3 meters, and 5 meters, using direct and isolated feed, compared with 120 ground mounted radials. In his experiment, he recorded 18 field strength values, but he had to reject a block of four values since the results (impedance and field strength) were quite inconsistent with the full set of measurements. His measurements, in my view, illustrate the difficulty experienced in accurately measuring small differences in gain between different antenna systems at a different sites on different days. For example, his set of measured field strengths at three sites for a quarter wavelength monopole with four radials at 1 meter and 3 meters, direct feed, compared with 120 radials on the ground, corresponds to relative gain differences, of -4, -2, -1, 0, 0, and +1 dB, for a median difference between 0 and -1 dB.

Beverage[16] (no relation to Bev Beverage) determined the efficiency of an experimental 0.17 λ tower with six 0.25-λ radials, 0.024 λ high, at the operating frequency 1580 kHz, by measuring field intensity along 12 radial directions extending out to a distance of up to 85 kilometers. The measured RMS efficiency was 287 mV/m for 1 kilowatt radiated at 1 kilometer, which is the same measured value as would be expected (FCC files) for a 0.17-λ tower above 120 buried radials.

In spite of this good agreement between theory and experiment, there are some measurements (for a simple monopole antenna) that are not in accord with expectation. Rauch's elevated radial measurements[13] do not agree at all with prediction. He measured a trend in the change of relative gain with change in number of radials (for a radial height of 2.44 meters, or 0.03 λ at 3.7 MHz) that is almost identical with that (earlier reported) for radials on the ground.

For four, eight, and 16 elevated radials, referenced to 60 radials on the ground, Rauch measured relative gains of -4.17 dB, -2.28 dB, and -1.08 dB. For four, eight, 16, and 32 quarter wavelength elevated radials, EZNEC predicts spacewave gains of -0.02 dBi, +0.08 dBi, +0.13 dBi, and +0.16 dBi.

Direct feed versus isolated feed

There is no doubt that a coax feeder supplying power to a monopole with elevated radials can have currents induced to flow on the outer surface of the shield, if the antenna is directly fed. Beverage[16] noted that if he disconnected the feedline from the antenna tuning unit input to an 1160-kHz ND tower with elevated radials (radial height 0.018 λ), and installed an RF choke made up of toroidal cores around the coaxial cable, that the antenna's impedance changed by a small amount, and a slight heating of the cores indicated that an RF current path did exist along the outer shield of the coaxial cable. When the antenna was retuned, however, no change in field strength could be detected.

I recommend however that a current balun be used to feed GP-type antenna systems with elevated radials.

Feeding grounded towers

Numerical modeling studies using NEC-2 or NEC-4 are for the case of insulated base towers, and broadcasters who have used elevated radials have used them with insulated base towers. Radio amateurs, however, have used elevated radials in a sort of reversed feed arrangement as a method of feeding a grounded tower (a tower with or without top-loading by a Yagi antenna), c.f. Russell.[17] The radials are attached to a ring centered on the tower at the point of feed, but insulated from the tower. The feed uses coaxial cable with the shield connected to the tower leg and the center conductor to the ring. The legs of the tower should be strapped together at that point. Evaluation by impedance measurement and over-the-air testing support the view that this method of feed works well, and indeed NEC-4 confirms that this method can be used, providing the height of the monopole (height above the feed height) is not greatly different from 0.25 λ (see **Appendix 2**).

I have compared the insulated base feed with the grounded tower arrangement just described for a tower height of 20 meters (a resonant height for a frequency of 3.75 MHz for the case of an insulated base tower, base height 2.5 meters, with four resonant radials of length 19.184 meters). The base impedance according

Appendix 1

K5IU's Elevated Radial Vertical Antenna Is Modeled

Dick Weber, K5IU,[10] has used an elevated radial vertical antenna suspended from a sloping wire (broken by insulators) attached to his 140-foot tower at the 120-foot level (**Figure 9A**) for about 13 years. He was quite satisfied, until recently, with the performance of this antenna, but had noted that it seemed to work better in one direction. He considers that this might be due to unequal currents on his radial wire system—unequal because the lengths of the radial wires may not have been identical.

The more likely explanation for any directional effect, in my view, is that currents are induced to flow on the tower, on any Yagi antenna it may support, and on the wire (broken by insulators) used to support his antenna. This effect is also due to directional differences in ground conductivity, a particular concern when working distant stations due to the elongated extent of the Fresnel zone for signal arriving at low elevation angles. The latter effect is a dominant factor at my QTH (see **Reference 18**) and came as a surprise since the direction of least gain was in the direction of a golf course (no buildings, perhaps good ground).

K5IU did not tell us what was on top of his 140-foot tower. Undoubtedly this tower supports a
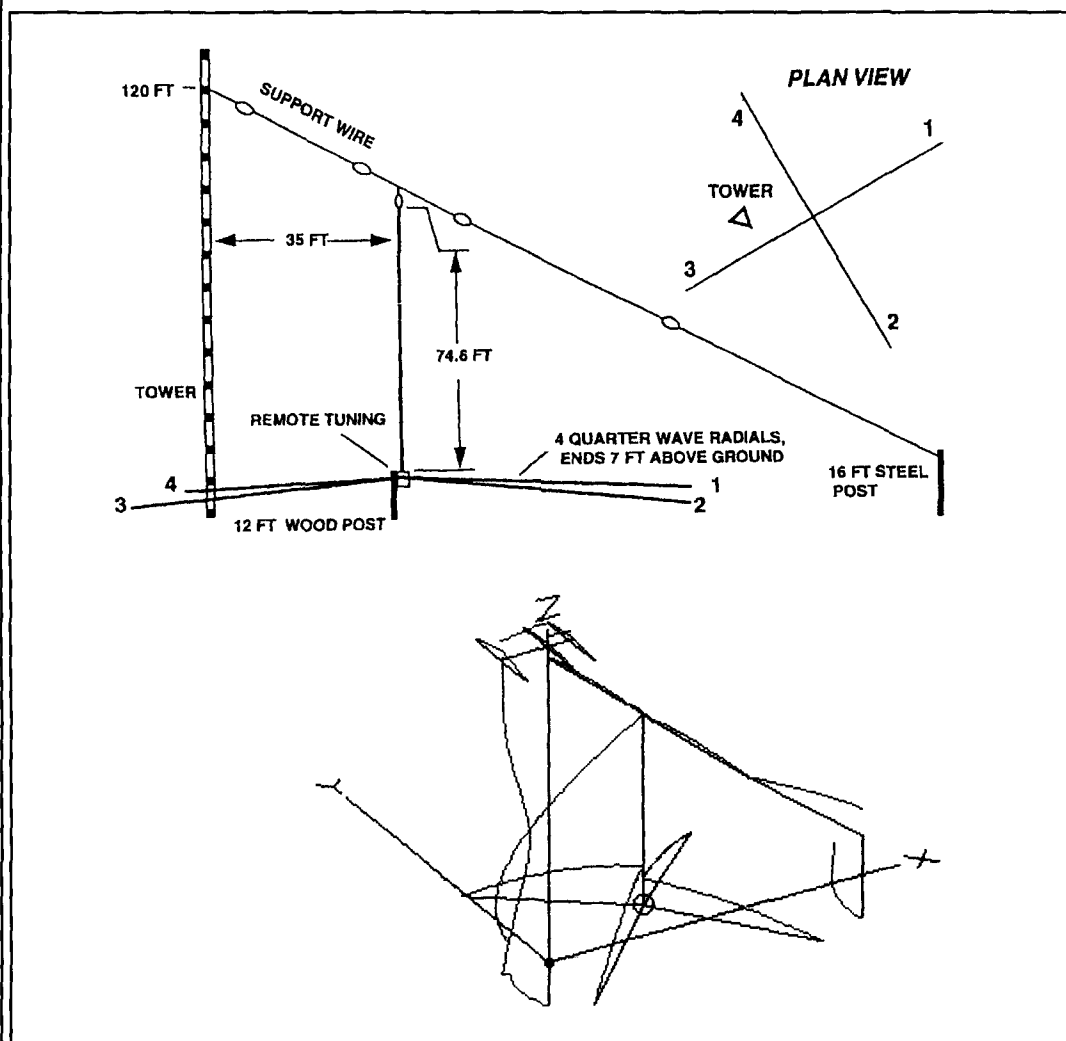

Figure 9 (A). K5IU's elevated radial vertical antenna; and (B) the model for this antenna system, modeled with a 20-meter Yagi on top of the tower. The figure shows the model and currents on the conductors (amplitude only to emphasize magnitude) at a frequency of 4 MHz.
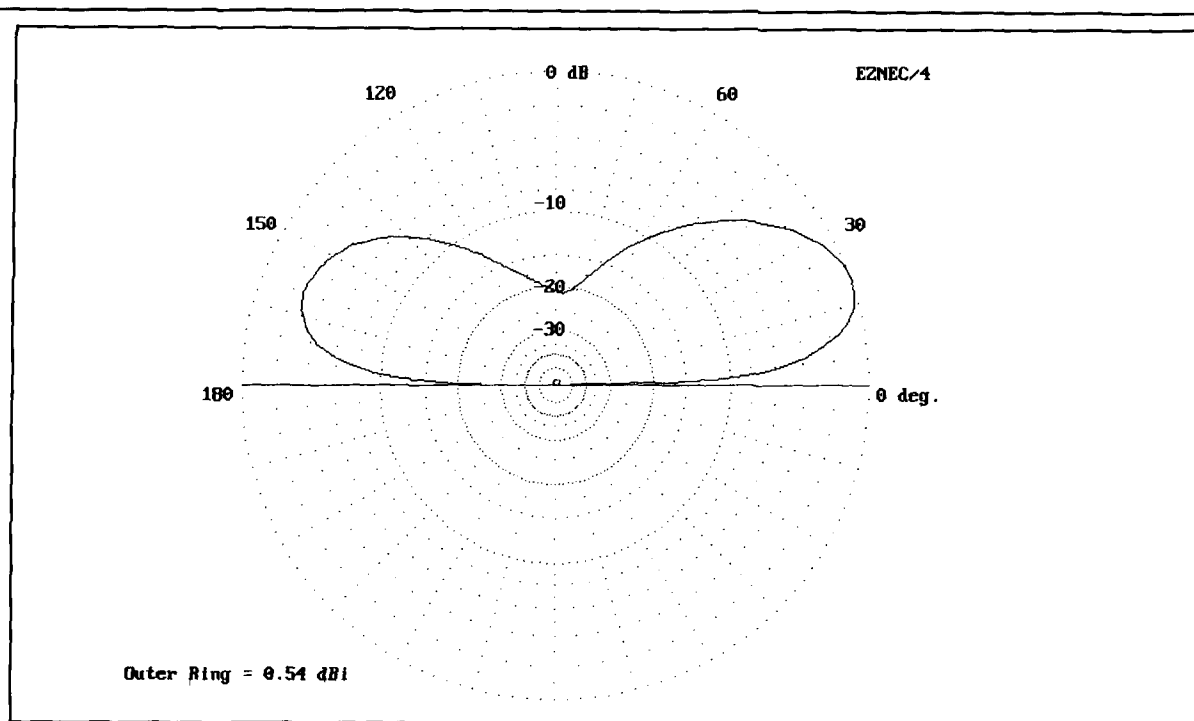
Figure 10. Radiation patterns (see text) at a frequency of 4 MHz for Figure 9(B)'s antenna system.

beam or beam antennas. For purposes of illustrating the point I wish to make, I have assumed (see **Figure 9B**) that his tower supports a wide spaced monoband 20-meter Yagi antenna. **Figure 9(B)** also shows the currents on all conductors (traces superimposed on the antenna diagram). It is clear that, as expected, an appreciable current is carried by all conductors: the grounded tower (in this model I have used a 5-meter ground rod), the 20-meter Yagi, the sections of the support wire, the grounded steel post, and the piece of wire connected to it. The phase and amplitude of these currents are frequency dependent, and so is the resulting radiation pattern.

The vertical plane pattern, for a modeling frequency 4 MHz is shown in **Figure 10(A)**; the azimuth angle is 0°. The principle plane azimuthal pattern is shown on **Figure 10(B)** at an elevation angle of 19°.

to NEC-4 is 36 - j 0.8 ohms, and the spacewave gain 0.01 dBi. For a grounded tower, "ground" being a 5-meter ground rod (a somewhat impractical length but no problem for modeling), with the four elevated resonant radials as above, the source impedance is 40 + j 15 ohms and the gain is -0.63 dBi. The small decrease in gain is certainly due to current on the part of the tower below the feed, which for 1 ampere ∠0° into each radial wire is 1.1 amp ∠110°. Note that, for this grounded tower model, the tower height is 22.5 meters since we have kept the height of the tower above the radial wires 20 meters.
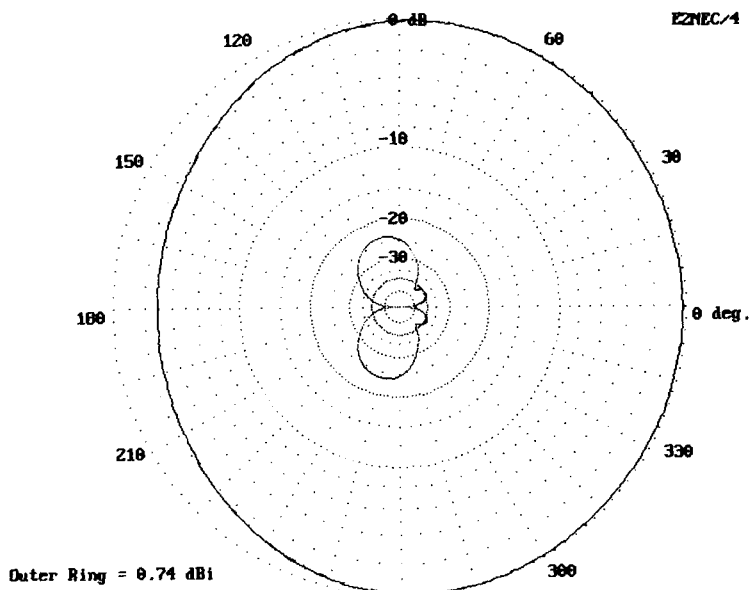
Figure 8 shows a wire model for the grounded tower arrangement and the currents on the wires (current amplitude only is shown).

