NBS TECHNICAL NOTE 1098

U.S. DEPARTMENT OF COMMERCE/National Bureau of Standards

Linear Gain - Standard Antennas Below 1000 MHz

R.G. FitzGerrell

The National Bureau of Standards[1] was established by an act of Congress on March 3, 1901. The Bureau's overall goal is to strengthen and advance the nation's science and technology and facilitate their effective application for public benefit. To this end, the Bureau conducts research and provides: (1) a basis for the nation's physical measurement system, (2) scientific and technological services for industry and government, (3) a technical basis for equity in trade, and (4) technical services to promote public safety. The Bureau's technical work is performed by the National Measurement Laboratory, the National Engineering Laboratory, the Institute for Computer Sciences and Technology, and the Institute for Materials Science and Engineering.

The National Measurement Laboratory

Provides the national system of physical and chemical measurement; coordinates the system with measurement systems of other nations and furnishes essential services leading to accurate and uniform physical and chemical measurement throughout the Nation's scientific community, industry, and commerce; provides advisory and research services to other Government agencies; conducts physical and chemical research; develops, produces, and distributes Standard Reference Materials; and provides calibration services. The Laboratory consists of the following centers:

- Basic Standards[2]
- Radiation Research
- Chemical Physics
- Analytical Chemistry

The National Engineering Laboratory

Provides technology and technical services to the public and private sectors to address national needs and to solve national problems; conducts research in engineering and applied science in support of these efforts; builds and maintains competence in the necessary disciplines required to carry out this research and technical service; develops engineering data and measurement capabilities; provides engineering measurement traceability services; develops test methods and proposes engineering standards and code changes; develops and proposes new engineering practices; and develops and improves mechanisms to transfer results of its research to the ultimate user. The Laboratory consists of the following centers:

- Applied Mathematics
- Electronics and Electrical Engineering[2]
- Manufacturing Engineering
- Building Technology
- Fire Research
- Chemical Engineering[2]

The Institute for Computer Sciences and Technology

Conducts research and provides scientific and technical services to aid Federal agencies in the selection, acquisition, application, and use of computer technology to improve effectiveness and economy in Government operations in accordance with Public Law 89-306 (40 U.S.C. 759), relevant Executive Orders, and other directives; carries out this mission by managing the Federal Information Processing Standards Program, developing Federal ADP standards guidelines, and managing Federal participation in ADP voluntary standardization activities; provides scientific and technological advisory services and assistance to Federal agencies; and provides the technical foundation for computer-related policies of the Federal Government. The Institute consists of the following centers:

- Programming Science and Technology
- Computer Systems Engineering

The Institute for Materials Science and Engineering

Conducts research and provides measurements, data, standards, reference materials, quantitative understanding and other technical information fundamental to the processing, structure, properties and performance of materials; addresses the scientific basis for new advanced materials technologies; plans research around cross-country scientific themes such as nondestructive evaluation and phase diagram development; oversees Bureau-wide technical programs in nuclear reactor radiation research and nondestructive evaluation; and broadly disseminates generic technical information resulting from its programs. The Institute consists of the following Divisions:

- Inorganic Materials
- Fracture and Deformation[3]
- Polymers
- Metallurgy
- Reactor Radiation

[1] Headquarters and Laboratories at Gaithersburg, MD, unless otherwise noted; mailing address Gaithersburg, MD 20899.
[2] Some divisions within the center are located at Boulder, CO 80303.
[3] Located at Boulder, CO, with some elements at Gaithersburg, MD.

Linear Gain - Standard Antennas Below 1000 MHz

R.G. FitzGerrell

Electromagnetic Fields Division
Center for Electronics and Electrical Engineering
National Engineering Laboratory
National Bureau of Standards
Boulder, Colorado 80303

U.S. DEPARTMENT OF COMMERCE, Malcolm Baldrige, Secretary

NATIONAL BUREAU OF STANDARDS, Ernest Ambler, Director

Issued May 1986

National Bureau of Standards Technical Note 1098
Natl. Bur. Stand. (U.S.), Tech Note 1098, 44 pages (May 1986)
CODEN:NBTNAE

U.S. GOVERNMENT PRINTING OFFICE
WASHINGTON: 1986

For sale by the Superintendent of Documents, U.S. Government Printing Office, Washington, DC 20402

Contents

LINEAR GAIN-STANDARD ANTENNAS BELOW 1000 MHz

R.G. FitzGerrell
Electromagnetic Fields Division
National Engineering Laboratory
National Bureau of Standards
Boulder, Colorado 80303

Gain and antenna parameters related to input impedance are calculated using a computer program named HVD6. This program uses well documented equations to compute these parameters for gain-standard antennas used in relative-gain or gain-transfer measurements at frequencies below 1000 MHz. The utility of this program is that it calculates gain patterns and input impedances for linear dipoles above perfect or imperfectly conducting plane ground and in free space, and for monopoles on perfectly conducting plane ground. Examples are included to illustrate the use of the program. Uncertainties in the calculated parameters are estimated to be less than those of the measured parameters.

Key words: antenna gain; dipole antennas; gain standards; monopole antennas.

1. Introduction

"The power gain of an antenna, in a specified direction, is 4π times the ratio of the power radiated per unit solid angle in that direction to the net power accepted by the antenna from its generator. This quantity is an inherent property of the antenna and does not involve system losses arising from a mismatch of impedance or polarization.

"Antennas which are to be used for gain standards should have the following characteristics:

(1) The gain of the antenna shall be accurately known.
(2) The antenna shall have a high degree of dimensional stability.
(3) The antenna's polarization should be linear or, for some applications, circular....

"Although any antenna meeting these criteria may be used as a gain standard, the two universally accepted antenna types are the dipole and the pyramidal horn. The gains of these antennas can be fairly accurately calculated, and because of their mechanical simplicity they can be manufactured with a high degree of reproducibility." [1]

The purpose of this document is to present an interactive computer program, listed in the Appendix, for calculating power gain (the term gain will be used henceforth) of dipoles used as gain standards over perfect or imperfectly conducting plane ground, and in free space, and of monopoles used on perfectly conducting plane ground. In addition to gain versus elevation angle, the computer program lists the following antenna parameters:

(1) Input impedance

(2) Mutual impedance between the dipole and its image in ground

(3) Antenna factor

(4) Antenna VSWR

(5) Mismatch loss

The equations used to calculate gain and various antenna parameters are located in Section 2. As discussed in [2], monopoles should be considered for use as gain standards only on electrically large, highly conducting ground screens.

These standard antennas are used in gain-transfer measurements to determine the gain of test antennas [1]. Below 1000 MHz, these measurements are frequently performed outdoors because of the size of the antennas or the expense of anechoic chambers large enough to simulate a free-space environment at these frequencies. Measurements are also made outdoors because the test antennas may be outdoors and, as an added complication, may be within a few wavelengths of the ground. As a result, gain of the standard antenna must be calculated taking the effect of ground into account.

The electrical properties of the ground must be known to calculate the gain of dipoles over imperfect ground. These properties may be estimated by measuring soil samples and assuming the entire test site is uniform plane ground exhibiting these properties. The curvature of the earth and the effects of ground-wave propagation are neglected in these gain calculations. It is often very difficult to measure the gain of standard antennas below 1000 MHz, therefore the calculated gain must be assumed to be correct in many gain measurement situations.

Actual antennas having calculable gains are described in Section 3. Recent measurements of insertion loss between pairs of these antennas in the 30-MHz to 1000-MHz frequency range have been made using the NBS ground screen [3]. Comparisons of measured and calculated data imply that the calculated gain, at or near the maximum, may have uncertainties on the order of 0.4 dB or less. This does not mean that the entire gain pattern of a standard antenna will have this small an uncertainty.

Section 4 is a compilation of examples of the use of the computer program. Most of the examples are for radiating elements with a half-length of a quarter wavelength or less, which is typical of most gain-standard antennas. The term half-length is used for the length of a single radiating element. It is the distance from the dipole feedpoint to the end of one radiating element, or the distance from the monopole feedpoint to the end of its radiating element. Validity of the equations used in the computer program is restricted to half-lengths less than one-half wavelength.

2. Definitions and Equations

All equations in this document are generally considered to be good engineering approximations. They are presented in a format incorporating the variable names and library functions used in the computer code while at the same time retaining the conventional form of the equations as they appear in the referenced material. The purpose of this somewhat mixed format is to enable the reader to easily recognize the lines of code embodying the equations from the references.

The radiating elements of the gain-standard antennas have a half-length, L, a circular cross section, may have a linear taper, have no internal losses, and no shunt admittance in the input region. The principal quantity required for calculating most antenna performance parameters is input impedance, ZR. It is obtained by calculating the intrinsic impedance, ZI, and adding the mutual impedance between the antenna and its image in ground if the antenna is located over ground. The intrinsic impedance is the input impedance of a dipole in free space or a monopole on a perfectly conducting ground plane. The mutual impedance between a dipole and its image in ground, ZMB, is obtained by calculating ZML, the mutual impedance between two free-space dipoles in echelon [4], one representing the image dipole, and changing the reference from the loop current to the base current. The mutual impedance, ZMB, is then multiplied by the reflection coefficient of the ground evaluated at an elevation angle ψ = 90 deg and denoted RH90 for horizontal polarization and RV90 for vertical polarization. Because of the length of the mutual impedance equations, the reader is referred to reference [4] and Subroutine Mutual in program HVD6 located in the appendix.

The equations yielding intrinsic impedance are from [5]. All linear dimensions and wavelength, λ, are in meters. Upper-case variables, except M and N, are the variable names actually used in program HVD6.

$$ZI = \frac{KA((KA-M)\cos(\beta L)+j(ZA+JWCT*KA^2-jN)\sin(\beta L))}{(ZA+JWCT*KA^2+jN)\cos(\beta L)+j(KA+M)\sin(\beta L)} = \frac{ZINN}{ZIND}, \tag{1}$$

where

$$\beta = 2\pi/\lambda, \text{ and}$$

$$KA = 120(\log_e(2L/RT)-1)$$

for antenna elements with a uniform cross section, and

$$KA = 120(\log_e(2L/RB)+(RT/(RB-RT))\log_e(RT/RB))$$

for antenna elements tapered from the base with radius RB, to the tip with radius RT.

$$M = 60(Cin(2\beta L)-1+\cos(2\beta L)) = MBL,$$

$$N = 60(Si(2\beta L)-\sin(2\beta L)) = NBL,$$

$$JWCT = jRT/30\lambda, \text{ and}$$

$$ZA = RABL+jXABL, \text{ where}$$

$$\begin{aligned}Real(ZA) = RABL = {} & 60Cin(2\beta L)+30(2Cin(2\beta L)-Cin(4\beta L))\cos(2\beta L) \\ & +30(Si(4\beta L)-2Si(2\beta L)\sin(2\beta L)), \text{ and}\end{aligned}$$

$$Imag(ZA) = XABL = 60Si(2\beta L)-30(Cin(4\beta L)-\log_e 4)\sin(2\beta L)-30Si(4\beta L)\cos(2\beta L).$$

In the preceding equations, Si and Cin (and Ci in Subroutine Mutual) are functional notations for sine and cosine integrals. These integrals are calculated in Program HVD6 in Subroutine SCI using series expansions and rational approximations given in [6].

For free-space dipoles,

$$ZR = ZI, \tag{2}$$

and for monopoles,

$$ZR = ZI/2. \tag{3}$$

For horizontal dipoles over ground,

$$ZR = ZI+RH90*ZMB. \tag{4}$$

For vertical dipoles over ground,

$$ZR = ZI+RV90*ZMB. \tag{5}$$

Antenna factor is the ratio, expressed in decibels, of the linearly polarized field strength incident upon a copolarized antenna to the voltage at the antenna terminals measured with a receiver having a characteristic impedance, ZCHAR. Antenna factor is

$$AF = 20 \log_{10}|(ZCHAR+ZR)/ZCHAR|/(\text{effective length of antenna}) \tag{6}$$

where $|(\lambda/\pi)\tan(\beta L/2)|$ is the effective length of a free-space dipole, and $|(\lambda/2\pi)\tan(\beta L/2)|$ is the effective half-length of a monopole on infinite, perfectly conducting ground.

The voltage reflection coefficient at the antenna terminals is

$$R = (ZR-ZCHAR)/(ZR+ZCHAR), \tag{7}$$

and the voltage standing-wave ratio is

$$VSWR = (1+|R|)/(1-|R|). \tag{8}$$

The conjugate mismatch loss [7], expressed in decibels, is

$$LOSS = 10 \log_{10}(1/(1-|R^2|)). \tag{9}$$

Antenna gain is a function of input impedance, free-space effective length, and radiation pattern of the array formed by the antenna and its image in the ground. Based upon equations in [8,9,10,11], antenna gain is expressed in decibels as

$$\mathrm{GAIN} = 10 \log_{10}(120|E^2|/\mathrm{Real}(ZR)) \qquad (10)$$

where E is the effective length of a dipole over ground, multiplied by π/λ.

The three equations for E for a dipole with its feedpoint H meters above ground and for a monopole on perfect ground are as follows:

Horizontal dipole over ground, H-plane

$$E = |\tan(\beta L/2)|(e^{j\beta H\sin\psi} + RH\ e^{-j\beta H\sin\psi}) \qquad (11)$$

Vertical dipole over ground or monopole on perfect ground, E-plane

$$E = |(\cos(\beta L\sin\psi)-\cos(\beta L))/(\cos\psi(\sin\beta L))|(e^{j\beta H\sin\psi} + RV\ e^{-j\beta H\sin\psi}) \qquad (12)$$

(Monopole gain is computed using the value of E for a vertically polarized dipole in free space.)

Horizontal dipole over ground, E-plane

$$E = |(\cos(\beta L\cos\psi)-\cos(\beta L))/(\sin\psi(\sin\beta L))|(e^{j\beta H\sin\psi} - RV\ e^{-j\beta H\sin\psi}) \qquad (13)$$

The vertical and horizontal reflection coefficients [8] for the ground plane or test site ground are

$$RV = (((EPSN-jX)\sin\psi)-TSQ)/(((EPSN-jX)\sin\psi)+TSQ), \text{ and} \qquad (14)$$

$$RH = (\sin\psi-TSQ)/(\sin\psi+TSQ), \qquad (15)$$

where

$X = 17.975\ SIGMA/FREQ$,

FREQ = frequency, in MHz,

SIGMA = σ = conductivity in millisiemens/m (abbreviated mS/m, and originally millimhos/m in past usage),

EPSN = ε_r = relative dielectric constant, and

$TSQ = (EPSN-jX-\cos^2\psi)^{1/2}$.

3. Gain-Standard Antennas

Half-wave gain-standard dipoles and quarter-wave monopoles are fabricated using rigid metal tubing above about 30 MHz and tensioned wires below this frequency. This approximate frequency crossover may be reduced when using electrically small antennas. The feedpoints are electrically small, and the amount of low-loss dielectric material used as a support is kept to a minimum. The dipole balun (balanced-to-unbalanced transmission-line transformer) is removable for calibration.

Figures 1 and 2 show dipoles used for insertion loss measurements in the 30-MHz to 1000-MHz frequency range [3]. The feedpoint assembly is a dielectric cylinder 8.9 cm (3.5 in) long and 2.54 cm (1 in) in diameter. Two, small, coaxial panel jacks (Type SMA) form the feedpoint, and banana jacks soldered to the inner conductors provide a simple slip fit to the radiating elements. Below about 97 MHz, the radiating elements are extensible whips used down to about 30 MHz. Above 97 MHz, thin-wall brass tubing is used for elements up to 1000 MHz. Precision attenuators (pads) and equal length, 50-ohm, coaxial cables connect the dipole terminals to the collinear (0 and 180 deg) ports of a coaxial hybrid junction serving as the dipole balun. Figure 3 shows the monopole antenna using the same radiating elements as the dipole.

Figure 4 shows how the hybrid junction, cable, and precision attenuator assemblies are calibrated for use with the dipole antennas. The initial received signal level at the spectrum analyzer is measured with the cables, shown attached to the E-ports, joined with a coaxial adapter. The final received signal level is measured as shown, and the difference between the two levels is the total insertion loss of two assemblies providing the spectrum analyzer and signal generator have input- and output-port impedances that are matched to the impedance of the cables. It is assumed that the assemblies are identical, and that the loss of a single assembly is just one-half the total measured loss. The 3-dB attenuators are used at the dipole feedpoint end of the cables to force the actual value of ZCHAR toward the 100-ohm value assumed for the calculations.

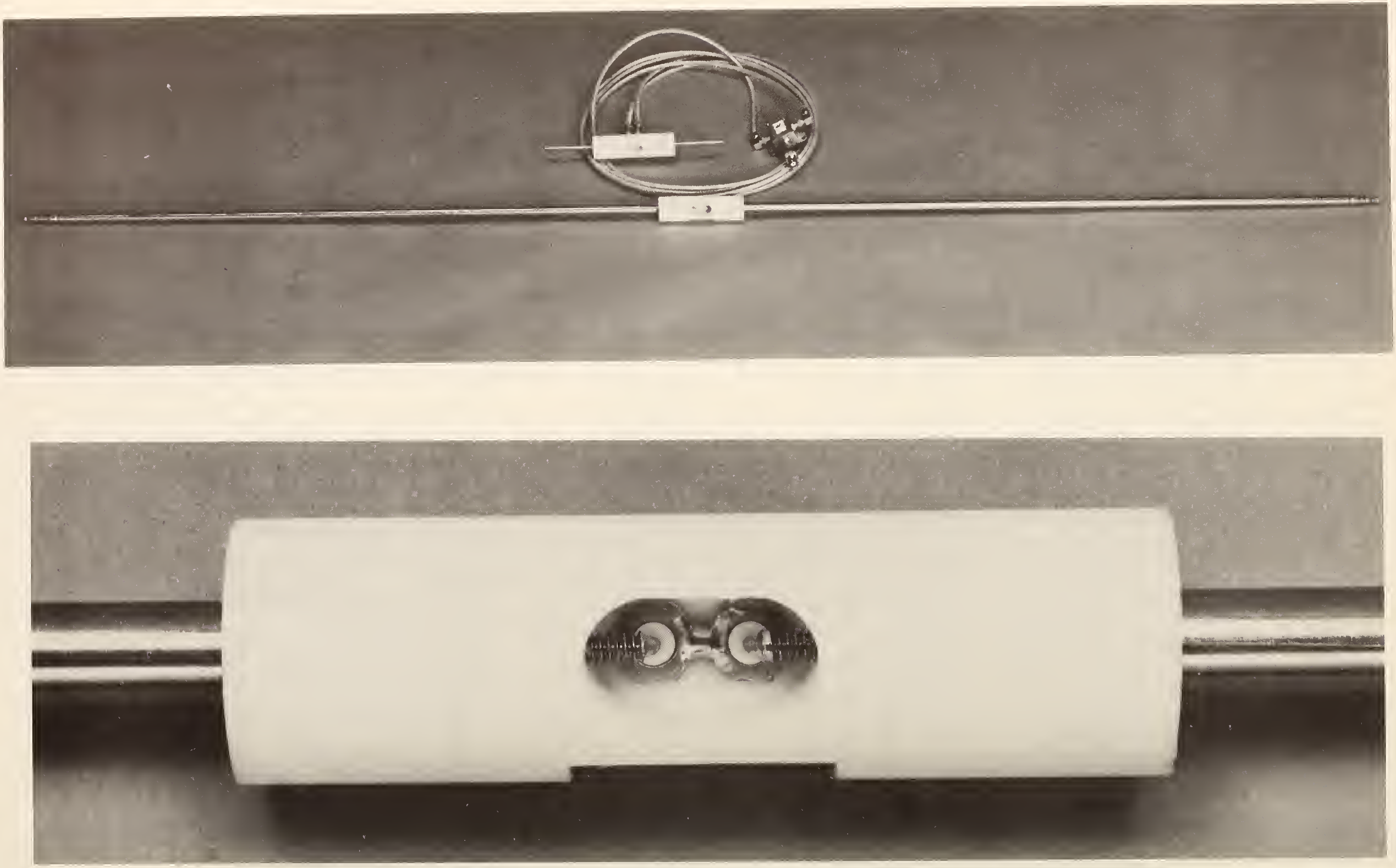

Figure 1. A standard dipole -- balun, cable, attenuators, and feedpoint assemblies shown with 677 MHz and 97 MHz elements in place in the upper photograph, and a close-up of a feedpoint assembly in the lower photograph.

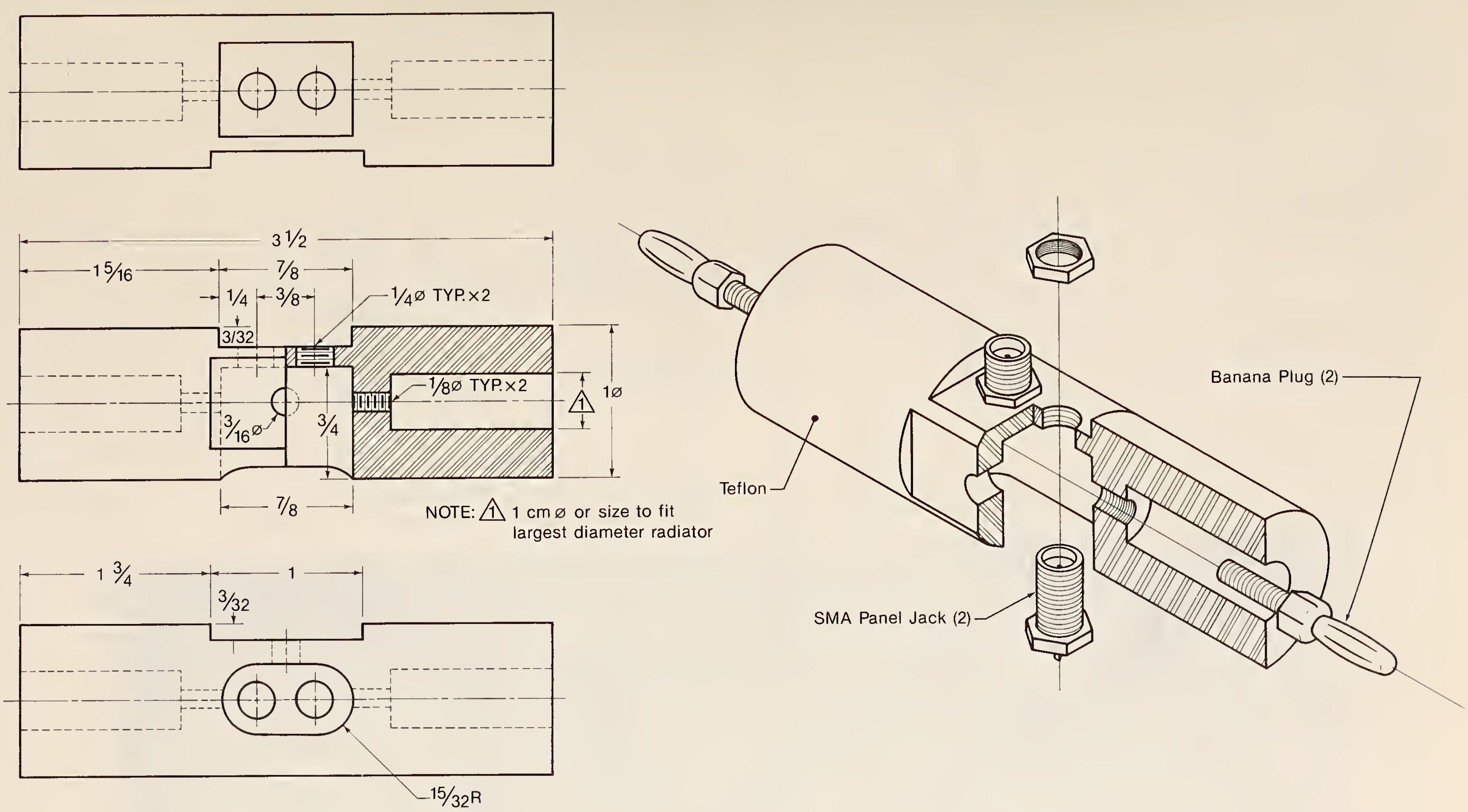

Figure 2. Schematic drawing of the dipole feedpoint assembly. Note, for use at frequencies above 300 MHz only, the assembly may be shortened and the diameter may be reduced.