Conclusions

Elevated radial ground systems have many

applications, including: 1) realizing achievable gain for ground plane type antennas (monopoles and loops) over real ground with only a few radials; 2) providing versatility, e.g., control of radiation pattern; and 3) modeling to simulate a connection to ground. To model GP type antennas, one would often want to simulate a connection to ground; and, for purposes of modeling, a connection to ground is sometimes desired to simulate the effect of support structures or other grounded towers in the vicinity of the antenna system.

To work well, and to not change the resonant frequency of the antenna system, *the radials must be resonant.* On discovery that resonant radials should be used, in retrospect, this should have been anticipated, it is perhaps a surprise to see how different the characteristics of the antenna can be, compared with using non-resonant radials. This is particularly striking when there is a significant difference

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                         0 dB
        120                        60        EZNEC/4

   150                 -10                30

                     -20
                   -30

  180                                      0 deg.

   210                                     330

Outer Ring = 0.74 dBi               300
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Notice in particular the strong current on the 16-foot steel post in **Figure 9(B)** and on the piece of support wire connected to. While this certainly has an effect on the radiation pattern, we can remove the support wires entirely from our model (assuming a nylon rope), and we'll still find a pattern not unlike that shown in **Figure 10**.

For our purposes, there is no need to model K5IU's antenna system exactly, because I do not have data on the directional pattern, and for whatever model, the effects are very frequency dependent (the direction gain effect is less at 3.5 MHz compared to 4 MHz for this model). The point of this analysis is only to illustrate that one cannot hang a vertical antenna in front of a tower and carry out a numerical modeling analysis to calculate gain and pattern as though tower were not there.

between the electrical and physical length of the radial wire, such as a radial wire at a very low height.

We should note that the case studies discussed here are for ideal antenna systems, i.e. there are no nearby antenna systems or towers which could affect impedances, currents, and radiation patterns, c.f. **Appendix 1**.

A detailed study by the author (experimental and numerical modeling) of full- and half-wavelength ground-plane type 80-meter transmitting loops, where elevated resonant radials are used to simulate connection to ground for half-loops, has recently been published.[18]

In Part 2 of this article, I will discuss case studies that confirm that phased array directional systems can indeed employ elevated resonant radials, and I'll note, in particular, that the currents on the radial wires can be unequal.

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Appendix 2

Predicted Performance for Monopoles with Elevated Radials for Heights Much Different from a Quarter Wavelength

My analysis so far has been concerned with vertical antennas employing elevated radials, but for heights not very different from 1/4 λ. Certainly resonant elevated radials can be used for any antenna height, providing the antenna is of the insulated base driven type (see **Figure 11**).

But if we employ the method of feed described by Russell 17 (see section in the present article entitled "Feeding Grounded Towers"), the height of the tower above the feed height must not be too greatly different from λ/4. Compare the predicted performance (space wave gain for antenna over average ground) for the grounded tower radial feed antenna type with the conventional base insulated base fed antenna (see **Figure 11**)—both antennas employ four resonant radials at a height of 2.5 meters. The graph is for a tower with no top loading, no Yagi antenna on the tower. Height in wavelengths is physical height. Problems with the grounded tower, reduced gain, will occur for lower tower heights if the tower supports a Yagi, since the electrical height of the tower with top loading is increased.
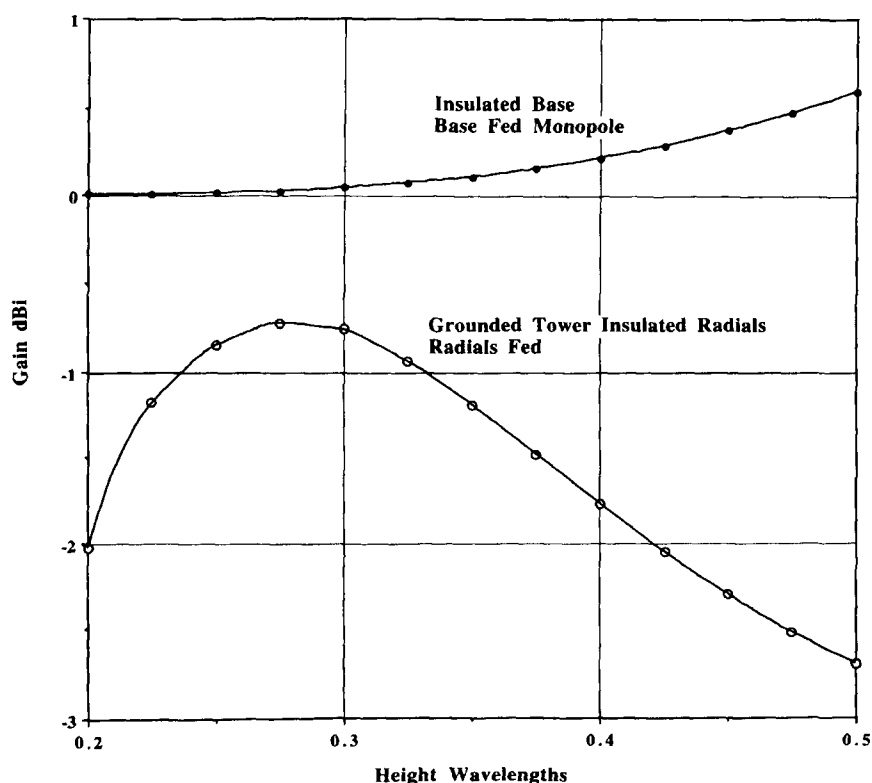

Figure 11. Gain versus height of monopole above feed height (wavelengths), frequency 3.75 MHz, average ground, elevated radials, radial height 2.5 meters. The upper curve is for the conventional method of feed, viz. insulated base tower base feed. The lower curve is for a grounded tower, radials insulated and fed.

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ELEVATED RADIAL WIRE SYSTEMS FOR VERTICALLY POLARIZED GROUND-PLANE TYPE ANTENNAS

Part 2—Phased Arrays

In Part 1 of this article,[1] I gave an overview of the subject of monopole ground-plane type antennas that use elevated horizontal resonant radials instead of the conventional multi-wire buried radial ground systems. Part 2 is concerned with phased array antenna systems, where each element of the array uses elevated radials. The conclusions reached are based on new information, measured results, and numerical analysis—a more detailed numerical analysis (using NEC-4D rather than NEC-2) then was available at the time I published an earlier paper on the subject. That paper was presented in a forum for radio amateurs.[2]

Introduction

As was noted in Part 1, some MF broadcasters in the United States who have tried elevated radials to resolve site problems swear by them, while others swear at them. Beverage[3] has achieved excellent performance for a 0.17-wavelength MF broadcast tower with six elevated radials, and Carl E. Smith has successfully used elevated radials for a broadcast station in Alaska.[4]

In spite of the agreement between theory and experiment reported in Part 1, there are some experiments not in accord with expectation. For example, Tom Rauch, W8JI's, experiments with elevated radials[5] do not agree at all with predicted outcomes. Rauch's measurements, as the number of radials were changed for an 80-meter wire monopole antenna, showed a trend that is almost identical with what one would expect for a radials-on-the-ground situation. He reports that others have found similar results.

Concerning directional arrays, some broadcast station engineers have reported problems in achieving standard horizontal pattern gains with directional arrays using elevated radials.[6] WVNJ is a four-tower directional array near Oakland, New Jersey, operating on 1160 kHz. The site is in a rocky area where a conventional buried radial wire ground system was considered to be impractical, so elevated radials were tried. The station was installed in 1993 and, with the elevated wire system installed, it never did achieve expected performance.

The site was restricted and some of the radials had to be shortened to approximately 70 percent of the full quarter wavelength. A free-space quarter wavelength for the operating fre-
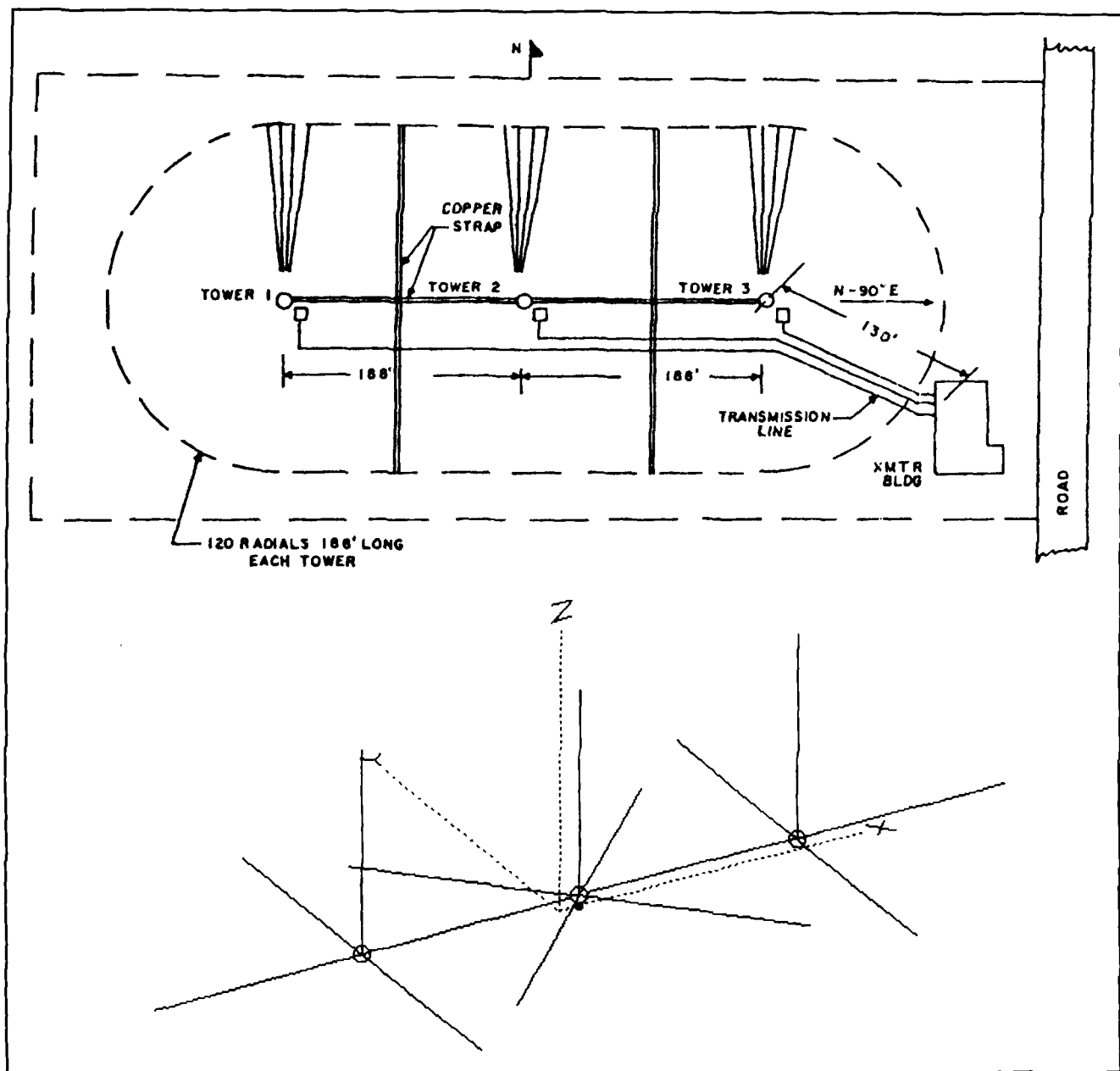
Figure 1. (A) An example of a conventional, three-tower MF broadcast directional array, after Smith;[7] and (B) a proposed antenna system that could be used instead, which has four elevated resonant radials associated with each tower in the array.

quency 1160 kHz is 64.6 meters. A resonant radial length (according to NEC-4D) is 62.15 meters, where the radial height is 6.1 meters over average ground. (The site conductivity, not measured, is probably somewhat worse.) Installed radial lengths varied from 45.3 to 66 meters. Because six elevated radials were installed on each tower, some of the radials ran almost parallel with a radial associated with an adjacent tower, and some were overlapping. This, I believe, was the problem.

Clearly, the subject of elevated radials needs further study. This is particularly true if the ele-

vated radials are used for the elements of a directive array.