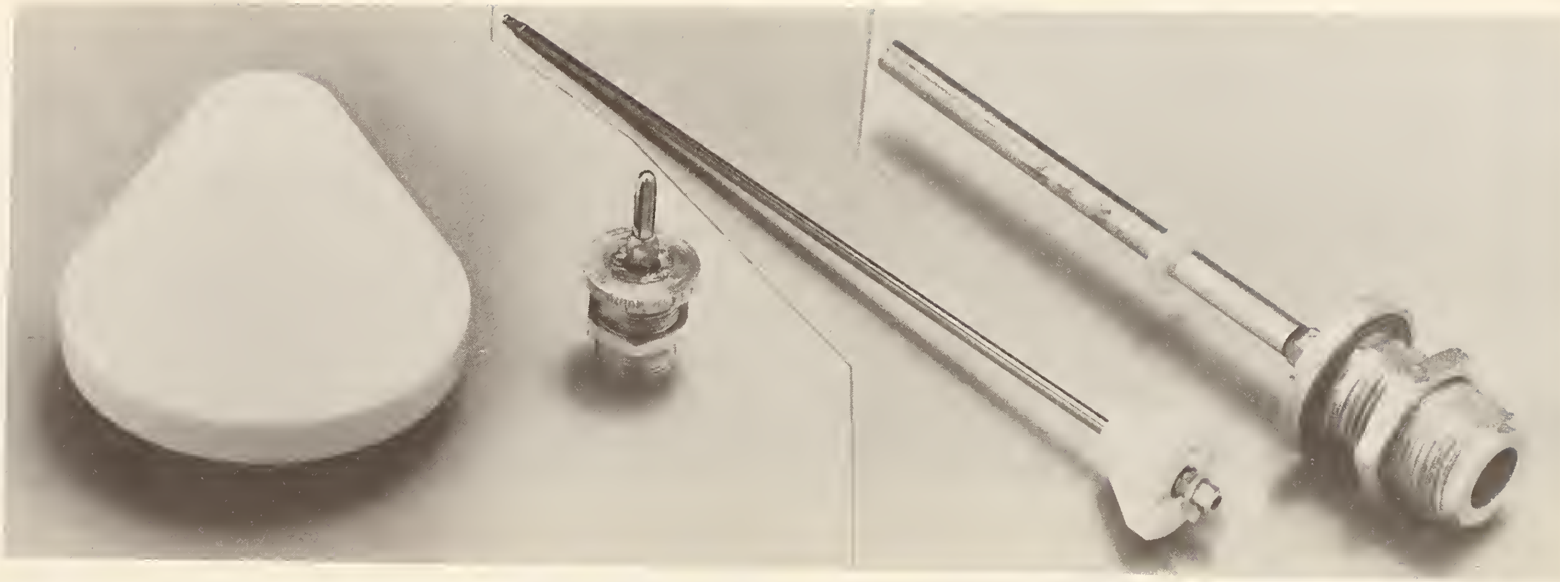

Figure 3. A composite photograph (not all to same scale) of the monopole assemblies -- feedpoint assembly, a 97 MHz monopole, and a 677 MHz monopole.

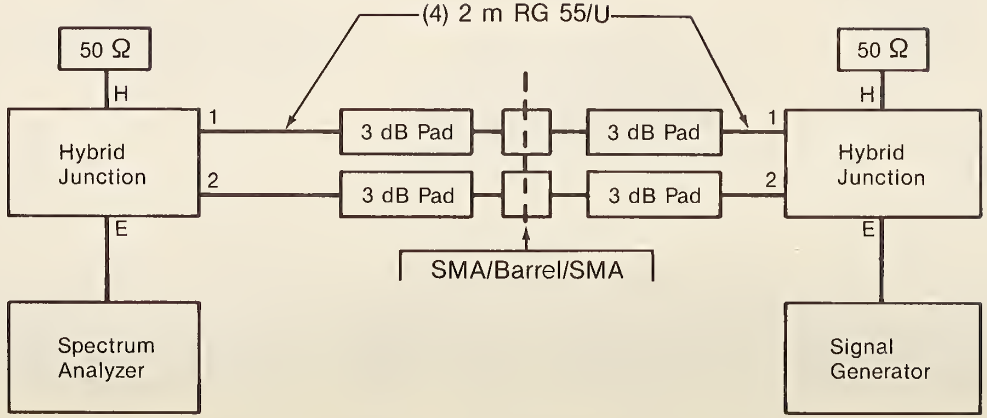

Figure 4. Schematic diagram of the balun and cable assembly calibration.

Insertion loss between pairs of these antennas has been measured using the 30-m by 60-m NBS ground screen. See reference [3] and Example #7 in Section 4 for a comparison of part of the measured and calculated data. In the 30-MHz to 1000-MHz frequency range of interest, the results imply that the mean difference between measured and calculated gain is typically $\leqq$ 0.05 dB, with a value $\leqq$ 0.42 dB on the outside. This result is for dipoles with $0.1\lambda \leqq L \leqq 0.25\lambda$ and for monopoles with $L = 0.25\lambda$, assuming the effective lengths are correct. Effective length is the only quantity used for calculating gain that is not used explicitly for calculating insertion loss. However, insertion loss between pairs of antennas in free space is precisely the quantity obtained using the antenna gains in Friis's transmission formula [5], assuming the mismatch losses are zero. Therefore, antenna gains are implicit in the more general insertion loss equations. Comparing measured and calculated insertion-loss data is a valid method of determining the uncertainty in the gain-product of two linear antennas.

4. Examples of Gain-Standard Antenna Calculations

#1 Thin $\lambda/2$ Dipole and $\lambda/4$ Monopole - 299.792458 MHz

The computer program assumes all free-space dipoles are "horizontal" and calculates both the E- and H-plane patterns. For this example, the half-length of the dipole and monopole are exactly $\lambda/4$ and the radii are 0 m. Since the program must have some nonzero dimension for the radius, a value of 0 input for the requested radius results in the program setting the value to 10^{-30}m. Figure 5a shows the dipole gain is a constant 2.14 dB in the H plane and exhibits a quarter-section of the "figure-eight" pattern in the E plane. Figure 5b shows the monopole gain is 5.14 dB and its pattern is an inverted copy of the dipole pattern.

The following data are copied from the computer screen during program execution:

```
TYPE THE REQUESTED DATA AFTER EACH ?
FREQUENCY, MHZ
? 299.792458
ANTENNA HALF-LENGTH < LAMBDA/2, M
? .25
ANTENNA RADII, FEEDPOINT THEN END, M
? 0
? 0
TYPE 1. FOR DIPOLE, 0 FOR MONOPOLE
? 1.
TYPE 1. FOR GROUND, 0 FOR FREE SPACE
? 0
IMPEDANCE OF T-LINE ATTACHED TO ANTENNA, OHMS
? 100.
- - - - - - - - - - - - - - - - - - - - - - - - - - -
INPUT IMPEDANCE =     73.3209+J[     42.6559]OHMS
- - - - - - - - - - - - - - - - - - - - - - - - - - -
ENTER NEW HALF-LENGTH, OR ENTER 0
? 0
- - - - - - - - - - - - - - - - - - - - - - - - - - -
ANTENNA FACTOR ASSUMING A 100.00-OHM RECEIVER
AND A 1:1 BALUN ARE EMPLOYED =    14.98 DB
VSWR =        1.7850
MISMATCH LOSS =        .3595 DB
- - - - - - - - - - - - - - - - - - - - - - - - - - -
PRESS RETURN FOR GAIN VS PHI, OTHERWISE TYPE CNTL T
   PAUSE
?
ELEV ANGLE INCREMENT FOR BELOW 10 DEG AND THE
      ADDITIONAL INCREMENT FOR ABOVE 10 DEG
? 2.
? 3.
```

H-PLANE ELEVATION ANGLE IN DEGREES AND GAIN IN DB HORIZONTAL POLARIZATION		E-PLANE ELEVATION ANGLE IN DEGREES AND GAIN IN D VERTICAL POLARIZATION	
2.000	2.140	2.000	-29.100
4.000	2.140	4.000	-23.076
6.000	2.140	6.000	-19.550
8.000	2.140	8.000	-17.046
10.000	2.140	10.000	-15.100
15.000	2.140	15.000	-11.554
20.000	2.140	20.000	-9.025
25.000	2.140	25.000	-7.054
30.000	2.140	30.000	-5.441
35.000	2.140	35.000	-4.081
40.000	2.140	40.000	-2.913
45.000	2.140	45.000	-1.902
50.000	2.140	50.000	-1.025
55.000	2.140	55.000	-.268
60.000	2.140	60.000	.379
65.000	2.140	65.000	.920
70.000	2.140	70.000	1.361
75.000	2.140	75.000	1.702
80.000	2.140	80.000	1.945
85.000	2.140	85.000	2.091
90.000	2.140	90.000	2.140

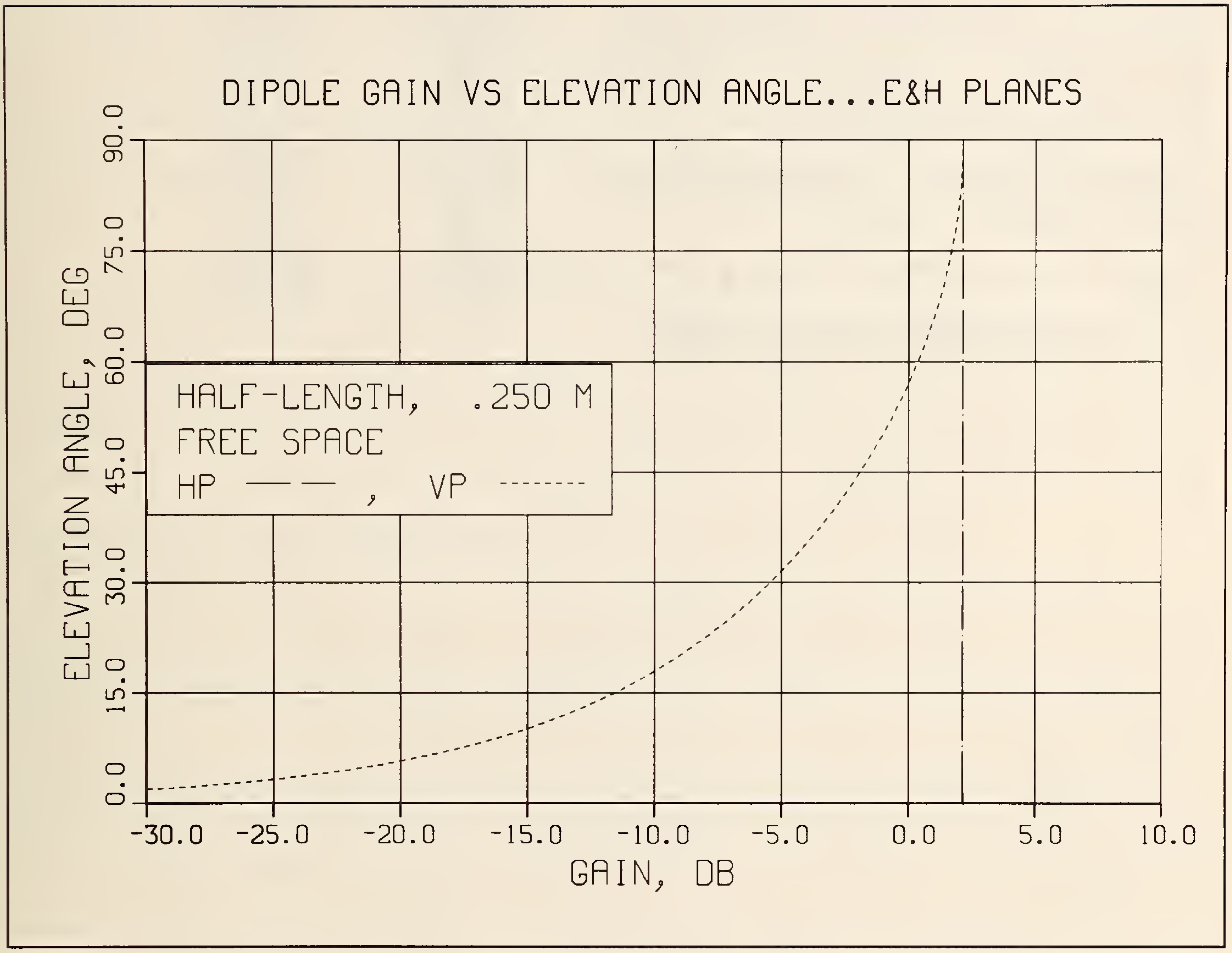

Figure 5 a. Calculated gain versus elevation angle for a thin, λ/2 dipole in free space. λ=1 m

```
TYPE THE REQUESTED DATA AFTER EACH ?
FREQUENCY, MHZ
? 299.792458
ANTENNA HALF-LENGTH < LAMBDA/2, M
? .25
ANTENNA RADII, FEEDPOINT THEN END, M
? 0
? 0
TYPE 1. FOR DIPOLE, 0 FOR MONOPOLE
? 0
IMPEDANCE OF T-LINE ATTACHED TO ANTENNA, OHMS
? 50.
- - - - - - - - - - - - - - - - - - - - - - - - - - - - -
INPUT IMPEDANCE =     36.6605+J[     21.3279]OHMS
- - - - - - - - - - - - - - - - - - - - - - - - - - - - -
ENTER NEW HALF-LENGTH, OR ENTER 0
? 0
- - - - - - - - - - - - - - - - - - - - - - - - - - - - -
ANTENNA FACTOR ASSUMING A  50.00-OHM RECEIVER
AND TRANSMISSION LINE ARE EMPLOYED =   21.00 DB
VSWR =      1.7850
MISMATCH LOSS =        .3595 DB
- - - - - - - - - - - - - - - - - - - - - - - - - - - - -
PRESS RETURN FOR GAIN VS PHI, OTHERWISE TYPE CNTL T
   PAUSE
?
ELEV ANGLE INCREMENT FOR BELOW 10 DEG AND THE
      ADDITIONAL INCREMENT FOR ABOVE 10 DEG
? 2.
? 3.
```

E-PLANE ELEVATION ANGLE IN DEGREES AND GAIN IN DB
VERTICAL POLARIZATION

2.000	5.142
4.000	5.119
6.000	5.080
8.000	5.026
10.000	4.956
15.000	4.712
20.000	4.371
25.000	3.931
30.000	3.389
35.000	2.742
40.000	1.985
45.000	1.108
50.000	.097
55.000	-1.070
60.000	-2.431
65.000	-4.044
70.000	-6.014
75.000	-8.543
80.000	-12.090
85.000	-18.126
90.000	-120.000

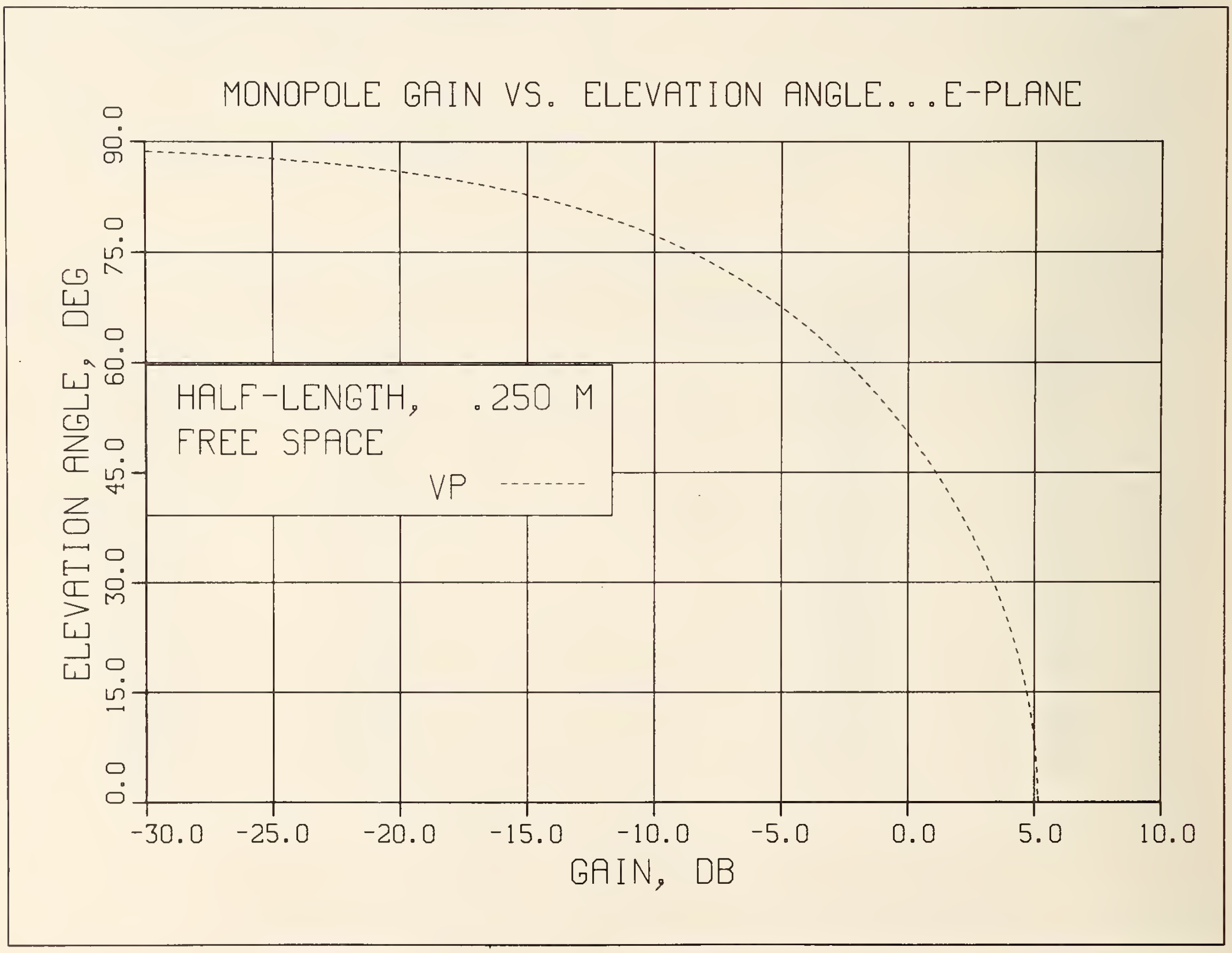

Figure 5 b. Calculated gain versus elevation angle for a thin, λ/4 monopole fed against an infinite, perfectly conducting, plane ground. λ=1 m

#2 A Vertical Dipole Over Imperfect Ground - 485 kHz

In 1979, an extensive set of measurements were made near Dateland, Arizona, to determine the gain of various medium-frequency antenna configurations at low elevation angles. The 485-kHz test signal was transmitted from an electrically short (61 m), vertical sleeve dipole suspended by a helicopter. An optical tracker provided elevation and azimuth angle data for these measurements.

The gain-standard antenna was a vertical sleeve dipole, with L = 152.4 m, supported by a 25-m^3 helium-filled blimp. A large toroidal choke suppressed undesired currents on the outer conductor of the antenna-to-receiver cable at ground level. The gain pattern of this antenna, shown in Fig. 6, is calculated for σ = 10 mS/m and ε_r = 50 based upon soil samples from the dry lakebed test site.

Measurements were made at a range of 1620 m, and, because of the strong ground-wave component in the electromagnetic field at the test site, the resulting data are "gain" values relative to the particular reference dipole measured at that specific range. In fact, "the concepts of power gain, directive gain, radiation resistance, and radiation efficiency are not directly applicable in this situation..."[1].

The following data are copied from the computer screen during program execution:

```
TYPE THE REQUESTED DATA AFTER EACH ?
FREQUENCY, MHZ
? 0.485
ANTENNA HALF-LENGTH < LAMBDA/2, M
? 152.4
ANTENNA RADII, FEEDPOINT THEN END, M
? 0.002
? 0.002
TYPE 1. FOR DIPOLE, 0 FOR MONOPOLE
? 1.
TYPE 1. FOR GROUND, 0 FOR FREE SPACE
? 1.
DIPOLE FEED-POINT HEIGHT ABOVE GROUND, M
? 153.
TYPE 1. FOR HORIZONTAL POLARIZATION, 0 FOR VERTICAL
? 0
TYPE 1. FOR PERFECT GROUND, 0 FOR IMPERFECT GROUND
? 0
GROUND CONDUCTIVITY, MILLISIEMENS/M
? 10.
GROUND RELATIVE DIELECTRIC CONSTANT
? 50.
IMPEDANCE OF T-LINE ATTACHED TO ANTENNA, OHMS
? 50.
- - - - - - - - - - - - - - - - - - - - - - - - - -
INPUT IMPEDANCE =     96.1373+J[    31.1427]OHMS
- - - - - - - - - - - - - - - - - - - - - - - - - -
ENTER NEW HALF-LENGTH, OR ENTER 0
? 0

- - - - - - - - - - - - - - - - - - - - - - - - - -
ANTENNA FACTOR ASSUMING A  50.00-OHM RECEIVER
AND A 1:1 BALUN ARE EMPLOYED =  -36.18 DB
MUTUAL IMPEDANCE DUE TO THE DIPOLE'S IMAGE
IN THE GROUND =     25.0490+J[    15.8547]OHMS
VSWR =      2.1875
MISMATCH LOSS =       .6489 DB
- - - - - - - - - - - - - - - - - - - - - - - - - -
PRESS RETURN FOR GAIN VS PHI, OTHERWISE TYPE CNTL T
   PAUSE
?
ELEV ANGLE INCREMENT FOR BELOW 10 DEG AND
THE ADDITIONAL INCREMENT FOR ABOVE 10 DEG
? 2.
? 3.
- - - - - - - - - - - - - - - - - - - - - - - - - -
E-PLANE ELEVATION ANGLE IN DEGREES AND GAIN IN DB
VERTICAL POLARIZATION
          2.000         -1.026
          4.000          1.998
          6.000          3.164
          8.000          3.707
         10.000          3.949
         15.000          3.885
         20.000          3.260
         25.000          2.237
         30.000           .866
         35.000          -.846
         40.000         -2.908
         45.000         -5.350
         50.000         -8.221
         55.000        -11.598
         60.000        -15.598
         65.000        -20.395
         70.000        -26.187
         75.000        -32.821
         80.000        -38.727
         85.000        -44.480
         90.000       -120.000
- - - - - - - - - - - - - - - - - - - - - - - - - -
```