Ground systems: buried versus elevated radial wires

You will remember that MF broadcast antennas conventionally use 120 buried radial wires, with each wire 0.25 to 0.4 wavelength long. Radio amateur installations typically use as many radials as possible. The number used depends on one's enthusiasm for burying wire
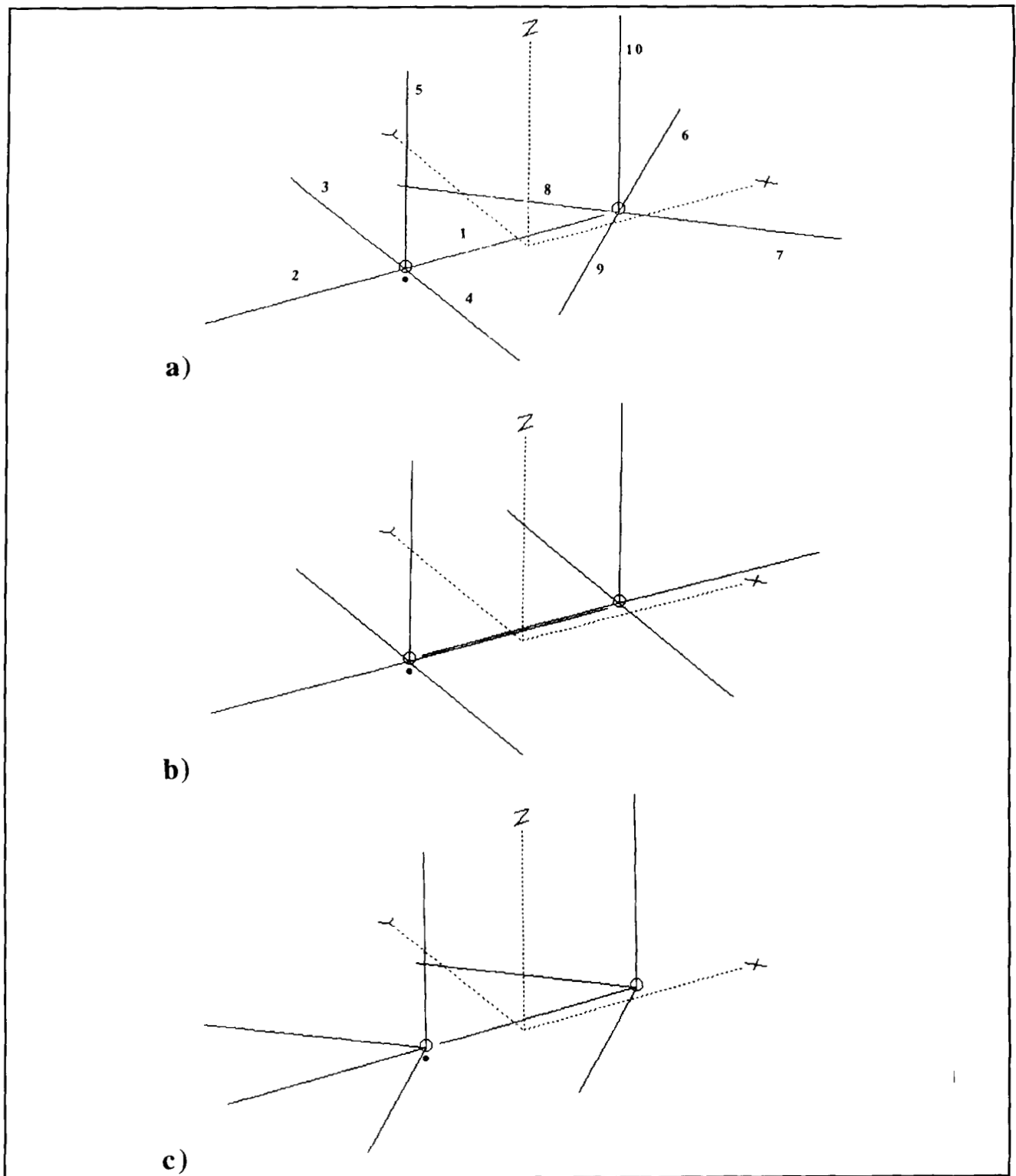
Figure 2. (A) A two-tower array using four elevated resonant radials, where the radials are oriented for maximum symmetrical separation between radials associated with each tower; (B) the radials of the adjacent tower are oriented for a minimum separation; and (C) a suggested arrangement for use with towers fed so the pattern is a cardiod, the "crow's foot" radials point in the direction of maximum gain.

and on practical and perhaps financial considerations. The ground systems for MF broadcast directional arrays use non-overlapping radial wire ground systems, where the radial wires (buried) are terminated and bonded to a copper strap at their junction. **Figure 1A** is a representative MF broadcast station installation for a 1310-kHz directive array antenna system
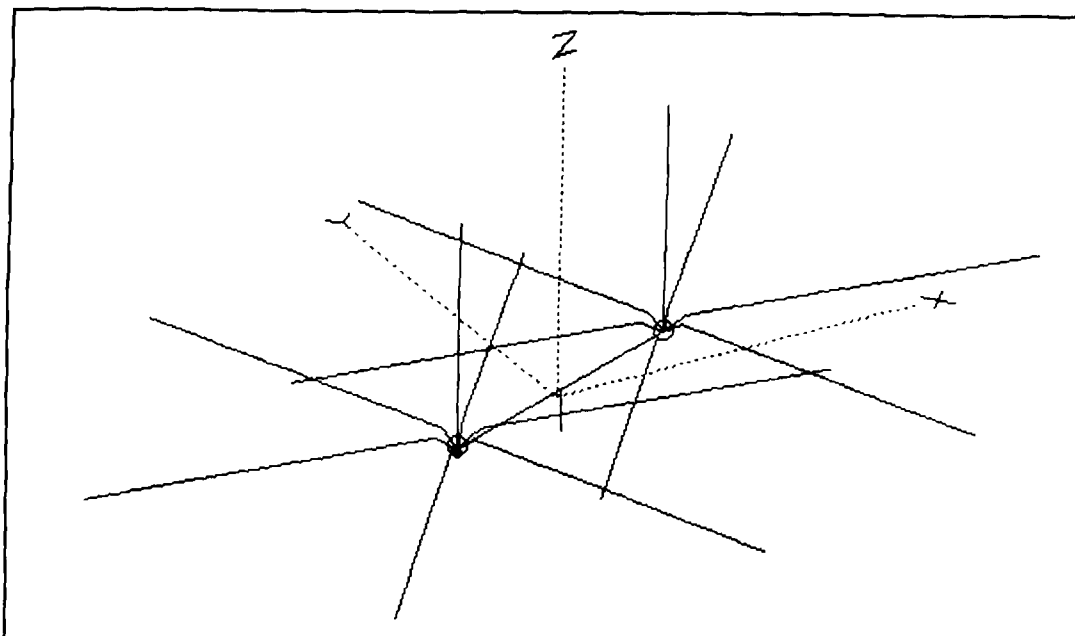
Figure 3. The model used to numerically simulate performance for the MF broadcast station KGGN 890 kHz, Gladstone, Missouri, which uses such an elevated radial system.

described in some detail by Smith.[7] Notice that (comment by the author), perhaps not in accord with the concept that radial wire ground systems are arranged to collect ground current associated with each tower separately, a copper strap between towers and the bonding of the wires to a copper strap at the junction of the ground radials provides connectivity of the ground systems.

Critical antenna systems use additional complexity to stabilize the base impedance. For example, in the case of another directional array given by Smith in the above reference (see also Belrose[8] who has numerically modeled this antenna system using elevated radials), the ground system for an MF (1360 kHz) directional array antenna system using six towers, has 120 radials 15 meters long equally

spaced between the 120 radials 67 meters long that are surrounding each tower. Can we expect comparable performance for directional arrays which use only four elevated radials, centered on each tower (**Figure 1B**)? That is the theme of this article.

Phased arrays

Comments on how to configure radial systems

Ground systems for directive arrays have traditionally used non-overlapping multi-wire ground systems. With elevated resonant radials, current flowing on one radial wire can couple with current flowing on an adjacent radial wire associated with another element of the

Wire	Phase difference source currents		
Number	0 degrees	90 degrees	180 degrees
1	0.11 < -32.1	0.31 < -28	0.36 < 23.8
2	0.36 < -9.4	0.33 < 18.4	0.16 < 18.9
3	0.28 < 12.4	0.21 < 6	0.25 < -10
4	0.28 < 12.4	0.21 < 6	0.25 < -10
5	1.0 < 0	1.0 < 0	1.0 < 0
6	0.33 < -4.3	0.23 < 76.2	0.20 < -164.6
7	0.33 < -4.3	0.23 < 76.2	0.20 < -164.6
8	0.18 < 8	0.28 < 100.8	0.31 < 170.4
9	0.18 < -8	0.28 < 100.8	0.31 < 170.4
10	1.0 < 0	1.0 < 90	1.0 < 180

Table 1. Currents on radials for a two-element phased array (see Figure 2A). All elements #10 wire, length 20 meters (λ/4 for the modeling frequency 3.75 MHz). Radial height 1 meter, over pastoral ground.

Figure 4. Map showing terrain features surrounding MF broadcast station KGGN, highlighting three azimuthal directions pertinent to our analysis of the measured data.
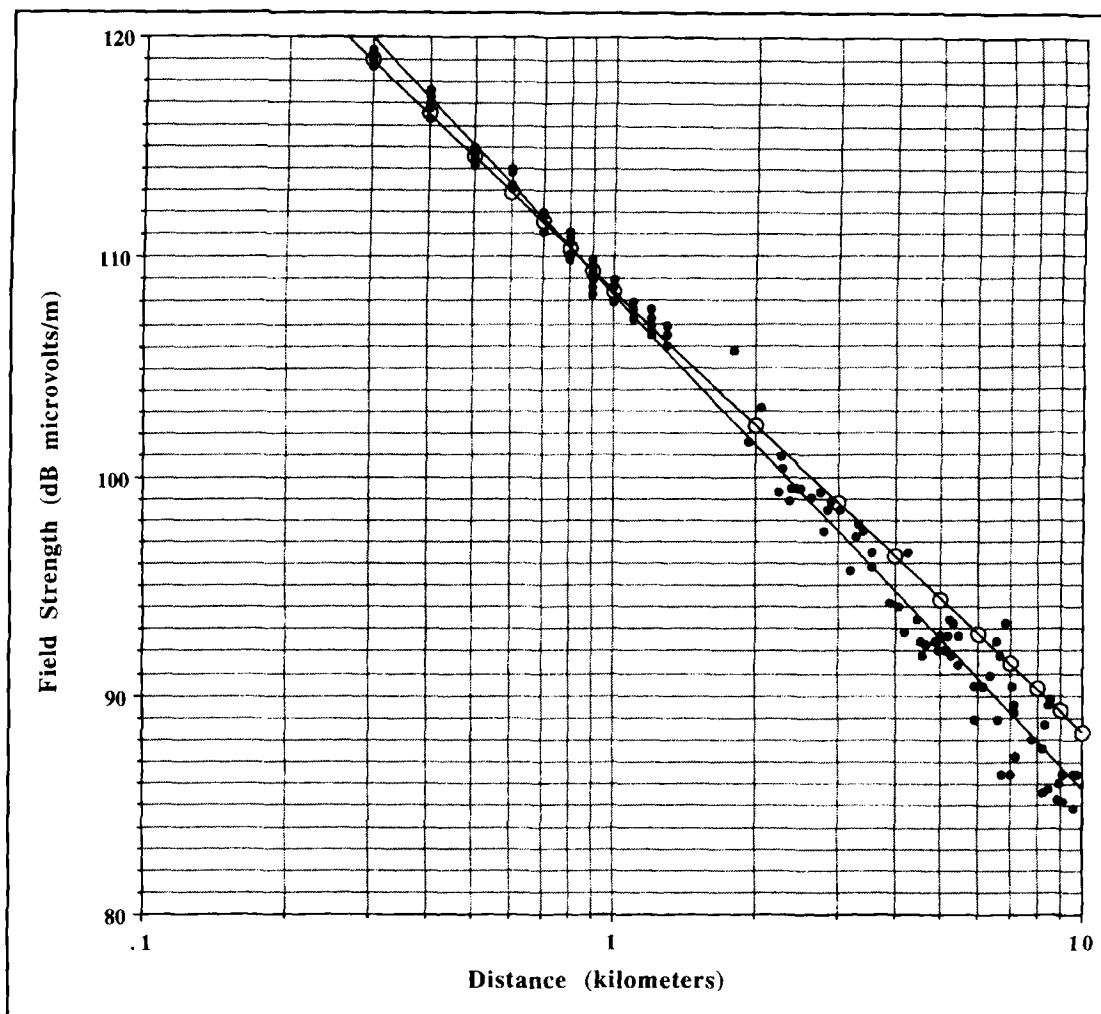
Figure 5. Measured ND field strengths (dB microvolts/m) versus distance for KGGN, for all data measured in eight azimuthal directions. The theoretical field strength is the continuous curve through the open circles; the continuous curve, which lies above and below this curve is the best logarithmic fit curve to the measured data.

array. This is a matter of no concern, or at least it is not considered in the case of buried radial wire systems.