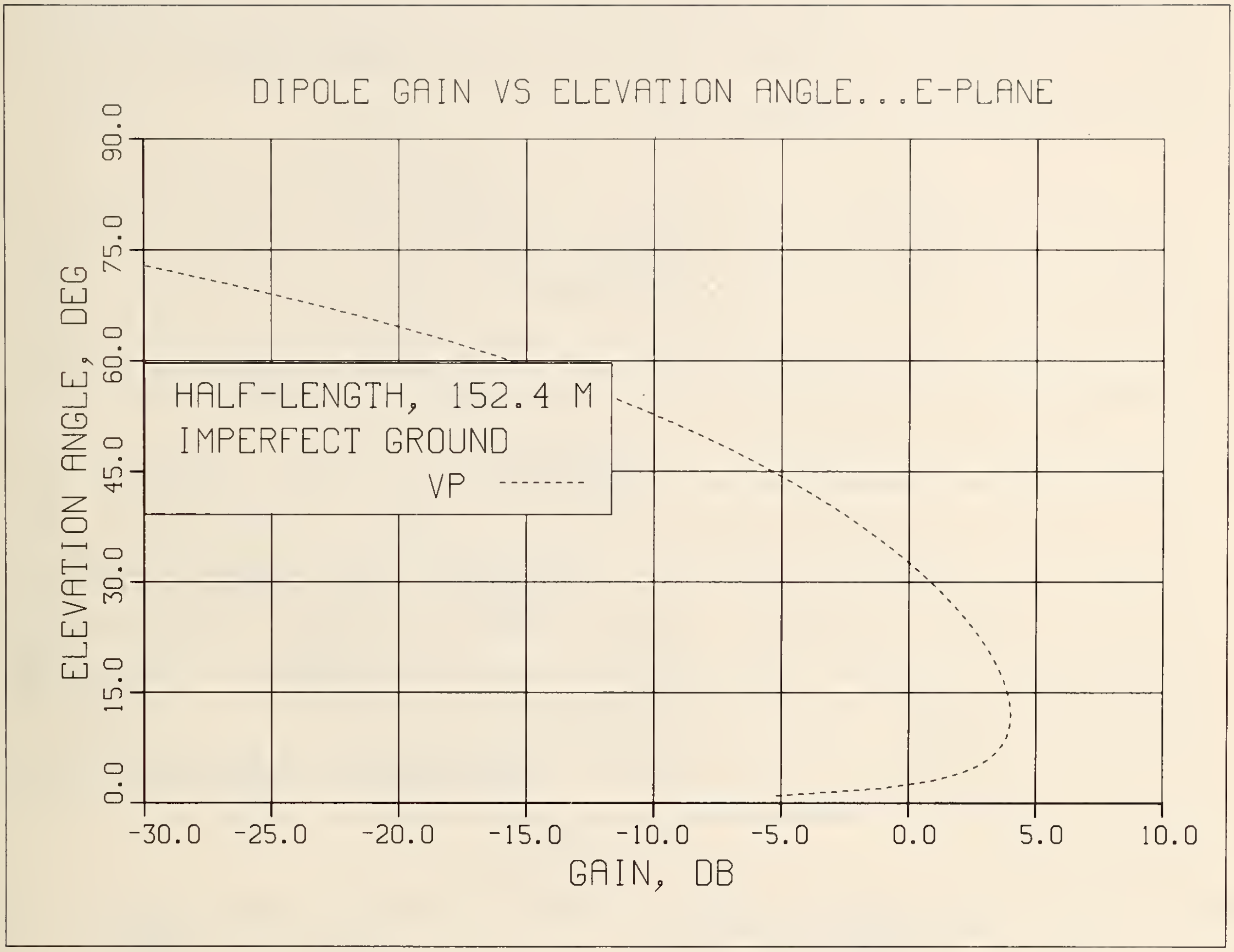

Figure 6. Calculated gain versus elevation angle for a vertical dipole over imperfect ground with lower tip of dipole at ground level. λ=618 m; σ=10 mS/m; ε_r=50

#3 A Horizontal Dipole Over Imperfect Ground - 11.555 MHz

The Table Mountain test site is located near Boulder, Colorado. Frequent high winds make the use of a blimp-supported vertical reference impractical in the high-frequency band, so a horizontal wire-dipole, stretched between two wooden poles, was used as a gain-standard antenna for some measurements performed in 1977.

The test antenna was a vehicular omnidirectional antenna mounted on a large van which was placed on a turntable rotating at about 1 rpm during the measurements. The test site was illuminated with an electrically-small, reflector-backed, vertically-polarized antenna mounted between the skids of a helicopter. This antenna pivoted so the main beam always pointed at the test site. The helicopter flew over the test site on a radial in the vertical plane through the gain-standard antenna. Test antenna gain data were presented as mean vertical-plane patterns with horizontal bars indicating the standard deviation of the sampled data measured in specific, elevation-angle increments. Figure 7 shows the gain of the standard, horizontal, $\lambda/2$ dipole, positioned at a 6.3-m height, used as a vertically polarized reference. That is, the E-plane gain-pattern of the dipole was used as the gain-transfer standard. Toroidal chokes are required in the dipole feed cable to reduce radiation by any currents on the outer conductor of this cable.

The following data are copied from the computer screen during program execution:

```
TYPE THE REQUESTED DATA AFTER EACH ?
FREQUENCY, MHZ
? 11.555
ANTENNA HALF-LENGTH < LAMBDA/2, M
? 5.7
ANTENNA RADII, FEEDPOINT THEN END, M
? 0.00125
? 0.00125
TYPE 1. FOR DIPOLE, 0 FOR MONOPOLE
? 1.
TYPE 1. FOR GROUND, 0 FOR FREE SPACE
? 1.
DIPOLE FEED-POINT HEIGHT ABOVE GROUND, M
? 6.3
TYPE 1. FOR HORIZONTAL POLARIZATION, 0 FOR VERTICAL
? 1.
TYPE 1. FOR PERFECT GROUND, 0 FOR IMPERFECT GROUND
? 0
GROUND CONDUCTIVITY, MILLISIEMENS/M
? 20.
GROUND RELATIVE DIELECTRIC CONSTANT
? 5.
IMPEDANCE OF T-LINE ATTACHED TO ANTENNA, OHMS
? 100.
- - - - - - - - - - - - - - - - - - - - - - - - - - -
INPUT IMPEDANCE =     58.9441+J[   -123.4851]OHMS
- - - - - - - - - - - - - - - - - - - - - - - - - - -
ENTER NEW HALF-LENGTH, OR ENTER 0
? 0
- - - - - - - - - - - - - - - - - - - - - - - - - - -
ANTENNA FACTOR ASSUMING A 100.00-OHM RECEIVER
AND A 1:1 BALUN ARE EMPLOYED =  -10.60 DB
MUTUAL IMPEDANCE DUE TO THE DIPOLE'S IMAGE
IN THE GROUND =      9.0674+J[     15.2329]OHMS
VSWR =       4.6582
MISMATCH LOSS =       2.3508 DB
- - - - - - - - - - - - - - - - - - - - - - - - - - -
PRESS RETURN FOR GAIN VS PHI, OTHERWISE TYPE CNTL T
   PAUSE
?
ELEV ANGLE INCREMENT FOR BELOW 10 DEG AND
THE ADDITIONAL INCREMENT FOR ABOVE 10 DEG
? 2.
? 3.
```

```
E-PLANE ELEVATION ANGLE IN DEGREES AND GAIN IN DB H-PLANE ELEVATION ANGLE IN DEGREES AND GAIN IN DB
VERTICAL POLARIZATION                             HORIZONTAL POLARIZATION
          2.000        -24.484                              2.000        -17.400
          4.000        -19.503                              4.000        -11.439
          6.000        -16.820                              6.000         -7.991
          8.000        -14.965                              8.000         -5.577
         10.000        -13.486                             10.000         -3.737
         15.000        -10.429                             15.000          -.515
         20.000         -7.726                             20.000          1.612
         25.000         -5.274                             25.000          3.110
         30.000         -3.103                             30.000          4.192
         35.000         -1.226                             35.000          4.975
         40.000           .373                             40.000          5.533
         45.000          1.719                             45.000          5.918
         50.000          2.839                             50.000          6.171
         55.000          3.762                             55.000          6.322
         60.000          4.511                             60.000          6.397
         65.000          5.107                             65.000          6.421
         70.000          5.569                             70.000          6.412
         75.000          5.912                             75.000          6.387
         80.000          6.148                             80.000          6.360
         85.000          6.286                             85.000          6.339
         90.000          6.331                             90.000          6.331
- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
```

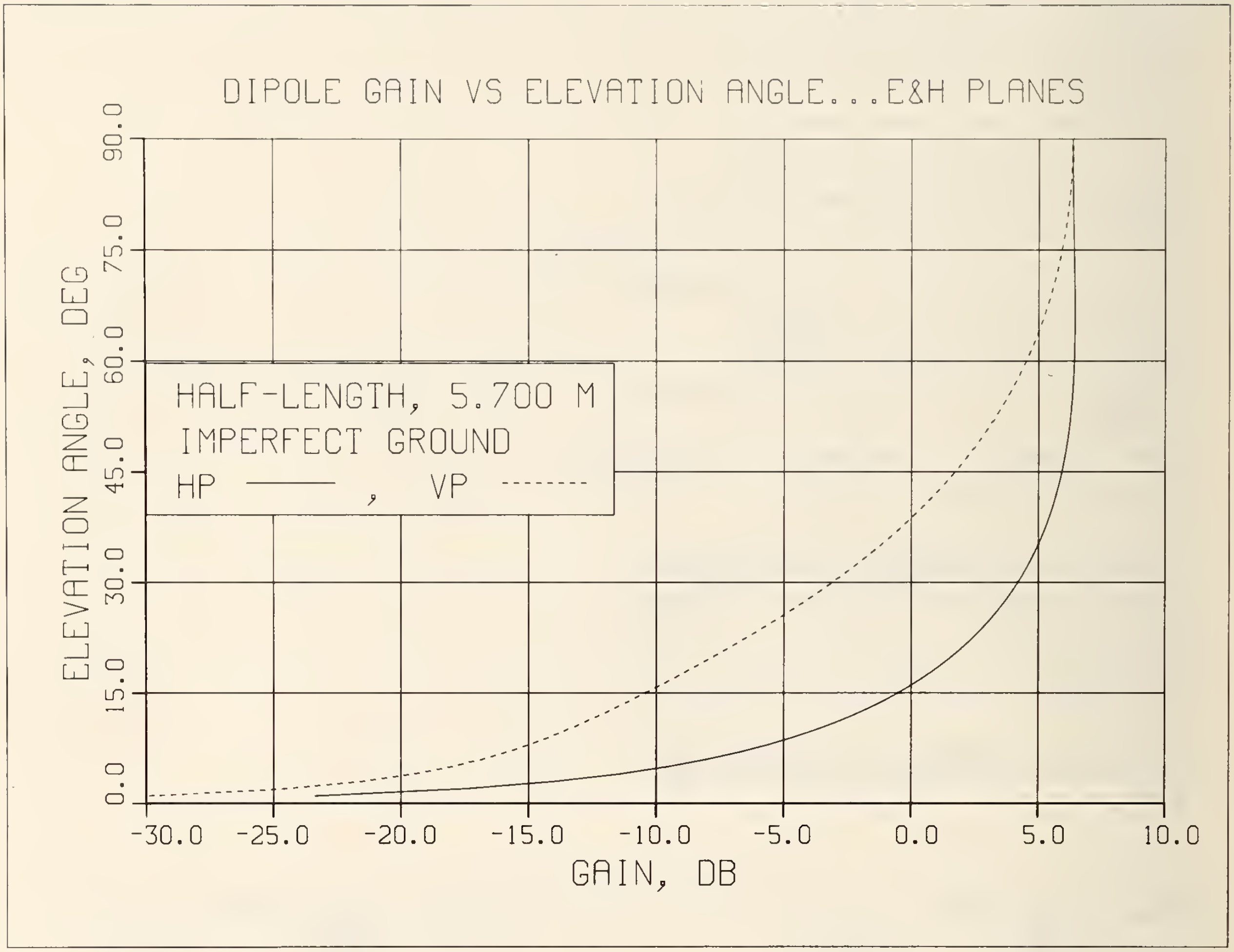

Figure 7. Calculated gain versus elevation angle for a horizontal dipole with its feedpoint 0.24 λ above ground. λ=25.9 m; σ=20 mS/m; ε_r=5

#4 Horizontal Dipole Over Imperfect Ground - 392.5 MHz

Reference [12] describes measurements of buried, vertically polarized antennas in the 225-MHz to 400-MHz frequency range. The gain-standard dipole used for the measurements at Table Mountain was a horizontal $\lambda/2$ dipole positioned 2.6 λ above the ground. A rotatable, reflector-backed dipole was used to illuminate the test range enabling the use of the H-plane pattern as a gain-transfer standard for these vertically polarized test antenna measurements [13]. Figure 8 shows the calculated gain versus elevation angle for the gain-standard dipole. This dipole was positioned at a height chosen to place its main beam at a 5-deg elevation angle to insure accurate measurements near this elevation angle. It is difficult to make accurate gain-transfer measurements near the nulls of gain-standard antennas.

The following data are copied from the computer screen during program execution:

```
TYPE THE REQUESTED DATA AFTER EACH ?
FREQUENCY, MHZ
? 392.5
ANTENNA HALF-LENGTH < LAMBDA/2, M
? 0.172
ANTENNA RADII, FEEDPOINT THEN END, M
? 0.003
? 0.003
TYPE 1. FOR DIPOLE, 0 FOR MONOPOLE
? 1.
TYPE 1. FOR GROUND, 0 FOR FREE SPACE
? 1.
DIPOLE FEED-POINT HEIGHT ABOVE GROUND, M
? 1.987
TYPE 1. FOR HORIZONTAL POLARIZATION, 0 FOR VERTICAL
? 1.
TYPE 1. FOR PERFECT GROUND, 0 FOR IMPERFECT GROUND
? 0
GROUND CONDUCTIVITY, MILLISIEMENS/M
? 20.
GROUND RELATIVE DIELECTRIC CONSTANT
? 4.
IMPEDANCE OF T-LINE ATTACHED TO ANTENNA, OHMS
? 100.
- - - - - - - - - - - - - - - - - - - - - - - - - - -
INPUT IMPEDANCE =     51.0038+J[     2.0276]OHMS
- - - - - - - - - - - - - - - - - - - - - - - - - - -
ENTER NEW HALF-LENGTH, OR ENTER 0
? 0
- - - - - - - - - - - - - - - - - - - - - - - - - - -
ANTENNA FACTOR ASSUMING A 100.00-OHM RECEIVER
AND A 1:1 BALUN ARE EMPLOYED =   17.22 DB
MUTUAL IMPEDANCE DUE TO THE ANTENNA'S IMAGE
     IN THE GROUND =       -.9154+J[      -.0995]OHMS
VSWR =       1.9617
MISMATCH LOSS =        .4839 DB
- - - - - - - - - - - - - - - - - - - - - - - - - - -
PRESS RETURN FOR GAIN VS PHI, OTHERWISE TYPE CNTL T
   PAUSE
?
ELEV ANGLE INCREMENT FOR BELOW 10 DEG AND THE
      ADDITIONAL INCREMENT FOR ABOVE 10 DEG
? 2.
? 3.
```

E-PLANE ELEVATION ANGLE IN DEGREES AND GAIN IN DB VERTICAL POLARIZATION		H-PLANE ELEVATION ANGLE IN DEGREES AND GAIN IN DB HORIZONTAL POLARIZATION	
2.000	-24.536	2.000	2.900
4.000	-24.565	4.000	7.238
6.000	-26.223	6.000	7.792
8.000	-16.208	8.000	5.304
10.000	-11.768	10.000	-2.896
15.000	-11.692	15.000	6.282
20.000	-8.484	20.000	2.928
25.000	-6.065	25.000	2.686
30.000	-4.715	30.000	5.779
35.000	-4.689	35.000	-4.242
40.000	-1.319	40.000	5.091
45.000	-.892	45.000	4.171
50.000	-3.059	50.000	-2.596
55.000	.917	55.000	3.604
60.000	2.901	60.000	5.208
65.000	1.752	65.000	3.163
70.000	-.951	70.000	-.533
75.000	-1.256	75.000	-1.131
80.000	.672	80.000	.809
85.000	2.004	85.000	2.048
90.000	2.422	90.000	2.422

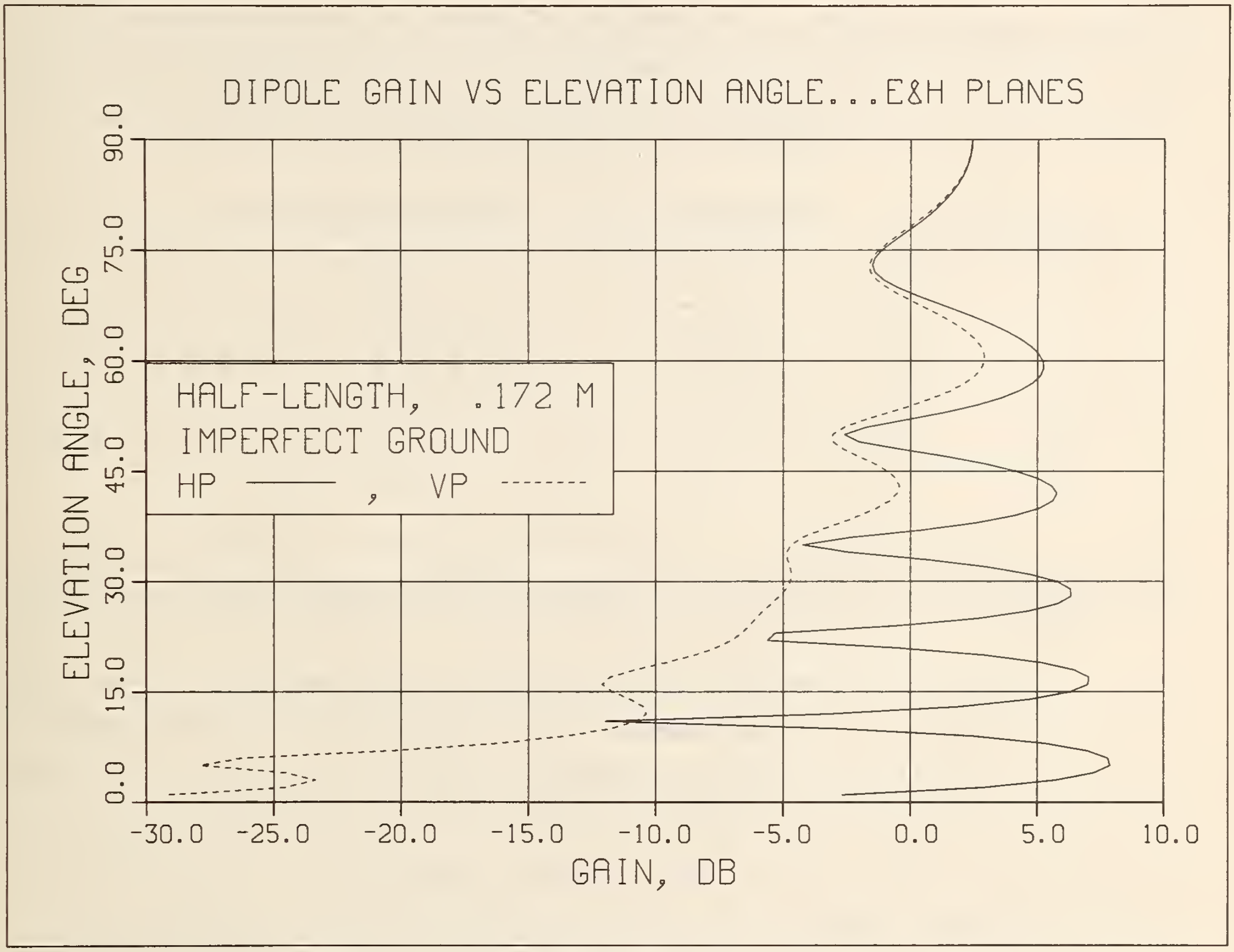

Figure 8. Calculated gain versus elevation for a horizontal dipole with its feedpoint 2.6 λ above ground. λ=0.76 m; σ=20 mS/m; ε_r=4

#5 Antenna Factor Calculation For Comparison With Measured Data - Monopole

A simple 1-m monopole antenna was fabricated using brass tubing with a 0.002-m radius. The antenna factor of this monopole was measured on the NBS ground screen during the calibration of a commercial active monopole in the 0.014-MHz to 72.5-MHz frequency range. The following table gives the results at six selected frequencies in this range.

Frequency, MHz	Measured AF, dB	Calculated AF, dB
0.1	75.7	75.58
1.0	55.5	55.58
10.0	35.6	35.42
20.0	28.8	28.88
30.0	25.6	24.44
50.0	15.8	16.32

#6 Antenna Factor Calculation For Comparison With Measured Data - Dipole

A commercial dipole was calibrated in the NBS anechoic chamber in the 400-MHz to 1000-MHz frequency range. This dipole consists of extensible radiating elements permanently attached to a balun. The element lengths are set using a scale provided by the manufacturer, and the larger radius sections are used to form the elements as specified. Calculations assume the antenna input impedance is 50 ohms, and the balun transformer ratio is 1:1. The following table gives the results at nine selected frequencies.

Frequency, MHz	Measured AF, dB	Calculated AF, dB
400.0	20.6	20.41
500.0	22.6	22.48
550.0	21.9	23.26
600.0	22.4	24.10
650.0	23.8	24.74
700.0	25.9	25.48
800.0	26.2	26.64
900.0	27.0	27.76
1000.0	28.7	28.70

These comparisons of measured and calculated data show the difference between the actual antenna factor and the "ideal" or calculated antenna factor.

Uncertainties in the antenna factor calibration technique may be determined by measuring the antenna factor of gain-standard dipoles and monopoles and comparing measured and calculated data.