I have redone my initial studies[2,8] using NEC-4—actually EZNEC-4D (a double precision), available from Roy Lewallen.* The initial work concerned a two-tower array with the towers a quarter of a wavelength high spaced a quarter of a wavelength apart. The ground system for each tower consisted of four radial wires, arranged symmetrically to provide minimum coupling between wires associated with the adjacent tower (see Figure 2A). Intuitively, I considered this a good arrangement. The length of each radial was the length necessary for the radial to be resonant. The radials were 1 meter above average ground ($\sigma = 5mS/m$, $\varepsilon = 13$), frequency 3.75 MHz.

Certainly, there are unequal currents on radial wires. It is interesting to examine the currents on the radial wires as the phase difference in the feed currents is changed. I have given the radial and radiator wires a number. **Table 1** shows the currents on these wires, the currents on the segments nearest the source, computed using EZNEC-4D-for radiator phase differences of 90 degrees (cardiod pattern), 180 degrees (figure-eight pattern), and 0 degrees (a broadside array). Currents on radials 3 and 4, 6 and 7, and 8 and 9 are equal; but, as might be expected, currents on radials 1 and 2 are different, and the difference is dependent on the phase differences of the source currents. I have not tried to interpret this result. In any case, it makes little difference, as the desired pattern and gain is realized.

I have since examined the situation where the radial wire systems are arranged, so a radial associated with one tower runs parallel to and beside (very close spacing) a radial associated

with the adjacent tower (**Figure 2B**), in which case currents on these radials can be reduced to almost zero. A radial carrying zero current is not a very effective radial, so these radial wires might as well not be there!

If a cardiod directional pattern is desired, radials can be arranged in a *crow's foot* pattern directed toward the azimuth of maximum gain, as in **Figure 2C**. This improves the front/back ratio, with only a small effect on forward gain (plus-or-minus a fraction of a dB).

A case study

To illustrate some of the pertinent factors and expectations if elevated radials are used, and to validate NEC-4D, I will consider two-tower array, MF broadcast station KGGN, operating on 890 kHz, near Gladstone, Missouri. I am fortunate to have the detailed proof of performance report for this station.[9]

KGGN uses two vertical radiators of 60 meters height (physical height 64 electrical degrees), 69.3 meters (74 electrical degrees)

apart, on a bearing of N 69 degrees E True. The towers are guyed, uniform triangular cross section, face width 0.457 meters. The ground system for each antenna consists of six counterpoise wires arranged at 60-degree intervals for symmetry, 86 meters long.** The radial system is elevated 5 meters above ground until the radials come to a point 5 meters from each tower base. At this point, they slope downward at an approximately 45-degree angle, terminating in insulators attached to the concrete base pier. The base height of the towers is 1 meter above ground. The two counterpoises are not connected to each other (and cannot accidentally touch) except at the base of each tower, where a copper strap runs along the tower line and through the transmitter building. The copper strap is for lightning protection, tying the phasor, transmitter, collection rings of each counterpoise, mains breaker panel, and tele-

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**Note: the radials are too long to be resonant. The resonant frequency for the 86-meter long radials configured as above, according to NEC 4-D is 841 kHz.
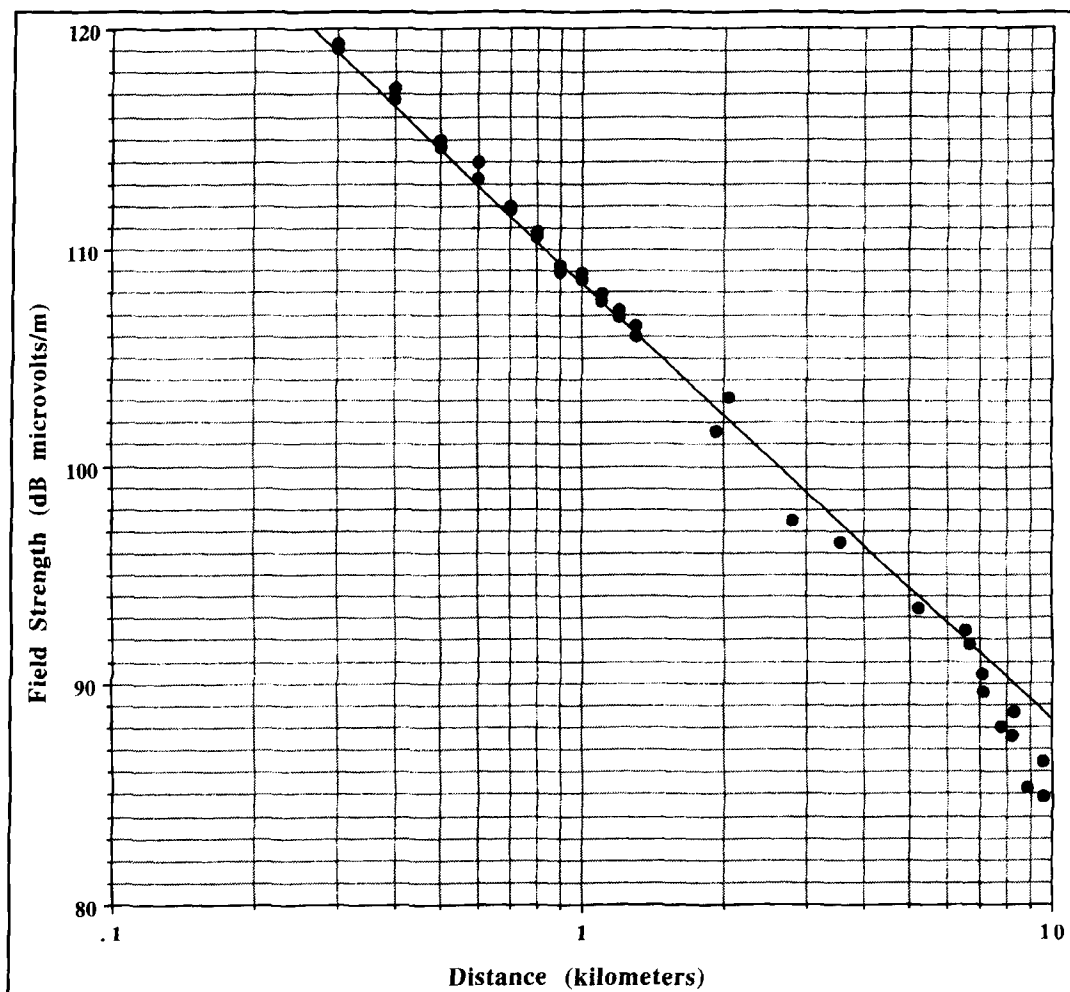

Figure 6. Measured ND field strengths versus distance for KGGN, for the best two azimuthal directions (80.5 degrees T and 138 degrees T)—see map in Figure 4. The continuous curve is the theoretical field strength (the same curve shown in Figure 5).
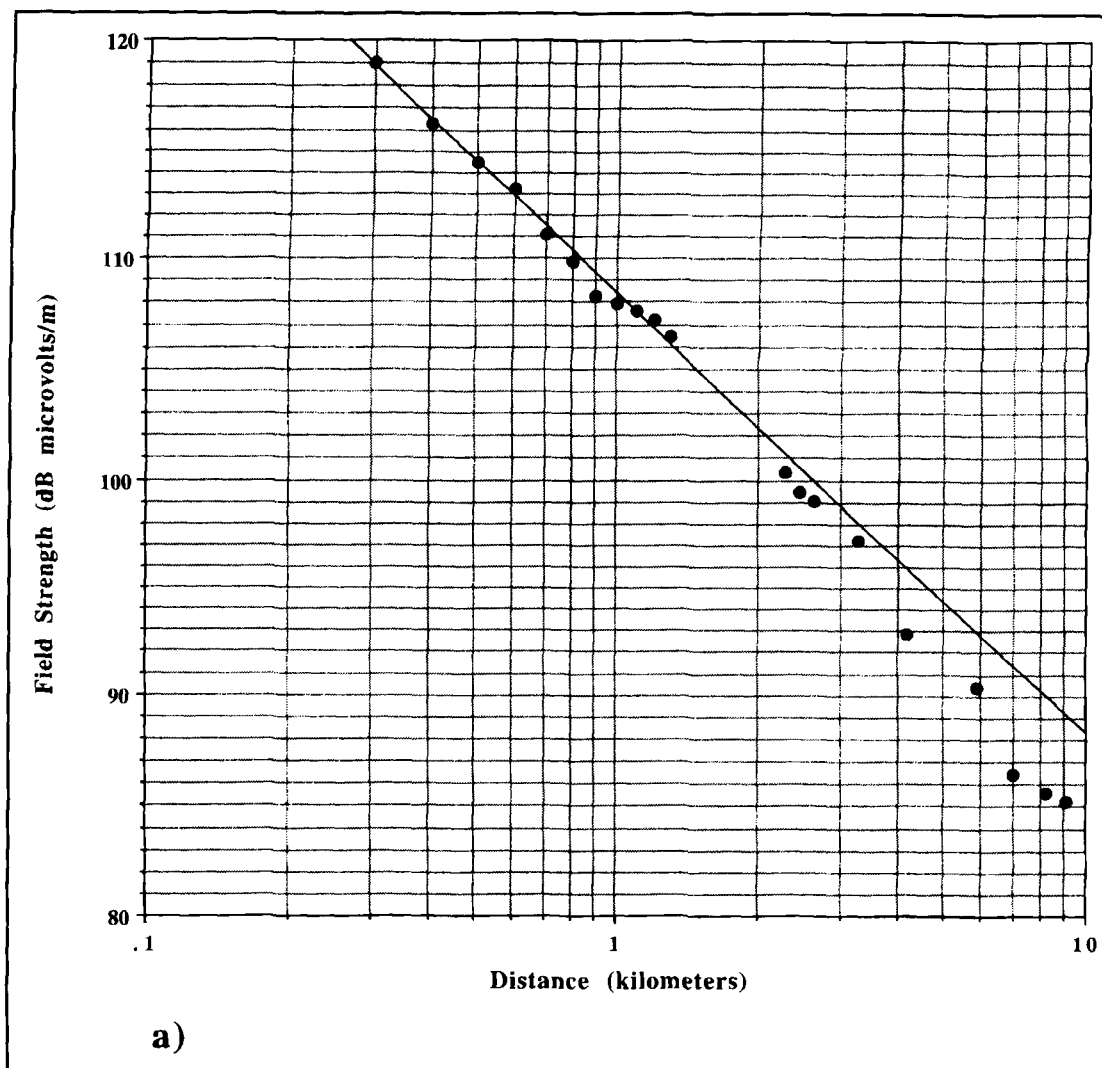
Figure 7A. Measured ND field strengths versus distance for the azimuthal directional array (249 degrees T), and theoretical field strength curve (the continuous line, which is the same curve in Figures 5 and 6).

phone gas protectors to a common earth. For this model, I have assumed that the connection to earth is by means of a 10-meter ground rod—the modeled antenna array is sketched in **Figure 3**. Tower 1, the tower on the left, carries a current 0f 1.0<0 degree amperes; Tower 2's current is 0.92<107.5 degree amperes.

The station's proof of performance documents: 1. field strengths, first for the case of single nondirectional (ND) tower; 2. measurements made at many locations in eight azimuthal directions, in the distance range 0.3 to 40 kilometers; and 3. field strengths for the directional array measured in the same azimuthal directions, and at the same locations, in the distance range 3 to 40 kilometers.

Gladstone is NNE of Kansas City, Missouri, and all azimuthal directions, except 80.5 degrees T and 138 degrees T, are initially over rough terrain (see **Figure 4**). Some of these

radial paths pass through residential and urban areas. This results in a scatter in the field strengths measured. In **Figure 5**, I show the measured ND tower field strengths in the distance range 0.3 to 10 kilometers in all eight azimuthal directions (the data points on the graph), and the best logarithmic fit curve to these data. The computed field strengths, according to EZNEC/4D (see first **Footnote**), are represented by the curve through the open circles. The reference transmitter power is 1000 watts. The best fit curve to the measured data lies above and below the theoretical curve. Clearly, there is a considerable scatter in the measured data (filled in circles), and there is a consistent departure with increase in distance between the best fit measured and calculated curves.

Figure 6 shows a similar plot, but here the data points are for only two azimuthal direc-
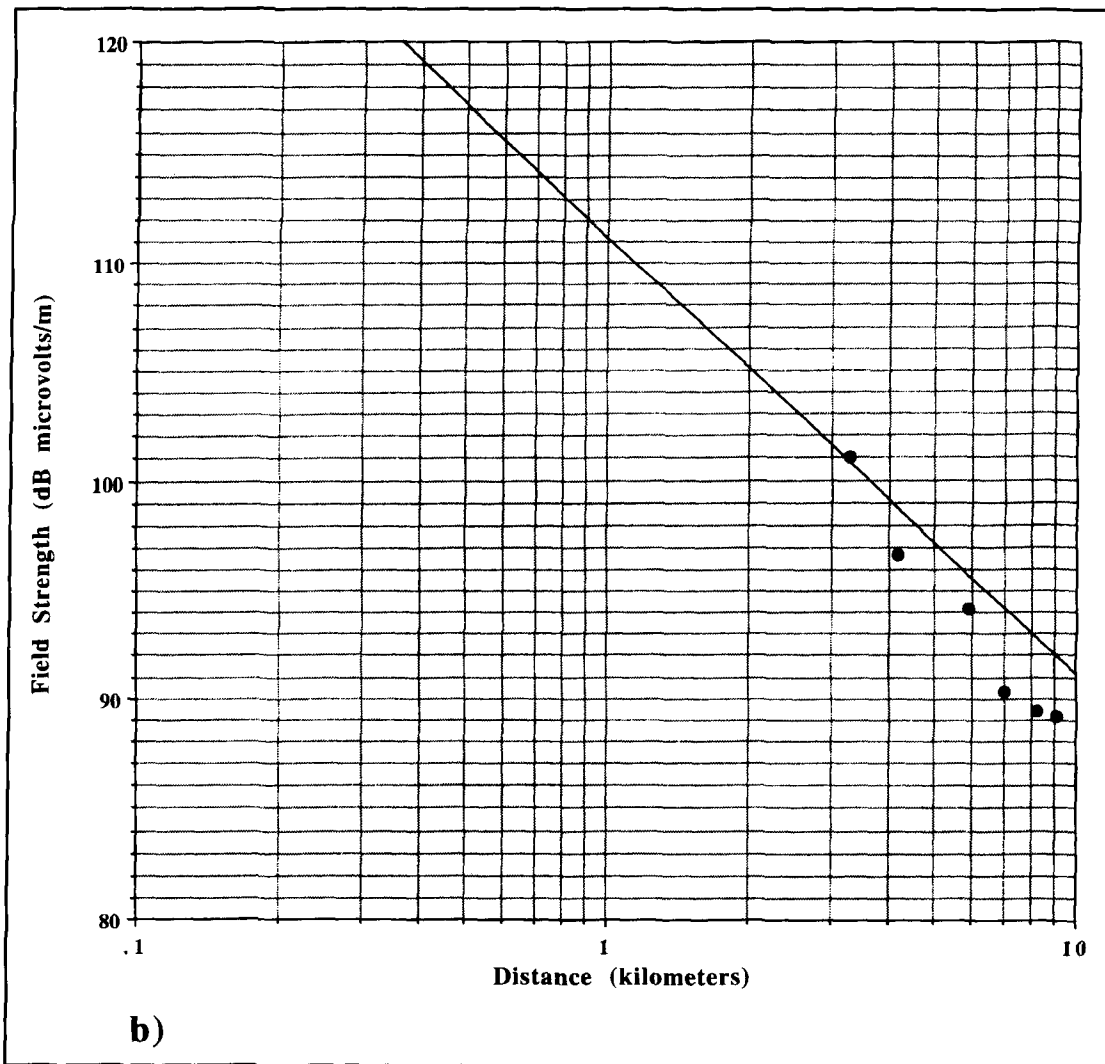
b)

Figure 7B. Measured directional gain field strengths versus distance and theoretical curve (the continuous line) for the array (Figure 3's antenna) for this same azimuth.

tions, 80.5 degrees T and 138 degrees T—the only two paths that lie over rural fairly open and level land (see **Figure 4**). The computed curve (the continuous line) has been calculated for average land (σ = 5 mS/m, ε = 13), a conductivity that is consistent with the measurements. I have not fitted a curve to the measured data. Notice that the measured data points cluster quite well about the theoretical curve. I conclude that indeed NEC-4D accurately predicts the ground wave field strength.

Now look at measured field strengths in the azimuthal direction corresponding to that of the main beam (249 degrees T) for the directional array. **Figure 7A** gives the results for the ND tower in this direction. Again, the continuous curve is the theoretical curve, and the filled-in circles are the measured data. Notice the sudden break in agreement between measured and predicted field strengths in the distance range of 4

to 10 kilometers. This is considered to be due to the rough terrain over which the wave passes to reach the various measurement locations.

In **Figure 7B**, I compare the theoretical field strength curve for the directional pattern (the continuous line) with the measured data (the filled in circle data points). Again notice that the data points in the range 4 to 10 kilometers lie below the theoretical curve. In fact, the only data point that lies on the theoretical curve is that measured at 3.3 kilometers, which fortunately is a location where the field strength for the ND tower is very close to the theoretical curve (see **Figure 7A**).

You may not consider this a very satisfactory agreement between measurement and numerical modeling. But you can compare measurement with theory in another way. The array gain, gain over the ND tower, can be quite accurately determined from the ratio of mea-
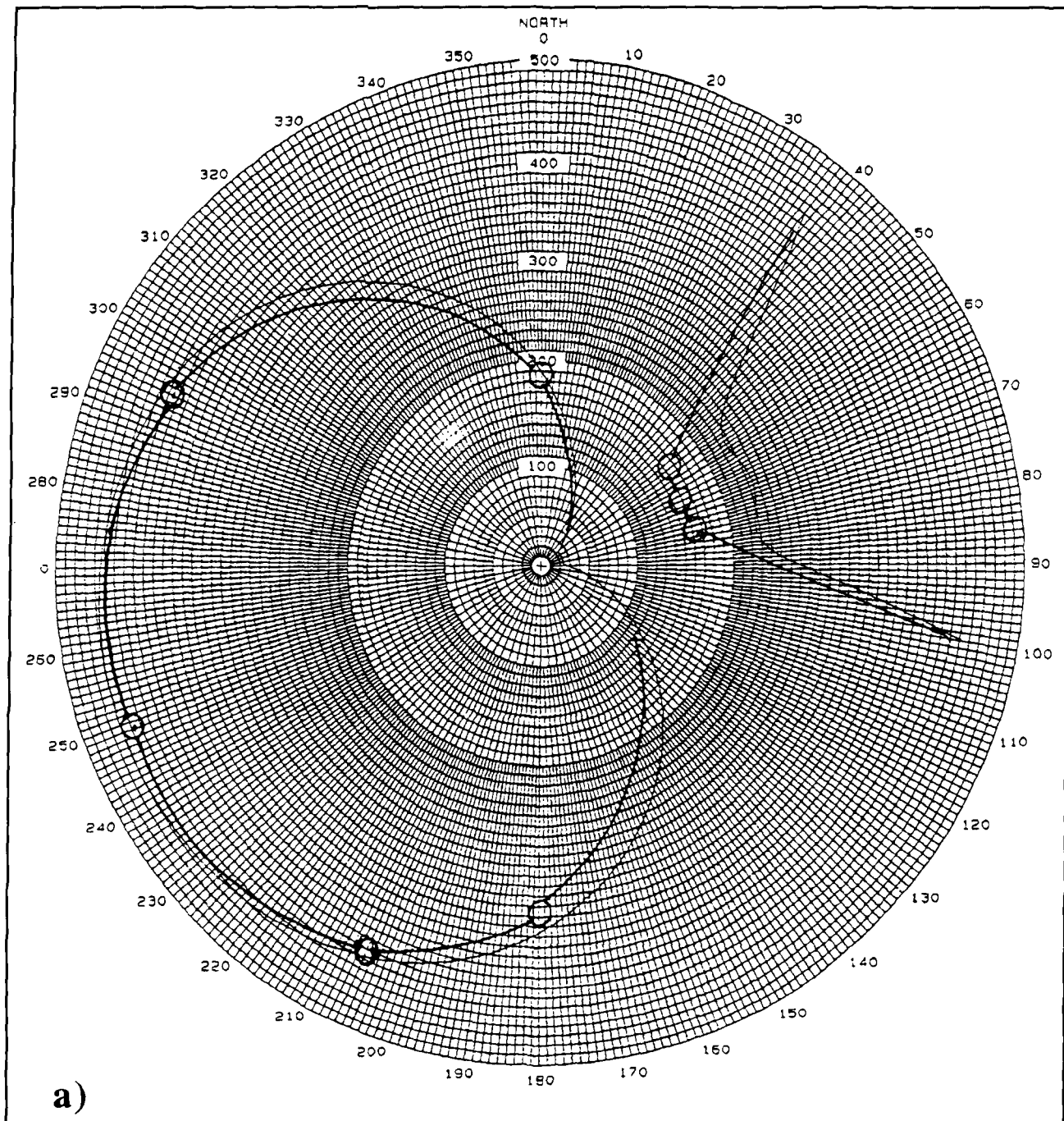
a)

Figure 8A. Measured and predicted horizontal plane patterns (standard pattern based on a simple analysis, which also assumes a PEC perfectly electrical conducting ground) for KGGN, after Glinter.[9] The scale is mV/m referenced to the unattenuated ground wave field strength at 1 kilometer for a transmitter power of 960 watts. Detail in the null direction is plotted on a x10 scale.

sured field strengths (since ND and directional field strengths were measured at the same locations) in the distance range 3 to 12 kilometers (nine values). The median value for the measured array gain is 3.83 dB. The predicted array gain, ratio of unattenuated field strengths at 1 kilometer (array versus ND tower), is 3.71 dB (difference -0.12 dB). You can also compare the front/back, predicted versus measured

(Figure 8), 28.9 dB compared with 28.8 dB.

In conclusion, the measurements show the difficulty in determining accurate field strengths for comparison with numerical modeling (modeling assumes a flat smooth earth). Fortunately sufficient detail was given in the station's proof of performance to sort the data and establish that indeed there is very good agreement between measured and predicted field strengths.
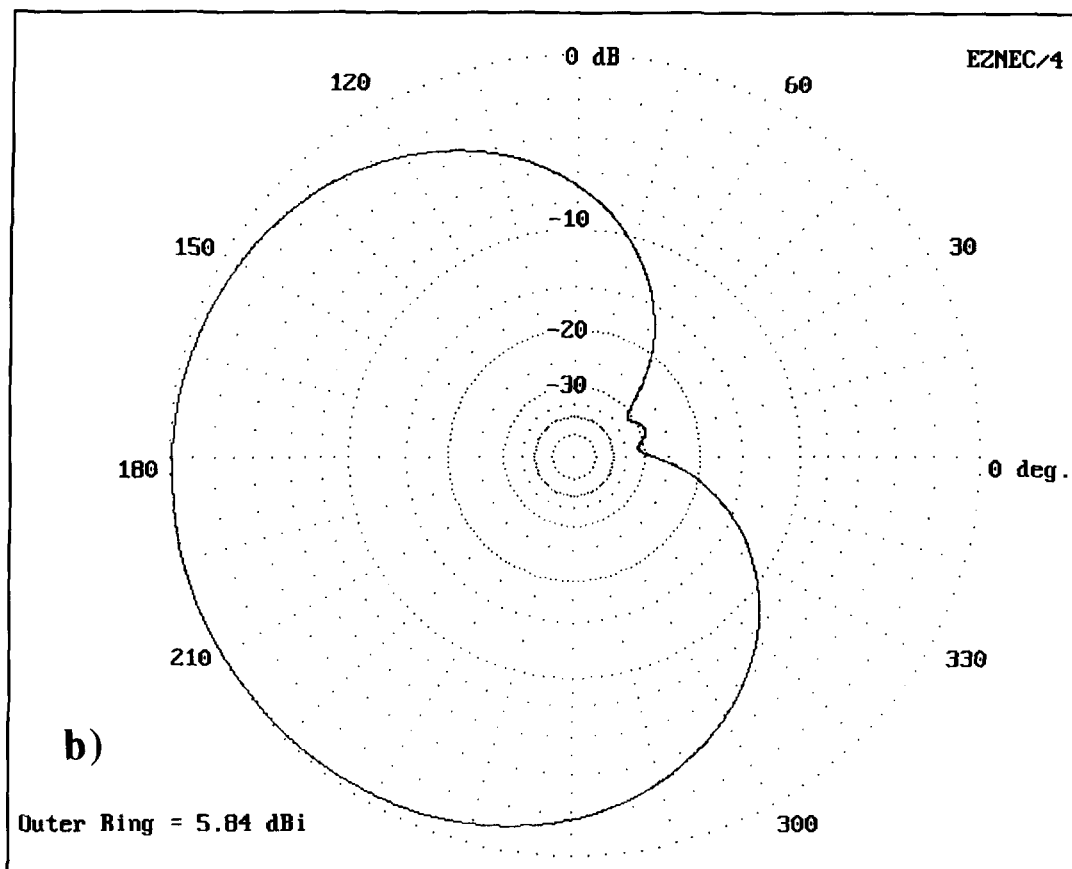
Figure 8B. Ground wave pattern (dBi) according to NEC-4D for qualitative comparison (distance 1 kilometer, height 1.5 meters).

A consideration of elements for directive arrays

I will now discuss antenna systems that might have a more practical interest for the radio amateur. In our discussion thus far, I have considered monopole GP-type antennas with four elevated horizontal resonant radials (excepting for the case study above), as shown in **Figure 9A**. But for the radio amateur, a monopole with drooping radials (**Figure 9B**) or a GP-type half-diamond loop (**Figure 9C**) could be used as an element for a directive array. Because I am concerned here with phased arrays to provide directivity in a particular direction, it would be useful if the elements of the array themselves had an intrinsic self-directivity in the desired direction. This can be realized if only one radial is used, pointing in the desired direction. Refer to the antenna arrangements shown in **Figures 9D, E**, and **F**.

Figure 10 shows the (spacewave) elevation patterns for each of the antennas shown in **Figure 9D, E**, and **F**. For this comparison, the antenna is resonant, the frequency is 3.75 MHz, and the radials are resonant at a height of 2.5

meters (a practical height because the radials are above head height). For the monopole with the drooping radial, the end height is more practically 1 meter. Average ground is assumed. As past experience indicates, the GP-type half-diamond loop is the antenna having the greatest gain. This is followed closely by the monopole with one drooping radial (this element is derived from a monopole with four drooping radials, in which case it behaves somewhat like a $\lambda/2$ radiator), and the $\lambda/4$ monopole with one horizontal radial has the least gain. But all antennas have a similar directive pattern.