#7 Site Attenuation Using Gain-Standard λ/2 Dipoles

Site attenuation is the minimum insertion loss between two copolarized antennas located above a test site. It is measured with one antenna at a fixed height, while the other antenna is located at a specified horizontal distance away and scanned vertically over a specified range of heights.

Gain-standard λ/2 dipoles, fabricated as described in Section 3, were used to measure site attenuation of the NBS ground-screen test site at ten frequencies from 30 MHz to 1000 MHz [14]. These dipoles are required for obtaining measured site-attenuation data that are used for comparison with calculated data. Calculated data are shown as the solid lines and + + + symbols, and measured data are shown as circles, in Fig. 9.

Although site attenuation calculations do not involve gain directly (some measurements are actually made in the near-field where gain is not defined), the input and mutual impedance formulations are the same as those used in the gain calculations. Program HVD6 is used to calculate the length of the gain-standard dipoles, given the radii of the radiating elements. This length is somewhat arbitrarily chosen to make the calculated, free-space value of ZR (ZI) purely real when the element length is near λ/4.

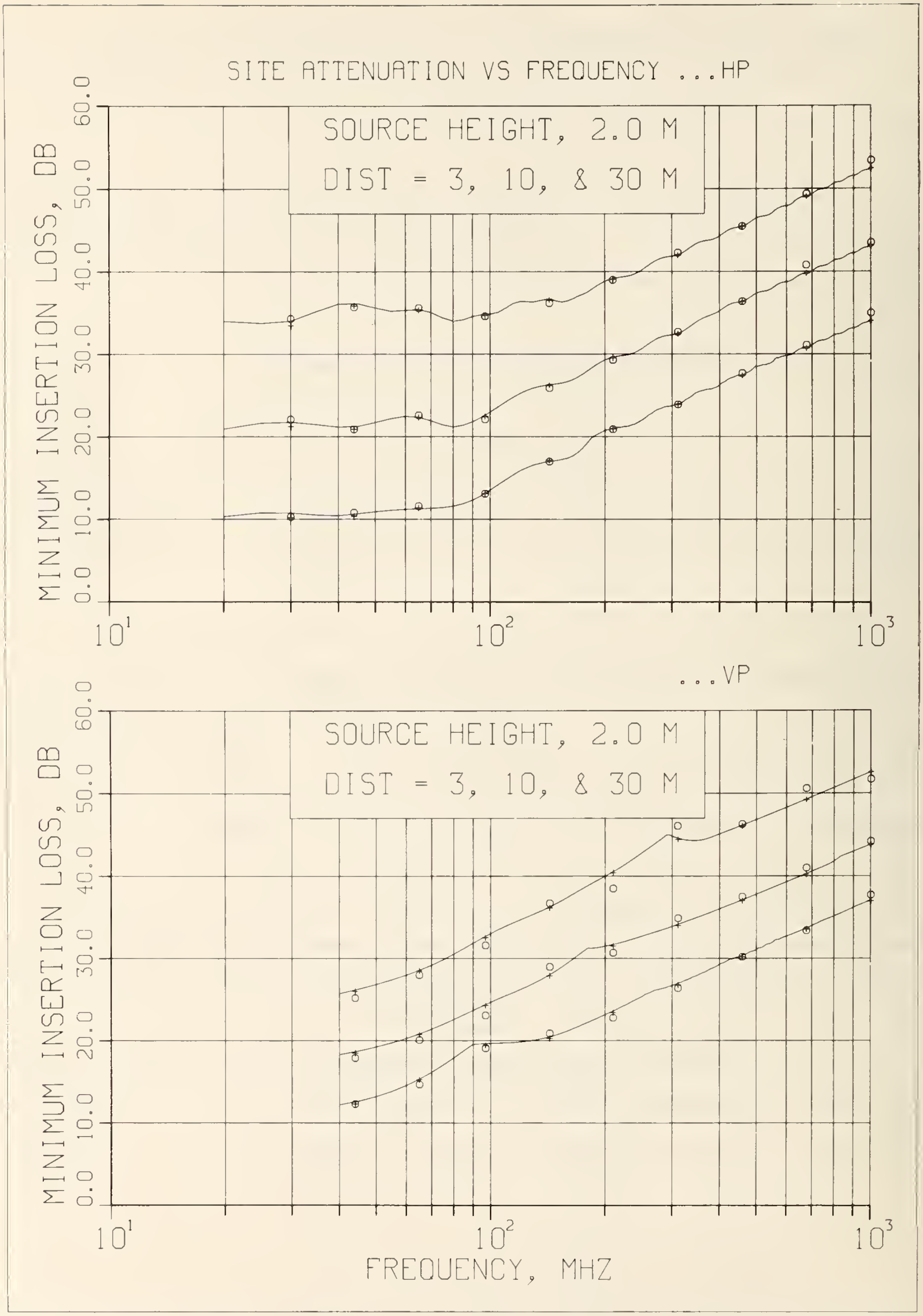

Figure 9. Minimum insertion loss vs. frequency for $\lambda/2$ dipoles horizontally polarized, HP, and vertically polarized, VP. Scan heights are 1 to 4 m for the 3 and 10 m distances and 2 to 6 m for the 30 m distance.

Solid line -- calculated for infinitely thin $\lambda/2$ dipoles
+ + + + + -- calculated using the actual dipole dimensions
o o o o o -- measured using gain standard dipoles

5. Conclusions

The examples given in Section 4 illustrate the usefulness of Program HVD6. It is written in the FORTRAN programming language because of the ease with which this language handles complex arithmetic. It is used on the large, main-frame computer installed at the NBS Boulder Laboratories, but it should run properly on any computer with a FORTRAN compiler.

The well documented equations used in this program are based upon conventional engineering approximations. It is the author's opinion that gain-standard antenna parameters, that is, parameters for thin linear dipoles with removable baluns, positioned over ground or in free space, and monopoles on highly conducting ground, can be calculated with less uncertainty than they can be measured. That is, the calculated parameters may more accurately represent the actual antenna performance than the measured parameters because of the difficulty of making accurate measurements in the frequency range below 1000 MHz.

6. References

[1] IEEE Standard Test Procedures for Antennas. IEEE Std 149-1979 (Revision of IEEE Std 149-1965). New York, NY: IEEE, Inc.; 1979.

[2] FitzGerrell, R.G. Limitations on vertically polarized ground-based antennas as gain standards. IEEE T-AP-23: 284-286; March 1975.

[3] FitzGerrell, R.G. Standard linear antennas, 30 MHz to 1000 MHz. Fifth International Conference on 'Electromagnetic Compatibility.' 1986 Sept. 29 - Oct. 2; University of York, York, England.

[4] King, H.E. Mutual impedance of unequal length antennas in echelon. IEEE T-AP-5: 306-313; 1957 July.

[5] Schelkunoff, S.A.; and Friis, H.T. Antennas, Theory and Practice. New York, NY: John Wiley & Sons; 1952.

[6] Abramowitz, M.; and Stegun, I.A. Handbook of Mathematical Functions With Formulas, Graphs, and Mathematical Tables. Nat. Bur. Stand. (U.S.) Appl. Math. Ser. 55; Washington, D.C.; 1964. 231-233.

[7] Beatty, R.W. Insertion loss concepts. Proc. IEEE. Vol 52: 663-671; 1964 June.

[8] Jordan, E.C. Electromagnetic Waves and Radiating Systems. Englewood Cliffs, NJ: Prentice-Hall; 1950.

[9] Ma, M.T. Theory and Application of Antenna Arrays. New York, NY: John Wiley & Sons; 1974.

[10] Ma, M.T.; and Walters, L.C. Power gains for antennas over lossy ground. ESSA Tech. Rept. ERL 104 - ITS 74. U.S. Govt. Printing Office, Washington, D.C.; 1969.

[11] Berry, L.A.; and Chrisman, L.E. Linear high frequency antennas over a finitely conducting spherical earth. ESSA Tech. Rept. ITSA No. 8. U.S. Govt. Printing Office, Washington, D.C.; 1966.

[12] FitzGerrell, R.G.; and Haidle, L.L. Design and performance of four buried UHF antennas. IEEE T-AP-20: 56-62; 1972 January.

[13] FitzGerrell, R.G. Gain measurements of vertically polarized antennas over imperfect ground. IEEE T-AP-15: 211-216; 1967 March.

[14] FitzGerrell, R.G. Site attenuation. IEEE T-EMC-28: 38-40; 1986 February.