All of these antennas, when dimensioned for the 80-meter band, are somewhat impractical for most amateurs; I am concerned here with the fundamentals of antenna performance. The $\lambda/4$ monopole with one horizontal radial is the most practical because it can be shortened (keeping the radial resonant), as is commonly the case for monopole elements used in MF broadcast arrays. A disadvantage when a shortened radiator is used is that the elements in the phased array have to be tuned and matched, as well as phased and power combined. But even when one uses antennas which are self-reso-
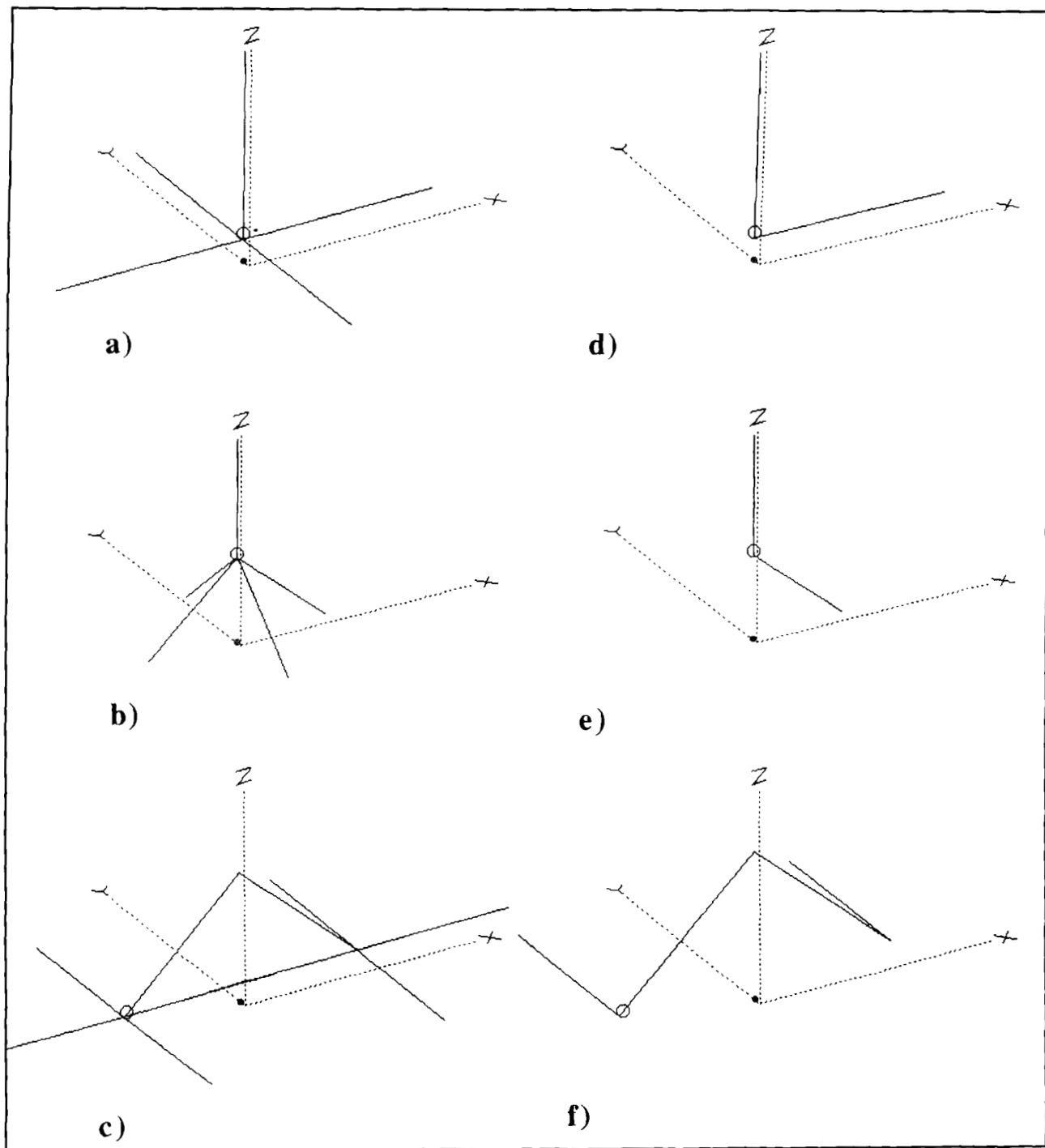
Figure 9. (A) A monopole with for elevated horizontal radials; (B) monopole with four drooping radials; (C) GP-type half-diamond-loop with three elevated radials (and as well as a wire which joins the fed end of the loop to the far end); (D) monopole with one horizontal radial (E) monopole with one drooping radial; and (F) GP-type half-diamond-loop with two horizontal radials.

nant, the elements of the array must be tuned, matched, and phased—at least for MF broadcast applications.

Some example directive systems

Next, I will describe three types of directional antenna arrays: two using monopoles and one using GP-type half-diamond loops. Although these antennas do not represent any particular installation that I put up and used operationally, they are technically correct and could be implemented by the interested reader. A two-element half-delta loop array has been experimentally modeled,[10] and my colleagues and I have successfully used a version of it
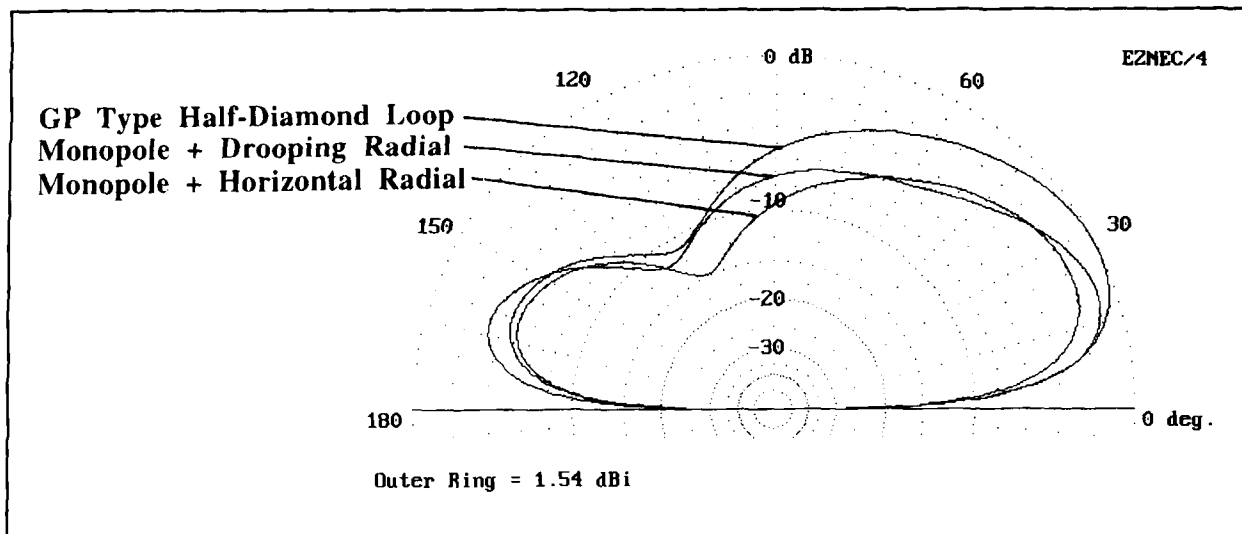
Figure 10. Elevation patterns (spacewave) for the antennas shown in Figures 9D, E, and F.

dimensioned for the 40-meter band for field day. This antenna system is very practical for this band.

Cardiod pattern directional arrays

A cardiod pattern is realized by using two or three in-line antennas, where the phase of the currents feeding adjacent elements or antennas differ by 90 degrees. **Figure 11A** is a sketch for a three-element directional array. The monopole elements are λ/4 resonant, and the radial length for a frequency of 3.75 MHz, radial height 2.5 meters over average ground is 19.2 meters. Note: the antenna elements do not touch—the monopoles are spaced 20 meters apart, and the length of the radials is 19.2 meters. Numbering the antenna elements 1, 2, and 3, from left to right, the currents for the three-element array are: 0.5<90 degrees amperes, 1.0<0 degree amperes, and 0.5<-90 degree amperes, respectively. Changing the amplitude and phase of the currents in antennas 1 and 3 changes the detail in the null of the pattern. For the two-element array, both antennas are fed with equal amplitude currents, but the phases differ by 90 degrees (1.0<90 degree amperes for the example here).

The principle plane patterns for the one, two, and three-element antenna arrays are shown in **Figures 11B** and **C**.

Unidirectional broadside monopole arrays

A unidirectional broadside antenna array is realized by using two or three in-line antennas—monopoles with one horizontal radial, where the phase and amplitude of the currents feeding adjacent elements are identical. **Figure 12A** is a sketch for a three-element unidirectional array. The monopole elements are λ/4

resonant, and the radial length for a frequency of 3.75 MHz, radial height 2.5 meters over average ground is 19.2 meters.

The principle patterns for the one, two, and three-element antenna arrays are shown in **Figures 12B** and **C**.

This antenna system would be much easier to adjust than the one described above. It makes a neat bidirectional antenna system because, to reverse the direction of the maximum gain, one would simply switch by relays to radials pointing in the opposite direction. There would be no change in matching or phasing.

Unidirectional broadside GP-type half-diamond loop array

I am a GP-type half-loop enthusiast.[11] They are much quieter (background noise levels are usually lower) compared with vertical monopoles, they are not subject to precipitation static, and wire loops are easy to set up and adjust. A unidirectional broadside antenna array is realized by using two in-line loops, where the phase and amplitude of the currents feeding adjacent elements are identical. In fact this is easily achieved since both loops are fed at a common point.

In **Figure 13A**, I show a sketch for a two-loop directional array. For a frequency of 3.75 MHz, the side length for the loops according to NEC-4D is 21.23 meters, the radial lengths for a height 2.5 meters over average ground is 19.2 meters. The input impedance for a single two-loop array (for loops having this same dimension) is 60 - j17 ohms.

The principle plane patterns for the single-loop and the two-loop array are shown in **Figures 13B** and **C**.

This antenna system is the easiest of the three
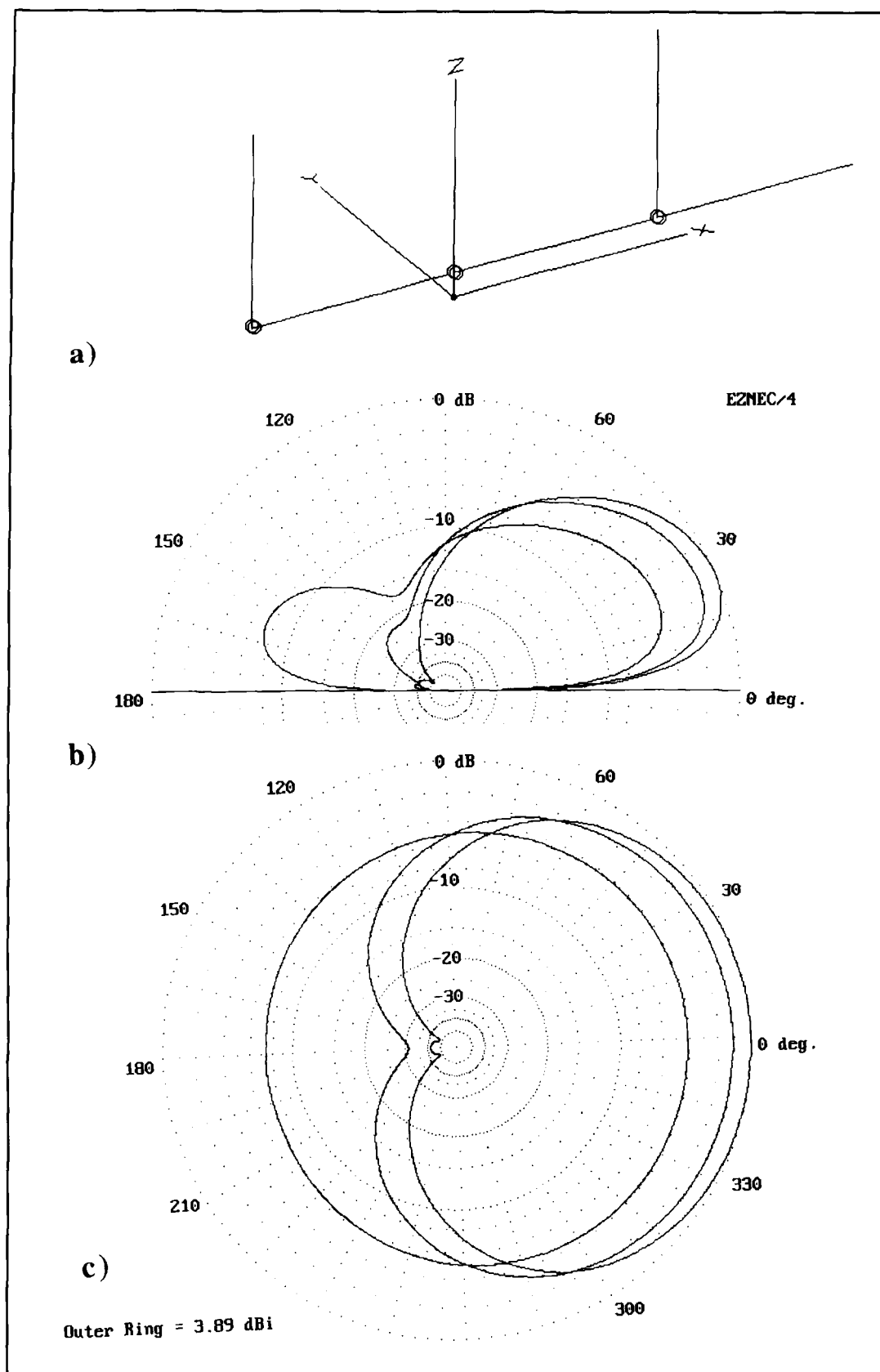
a)

b)

c)

Outer Ring = 3.89 dBi

Figure 11. (A) Sketch for a three-element directional array, where the monopole elements are fed to realize a cardiod pattern (see text); and, the principle plane elevation (B) and azimuthal (C) patterns for a one, two, and three-element array.
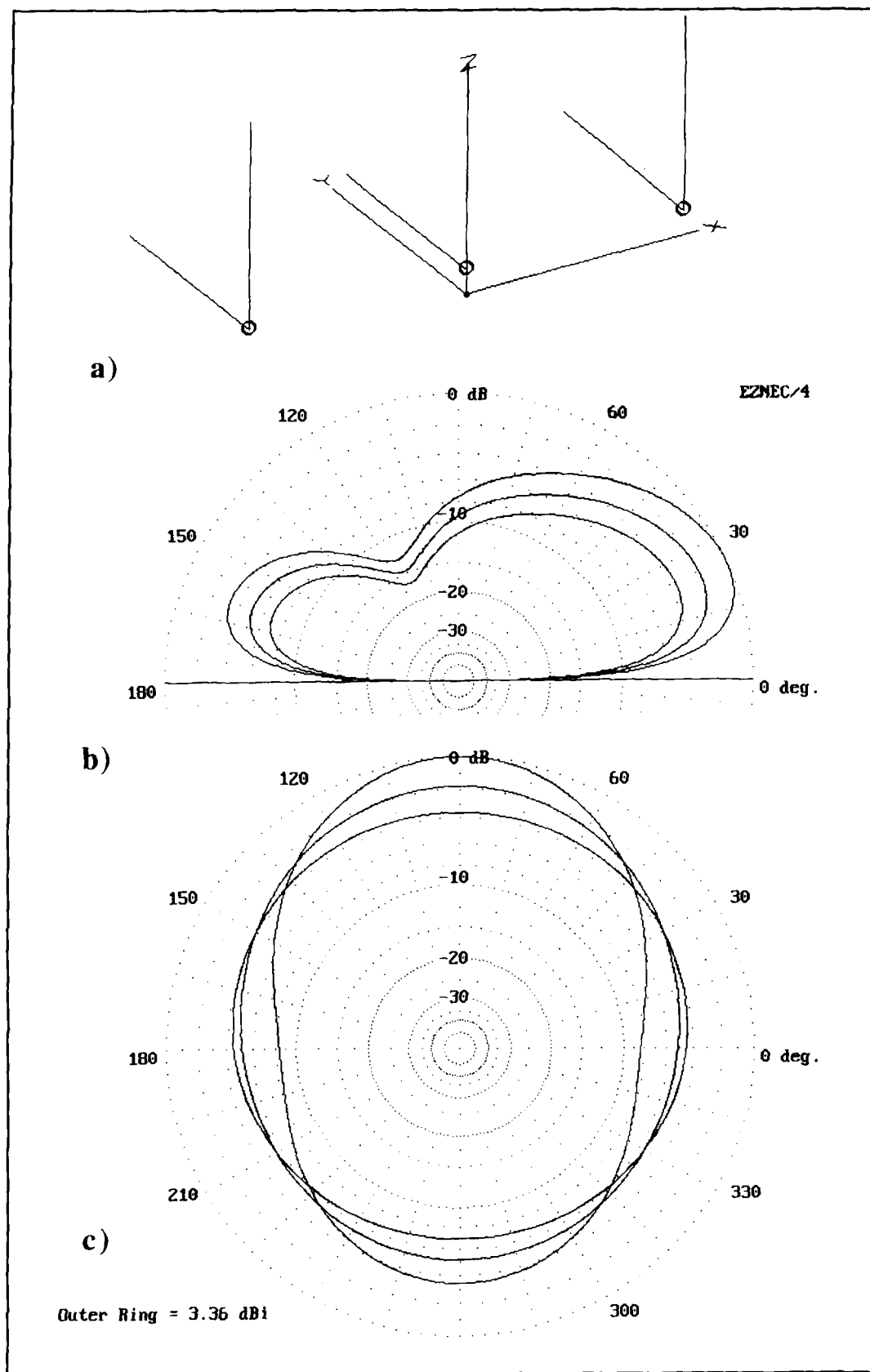
a)

b)

c)

Figure 12. Sketch for a three-element directional array, where the monopole elements are fed to realize a unidirectional broadside pattern (see text); and the principle plane elevation (B) and azimuthal (C) patterns for a one, two, and three-element.
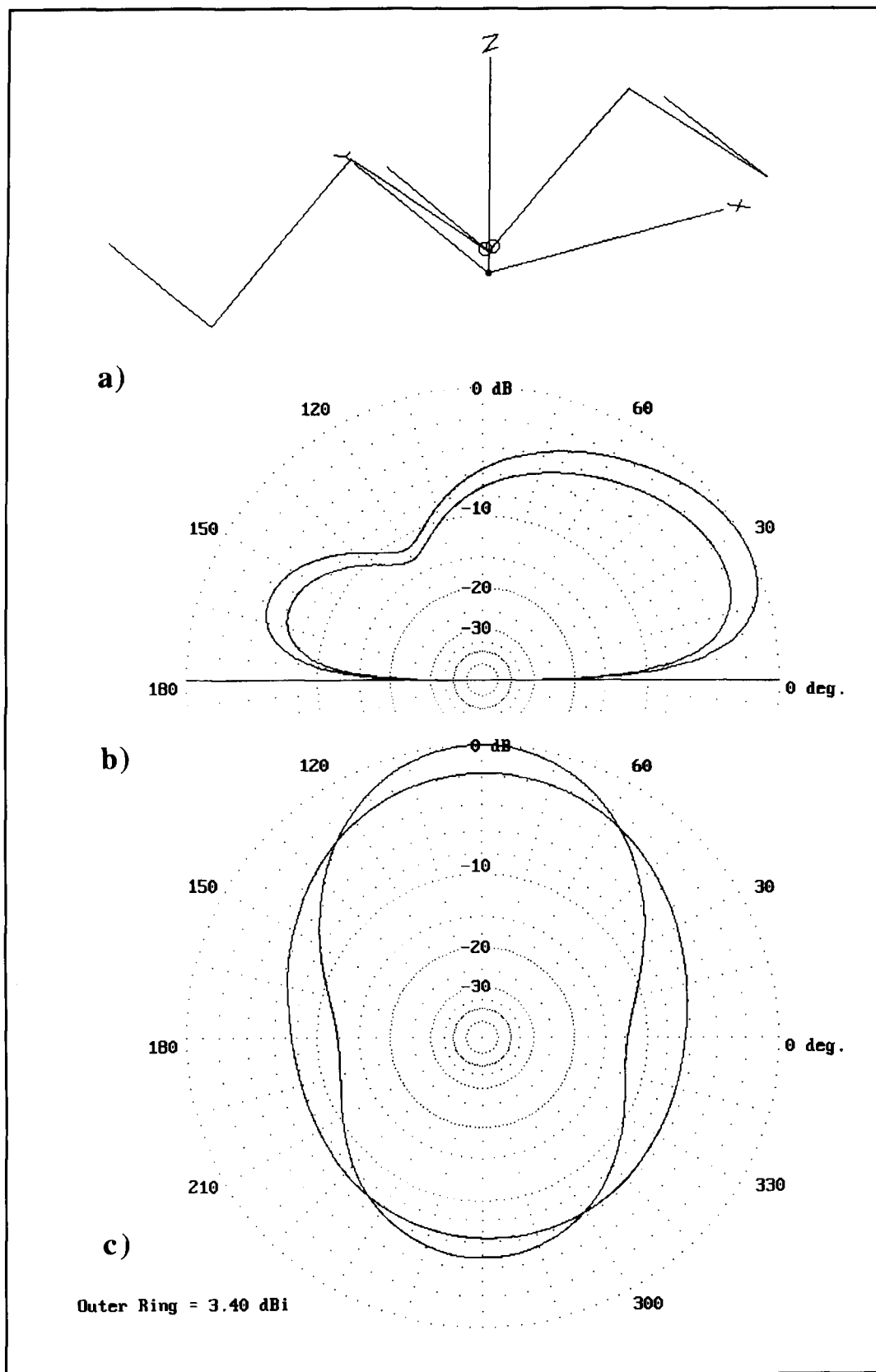
Figure 13. (A) Sketch for a two-element directional array, where the half-diamond-loop elements are fed to realize a unidirectional broadside array (see text); and the principle plane elevation (B) and azimuthal (C) patterns for a one and two-element array.

described to set up and adjust. Both loops are fed at a common point. It makes a good bidirectional antenna system because, to reverse the direction for the maximum gain, one would simply switch by relays to radials pointing in the opposite direction.

Concluding remarks

Phased arrays are, in general, not simple antennas to accurately set up and use. This is particularly true if one wants to reverse the azimuthal direction of maximum gain. They also present difficulties for amateur deployment because antenna systems are used for a band of frequencies. Most amateurs who use phased directive arrays pay no attention to tuning and matching the individual elements in the array. They simply use coaxial cables of differing lengths to provide a phase shift. The ideal patterns shown here would, therefore, seldom be realized in practice. I have not given details on antenna impedance for the monopole antenna arrays since towers or wires (tree-supported) could be used for the monopole elements and typically the monopoles would not be resonant. But the radials need to be resonant. Dimensions for the loop antenna array are given, since loops are wire antennas.

The purpose of this article is to convince the reader that elevated radials are very practical, whether the antenna is a single element, or the element is a part of a phased array. And, the gains realized in practice can be almost the same as those achievable by using extensive multi-wire buried radial wire ground systems.

A disadvantage is that the field strengths between the radial wires can be rather large, particularly in the vicinity of the ends of the radials, when high powers are used (amateur stations use powers up to 1000 watts, but MF broadcasters use powers up to 50,000 watts). EZNEC pro (whether one uses the NEC-2 or NEC-4 engine) can be used to estimate these fields. But this is a subject for a paper in itself concerned with near fields. A paper discussing the whole subject of elevated radials, giving new results of experiments yet to be done, is planned for publication in the *IEEE Antennas and Propagation Magazine*.

Acknowledgment

I am currently a radioscientist with the Radio Science Branch of the Communications Research Centre, Ottawa, ON K2H 8S2, and have access to their facilities. These facilities have sophisticated electronic instrumentation, computers, and plotters. I also have well-established channels for interaction with engineers in industry and the academic world, not normally available to the amateur in radio. ∎

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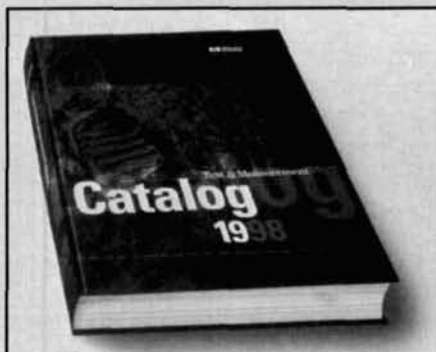
ELEVATED RADIAL WIRE SYSTEMS FOR GROUND-PLANE TYPE ANTENNAS

Part 3: A monopole antenna with parasitic wire elements

In Part 2 of this series of articles, I compared predicted field strengths (FS) with results measured for an MF broadcast station which used an antenna system employing elevated radials. Why report on a study of MF broadcast antennas in an article published in a magazine whose readers are interested in amateur radio? I did so because I had measured results and wanted to validate the application of NEC-4D (the EZNEC pro version*) to predict field strength and gain. I conclude that I have validated NEC-4D, particularly as I have carried out additional studies since publishing the earlier articles.[1,2]

Carrying on in the same theme, I then described a number of phased arrays for a band of interest to VE2CV, the 80-meter band. While the antenna systems described do not represent any particular installation, they are technically correct and could be used by an ambitious radio amateur. They are however, except for one (a twin half-diamond-loop GP

type array), not practically easy to adjust. This is because each of the elements of the antenna systems must be fed with currents having the appropriate phase and amplitude, otherwise the radiation patterns and gain calculated will not be realized in practice.

It is better to have one feed point. VE2CV has experimentally (see **Reference 3**) and numerically modeled twin half-delta-loop GP type antennas. For field-day application, he has used two orthogonal twin half-delta-loop GP type arrays, dimensioned for the 40-meter band. This antenna system certainly worked, but I had no reference antenna for comparison.

Here we consider a monopole antenna, a tower, with parasitic wire elements, active guys, which is a practical antenna from the point of view of space required and simplicity in feeding it (one feed point).

Introduction

Dipole antenna systems with parasitic elements (e.g. the Yagi antenna) are commonly used for the higher bands: 40 meters and down.
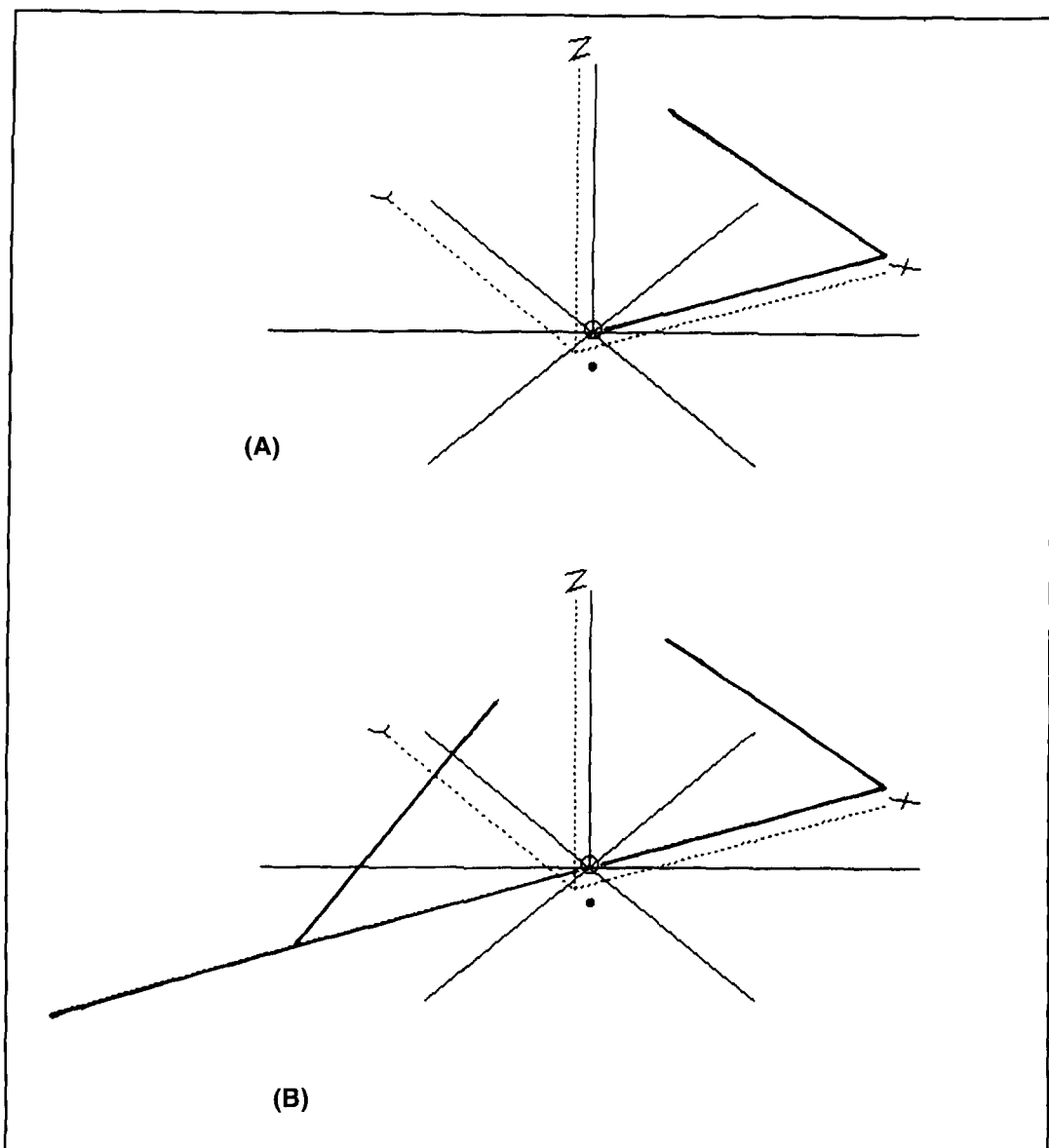
Figure 1. (A) Arrangement where a sloping wire is used as a reflector element. (B) Arrangement where two sloping wires are used.

While a GP type monopole antenna system with parasitic elements can be devised, and such antenna systems are in use for MF broadcasting, they are not very practical, particularly for the lower bands—40 meters and up—because, if lattice towers are used for the antenna elements, the height of a tower is not very easily adjusted to optimize forward gain. Broadcasters use tuned towers. And, multitower antenna arrays for the lower bands are not very practical for the radio amateur.

The sloping-reflector arrangement described by Ford,[4] which consists of a wire slung from near the top of a monopole antenna (but insulated from it) at a slope of 45 degrees is revisited here. Ford's reflector/or director, is tuned by inserting a passive reactance in series with the

base of the sloping wire, which is attached to its own ground system. Dimensions for various mast heights were investigated. For an overview of Ford's antenna systems, see Belrose.[5]

I describe here the results of a numerical modeling study for a monopole that comprises a typical lattice tower, with sloping reflector and director elements. If the tower height is 0.249 wavelength (19.9 meters or 65.3 feet) and it is fed against six elevated resonant radials over average ground (height of radials 2.5 meters, length of radials 0.24 wavelength or 19.2 meters), it is a resonant antenna for 3.75 MHz (Za = 36 ohms). A grounded tower could be used with shunt or gamma match feed, but since we are concerned here with elevated radials, our model is for this type of antenna.

The parasitically excited director and reflector elements are wire structures, suspended between the top of the tower and wooden posts 1/4 distant on one or both sides of the tower (height 2.5 meters, distance out from the tower 20 meters for 3.75 MHz). The lower ends of these elements are connected to a horizontal resonate radial wire running back toward the tower and in the direction of maximum gain, but are insulated from the tower. For the case where the sloping wire is supposed to act like a reflector, only one radial wire is needed

because this wire, running back toward the tower, is already pointing in the direction of maximum gain. Thus we have simulated a GP type monopole array with parasitic elements.

Antenna with a reflector

In **Figure 1A**, I have sketched the arrangement where a sloping wire is used as a reflector element. The optimum length of the sloping wire (according to NEC-4D) is 0.263 wavelength (21.04 meters). The length of the radial
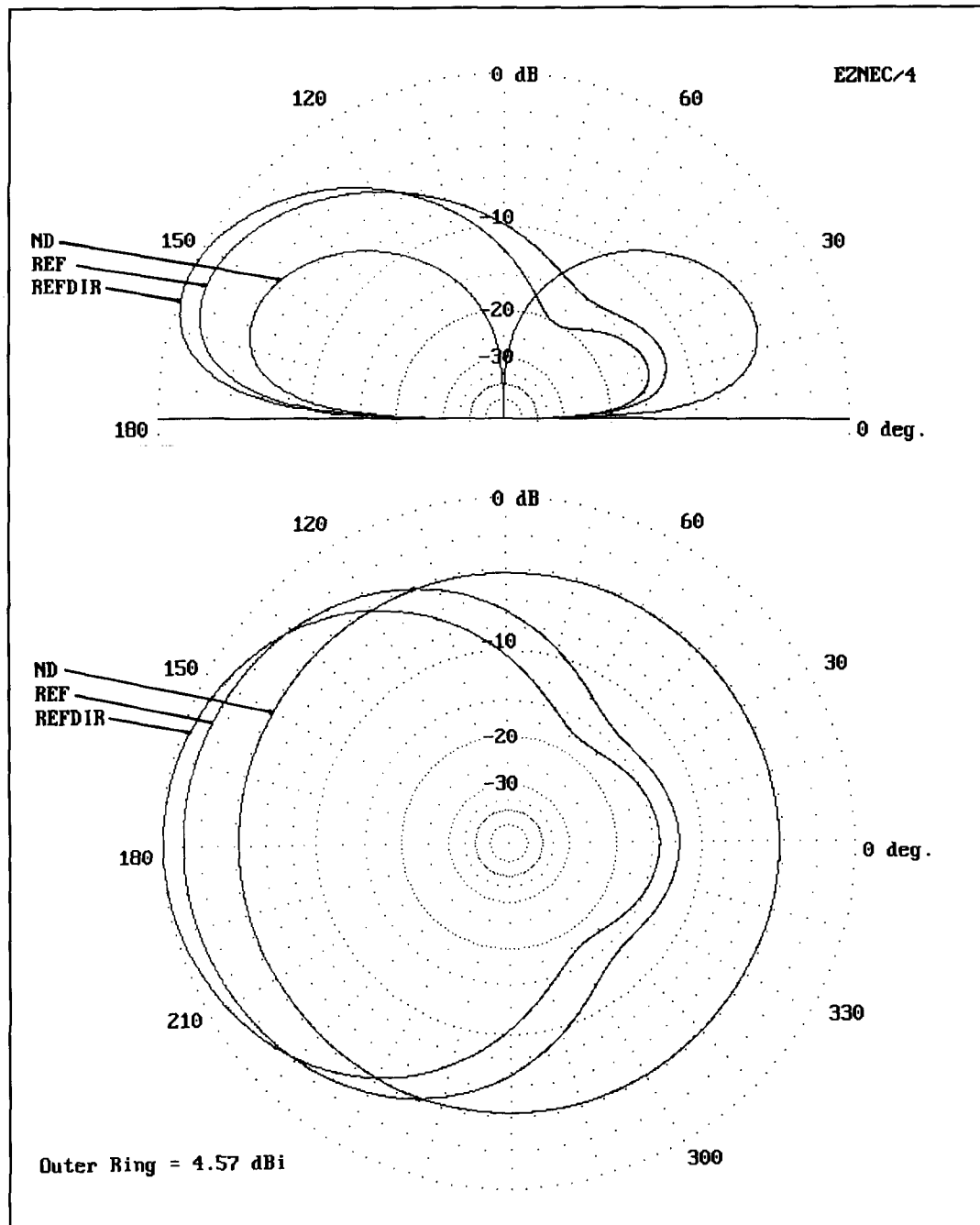

Figure 2. Calculated principle patterns.

(see above) is 0.24 wavelength (19.2 meters). The calculated space wave gain is 3.53 dBi, compared with 0.34 dBi for the tower alone. Thus this two-element array has a gain of 3.2 dB over the ND tower. The calculated antenna system impedance is Zas = 47.7 + j 29.6 ohms (recall that the tower alone was resonant, Za = 36 + j 0 ohms). I will discuss and compare the radiation patterns below.

Antenna with director and reflector

In **Figure 1B**, I have sketched the arrangement where two sloping wires are used: one whose length has been adjusted so it acts like a reflector (as discussed above); the other sloping wire on the opposite side of the tower is shortened, so it acts like a director. This sloping wire is connected to two resonant radials: one running back toward the tower and one running in the direction of maximum gain (to optimize realizable gain). The optimum length for this sloping wire is 0.242 wavelength (19.36 meters). The forward gain is increased by more than 1 dB, to 4.57 dBi. Thus the gain for this three-element array is 4.23 dB over the ND tower. The antenna system impedance is Zas (calculated) = 28 + j 27.3 ohms.

Radiation patterns compared

In **Figure 2**, I show the calculated principle plane patterns. The curves labeled ND are the non-directional patterns (tower alone). The curves labeled REF are for the arrangement where a sloping wire and radial have been added to form a two-element array, driven element, and reflector. The curves labeled REFDIR are the patterns for a three-element array, a driven element, and a reflector and director.

Clearly this is a simple way to realize significant gain and directivity, and the active guys help support the tower.

Concluding remarks

While various GP type arrays consisting of driven and parasitic elements can be fabricated (e.g., antenna systems employing separate towers tuned to act like a driven element, with director and reflector elements), the antenna system described here is much easier to fabricate and more practical for backyard installation. In fact, the director and reflector elements of the array described are merely tuned guys.

The two-element array (driven element and reflector) is the one easiest to construct, and an antenna system of this type could be arranged

to change the azimuth of maximum gain. We could install two (perhaps four) reflector elements, with two (or four) remote control connect/disconnect relays located at the junction between the sloping wires and the horizontal radials. Because floating quarter-wavelength wires are not resonant, the unwanted wires required to rotate the beam in other directions will not carry an appreciable current.

The reflector and director elements can be adjusted for maximum forward gain or for an optimum F/B ratio. We have optimized our model for maximum forward gain. When constructing the antenna, make the sloping wires initially longer than I have calculated—to optimize the antenna performance, you'll want to cut off short lengths of wire, rather than having to add lengths of wire.

The reflector/director elements for this model are wire elements. Two parallel conductors spaced by insulated spreaders could be used instead to broaden the bandwidth of the antenna system.

Note: This modeling study has assumed a base insulated tower, height 19.9 meters, height of base 2.5 meters, with elevated radials. But reflector or reflector/director elements could be added to an existing GP type antenna of any reasonable height. Whatever the tower height, the tower (the driven element) must be tuned, and it is necessary to retune when parasitic elements are added.

Have fun constructing, adjusted, and operating this antenna array and, if you do, let me know how it performs.

Postscript

I carried out a design study for adding a reflector to an MF broadcast tower in New Zealand, which I hoped might be installed as this would provide me with measured data.[6] While this project may go ahead, the broadcaster has not yet decided. If it does, VE2CV will report on the results obtained in a brief note in the "Technical Conversations" column of *Communications Quarterly.* ∎

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