Appendix -- Listing of Program HVD6

```
PROGRAM HVD6(INPUT,OUTPUT,TAPE50)
C******************************************************************
C*  GAIN VERSUS ELEVATION ANGLE AND IMPEDANCE RELATED PARAMETERS  *
C*  FOR VERTICAL AND HORIZONTAL DIPOLES OVER GROUND AND MONOPOLES *
C*  ON PERFECT GROUND.............R.G. FITZGERRELL (303) 497-3737 *
C*  TAPE50 IS USED IN A PLOTTING PROCEDURE FILE.  DELETE THE FOUR *
C*  CALLS TO FILE AND SUBROUTINE FILE IF DESIRED.                 *
C******************************************************************
DIMENSION ARG(2),CI(2),CIN(2),SI(2)
COMPLEX E,J,JWCT,R,RH,RV,RH90,RV90,TSQ,ZA,ZIND,ZINN,ZML,ZR,ZI,ZMB
REAL KA,LAMBDA,L,L2,LOSS,NBL,MBL,MONO
C***********************************************************
C*  USER SPECIFIES ANTENNA GEOMETRY.  ANTENNA ELEMENTS MAY *
C*  HAVE A LINEAR TAPER OR A ZERO (1.E-30) RADIUS.         *
C***********************************************************
10 FORMAT(*TYPE THE REQUESTED DATA AFTER EACH ?*)
PRINT 10
20 FORMAT(*FREQUENCY, MHZ*)
PRINT 20
30 FORMAT(F12.4)
READ 30,FREQ
40 FORMAT(*ANTENNA HALF-LENGTH < LAMBDA/2, M*)
PRINT 40
READ 30,L
50 FORMAT(*ANTENNA RADII, FEEDPOINT THEN END, M*)
PRINT 50
READ 30,RB
READ 30,RT
IF(RT.EQ.0.)RT=1.E-30
IF(RB.EQ.0.)RB=1.E-30
60 FORMAT(*TYPE 1. FOR DIPOLE, 0 FOR MONOPOLE*)
PRINT 60
READ 30, MONO
IF(MONO.EQ.0)POLAR=0.
IF(MONO.EQ.0) GO TO 140
70 FORMAT(*TYPE 1. FOR GROUND, 0 FOR FREE SPACE*)
PRINT 70
READ 30,GF
IF(GF.EQ.0.)POLAR=1.
IF(GF.EQ.0) GO TO 140
80 FORMAT(*DIPOLE FEED-POINT HEIGHT ABOVE GROUND, M*)
PRINT 80
READ 30, H
IF(H.LE.L)POLAR=1.
IF(H.LE.L) GO TO 95
90 FORMAT(*TYPE 1. FOR HORIZONTAL POLARIZATION, 0 FOR VERTICAL*)
PRINT 90
READ 30, POLAR
95 CONTINUE
100 FORMAT(*TYPE 1. FOR PERFECT GROUND, 0 FOR IMPERFECT GROUND*)
PRINT 100
```

```
      READ 30, GND
      IF(GND.EQ.1.) GO TO 130
  110 FORMAT(*GROUND CONDUCTIVITY, MILLISIEMENS/M*)
      PRINT 110
      READ 30,SIGMA
  120 FORMAT(*GROUND RELATIVE DIELECTRIC CONSTANT*)
      PRINT 120
      READ 30,EPSN
      GO TO 150
C***********************************************************
C*  PERFECT GROUND AND FREE-SPACE APPROXIMATIONS ARE MADE. *
C***********************************************************
  130 SIGMA=1.E30
      GO TO 145
  140 SIGMA=0.0
  145 EPSN=1.0
  150 CONTINUE
  160 FORMAT(*IMPEDANCE OF T-LINE ATTACHED TO ANTENNA, OHMS*)
      PRINT 160
      READ 30,ZCHAR
      J=CMPLX(0.,1.)
      LAMBDA=299.792458/FREQ
      BETA=6.2831853/LAMBDA
      X=17.975*SIGMA/FREQ
  170 FORMAT(*- - - - - - - - - - - - - - - - - - - - - - - - - -*)
      PRINT 170
C*********************************
C*  THE CALCULATIONS BEGIN HERE  *
C*********************************
  200 B=2.*BETA*L
      BL=BETA*L
      DO 210 M=1,2
      ARG(M)=M*B
  210 CALL SCI(ARG(M),SI(M),CI(M),CIN(M))
C*****************************************************************
C*  COMPUTE SELF-IMPEDANCE, ZI, USING SCHELKUNOFF'S EQN. 13-108  *
C*****************************************************************
      IF(RT.EQ.RB)KA=120.*(ALOG(2.*L/RT)-1.)
      IF(RT.NE.RB)KA=120.*(ALOG(2*L/RB)+(RT/(RB-RT))*ALOG(RT/RB))
      MBL=60.*(CIN(1)-1.+COS(B))
      NBL=60.*(SI(1)-SIN(B))
      RABL=60.*CIN(1)+30.*(2.*CIN(1)-CIN(2))*COS(B)+30.*(SI(2)
     +      -2.*SI(1))*SIN(B)
      XABL=60.*SI(1)-30.*(CIN(2)-ALOG(4.))*SIN(B)-30.*SI(2)*COS(B)
      ZA=RABL+J*XABL
      JWCT=J*RT/(30.*LAMBDA)
      ZINN=KA*((KA-MBL)*COS(BL)+J*(ZA+JWCT*KA*KA-J*NBL)*SIN(BL))
      ZIND=(ZA+JWCT*KA*KA+J*NBL)*COS(BL)+J*(KA+MBL)*SIN(BL)
      ZI=ZINN/ZIND
C********************************************************************
C*  COMPUTE ANTENNA INPUT IMPEDANCE, ZR.  SUBROUTINE MUTUAL RETURNS *
C*  MUTUAL IMPEDANCE REFERRED TO THE LOOP CURRENT, ZM, BETWEEN TWO  *
C*  FREE-SPACE DIPOLES. SIN(BL)**2 CHANGES REFERENCE TO BASE CURRENT*
C********************************************************************
```

```
IF(SIGMA.EQ.0.AND.MONO.EQ.1.)ZR=ZI
IF(MONO.EQ.0.)ZR=ZI/2.
IF(MONO.EQ.0.OR.SIGMA.EQ.0.) GO TO 240
CALL MUTUAL(BETA,H,J,L,ZML,POLAR)
ZMB=ZML/(SIN(BL)**2)
IF(H.GE.0.1*L) GO TO 230
H1=0.0001*LAMBDA
POLAR1=1.0
CALL MUTUAL(BETA,H1,J,L,ZML,POLAR1)
ZI=ZML/(SIN(BL)**2)
C***************************************************************
C*  THE ABOVE 5 LINES HELP PREVENT NEGATIVE VALUES OF ZR FOR   *
C*  DIPOLES NEAR THE GROUND BECAUSE SCHELKUNOFF'S ZI DOES NOT *
C*  CONVERGE TO THAT OBTAINED USING SUBROUTINE MUTUAL.         *
C***************************************************************
C*  COMPUTE REFLECTION COEFFICIENTS FOR PSI=90 DEG  *
C***************************************************
230 RV90=((EPSN-J*X)-CSQRT(EPSN-J*X))/((EPSN-J*X)+CSQRT(EPSN-J*X))
RH90=(1.-CSQRT(EPSN-J*X))/(1.+CSQRT(EPSN-J*X))
IF(POLAR.EQ.1.AND.MONO.EQ.1.)ZR=ZI+RH90*ZMB
IF(POLAR.EQ.0.AND.MONO.EQ.1.)ZR=ZI+RV90*ZMB
240 CONTINUE
250 FORMAT(*INPUT IMPEDANCE =*F12.4*+J[*F12.4*]OHMS*)
PRINT 250,ZR
PRINT 170
260 FORMAT(*ENTER NEW HALF-LENGTH, OR ENTER 0*)
PRINT 260
READ 30,L2
IF(L2.GT.0) L=L2
IF(L2.GT.0) GO TO 200
C*****************************************************************
C*  COMPUTE ANTENNA FACTOR; MUTUAL IMPEDANCE; VSWR; MISMATCH LOSS*
C*  ANTENNA FACTOR=VOLTAGE DIVIDER FACTOR/EFFECTIVE LENGTH       *
C*****************************************************************
IF(MONO.EQ.0.)AF=(CABS(ZCHAR+ZR)/ZCHAR)/ABS((1./BETA)*TAN(BL/2.))
IF(MONO.EQ.1.)AF=(CABS(ZCHAR+ZR)/ZCHAR)/ABS((2./BETA)*TAN(BL/2.))
PRINT 170
300 FORMAT(*ANTENNA FACTOR ASSUMING A *F6.2*-OHM RECEIVER*)
310 FORMAT(*AND A 1:1 BALUN ARE EMPLOYED =*F8.2* DB*)
320 FORMAT(*AND TRANSMISSION LINE ARE EMPLOYED =*F8.2* DB*)
PRINT 300,ZCHAR
IF(MONO.EQ.1.) PRINT 310, 20.*ALOG10(AF)
IF(MONO.EQ.0.) PRINT 320, 20.*ALOG10(AF)
330 FORMAT(*MUTUAL IMPEDANCE DUE TO THE DIPOLE'S IMAGE*/
+*IN THE GROUND =*F12.4*+J[*F12.4*]OHMS*)
IF(SIGMA.GT.0.) PRINT 330, ZR-ZI
R=(ZR-ZCHAR)/(ZR+ZCHAR)
VSWR=(1.+CABS(R))/(1.-CABS(R))
340 FORMAT(*VSWR =*F12.4)
PRINT 340,VSWR
LOSS=10.0*ALOG10(1.0/(1.0-CABS(R*R)))
350 FORMAT(*MISMATCH LOSS =*F12.4* DB*)
PRINT 350,LOSS
PRINT 170
```

```
C*****************************************************
C*  COMPUTE GAIN VERSUS ELEVATION OR EXIT PROGRAM.  *
C*****************************************************
 400 FORMAT(*PRESS RETURN FOR GAIN VS PHI, OTHERWISE TYPE CNTL T*)
 PRINT 400
 PAUSE
 410 FORMAT(*ELEV ANGLE INCREMENT FOR BELOW 10 DEG AND*/
+*THE ADDITIONAL INCREMENT FOR ABOVE 10 DEG*)
 PRINT 410
 READ 30, ENC
 READ 30, ENC2
 CALL FILE(ENC,ENC2,L,POLAR,SIGMA,0.,0.)
 IF(SIGMA.EQ.0.) H=1.
 BH=BETA*H
 IF(POLAR.EQ.0) GO TO 530
 PRINT 170
 420 FORMAT(*H-PLANE ELEVATION ANGLE IN DEGREES AND GAIN IN DB*)
 PRINT 420
 430 FORMAT(*HORIZONTAL POLARIZATION*)
 PRINT 430
 PSI=0
C*****************************
C*  HORIZONTAL POLARIZATION  *
C*****************************
 500  PSI=PSI+ENC
 IF (PSI.LT.10.1) GO TO 510
 PSI=PSI+ENC2
 IF(PSI.GT.90.) GO TO 530
 510 PSIRAD=0.01745329252*PSI
 SNPSI=SIN(PSIRAD)
 CNPSI=COS(PSIRAD)
 TSQ=CSQRT(EPSN-J*X-(CNPSI**2))
 RH=(SNPSI-TSQ)/(SNPSI+TSQ)
C*****************************************************************
C*  RH & RV ARE HORIZONTAL AND VERTICAL REFLECTION COEFFICIENTS *
C*****************************************************************
 EFLH=ABS(TAN(BL/2.))
 E=EFLH*(CEXP(J*BH*SNPSI)+RH*(CEXP(-J*BH*SNPSI)))
 E2=120.*CABS(E*E)/REAL(ZR)
C******************************************************************
C*  THE GAIN EQUATION IS BASICALLY JORDAN'S EQN. 12-18 USING      *
C*  (EFFECTIVE LENGTH)*PI/LAMBDA DENOTED AS E AND APPROPRIATELY   *
C*  DEFINED FOR THE ORIENTATION OF THE DIPOLE.                    *
C******************************************************************
 GAIN=10.0*ALOG10(E2)
 520 FORMAT(2F15.3)
 PRINT 520,PSI,GAIN
 CALL FILE(-1.,-1.,-1.,-1.,-1.,PSI,GAIN)
 GO TO 500
 530 PRINT 170
 IF(POLAR.GT.0) PAUSE
 540 FORMAT(*E-PLANE ELEVATION ANGLE IN DEGREES AND GAIN IN DB*)
 545 FORMAT(*VERTICAL POLARIZATION*)
 PRINT 540
```

```
 PRINT 545
 PSI=0
C*************************
C*  VERTICAL POLARIZATION  *
C*************************
 550 PSI=PSI+ENC
 IF (PSI.LT.10.1) GO TO 560
 PSI=PSI+ENC2
 IF (PSI.GT.90.) GO TO 580
 560 PSIRAD=0.01745329252*PSI
 SNPSI=SIN(PSIRAD)
 CNPSI=COS(PSIRAD)
 TSQ=CSQRT(EPSN-J*X-(CNPSI**2))
 RV=(((EPSN-J*X)*SNPSI)-TSQ)/(((EPSN-J*X)*SNPSI)+TSQ)
 IF(POLAR.EQ.1.) GO TO 570
 EFLV=ABS(COS(BL*SNPSI)-COS(BL))/(CNPSI*SIN(BL))
 E=EFLV*(CEXP(J*BH*SNPSI)+RV*(CEXP(-J*BH*SNPSI)))
 E2=120.*CABS(E*E)/REAL(ZR)
 IF(E2.EQ.0.) E2=1.E-12
 GAIN=10.0*ALOG10(E2)
 PRINT 520,PSI,GAIN
 CALL FILE(-1.,-1.,-1.,-1.,-1.,PSI,GAIN)
 GO TO 550
C***************************************************
C*  VERTICAL POLARIZATION FOR A HORIZONTAL DIPOLE  *
C***************************************************
 570 EFLVH=ABS(COS(BL*CNPSI)-COS(BL))/(SNPSI*SIN(BL))
 E=EFLVH*(CEXP(J*BH*SNPSI)-RV*(CEXP(-J*BH*SNPSI)))
 E2=120.0*CABS(E*E)/REAL(ZR)
 GAIN=10.0*ALOG10(E2)
 PRINT 520,PSI,GAIN
 CALL FILE(-1.,-1.,-1.,-1.,-1.,PSI,GAIN)
 GO TO 550
 580 PRINT 170
 END
C************************************************************
      SUBROUTINE MUTUAL(BETA,H,J,L,ZML,POLAR)
C*    COMPUTES MUTUAL IMPEDANCES BETWEEN DIPOLES IN ECHELON *
C************************************************************
 DIMENSION ARG(5),SI(5),CI(5),CIN(5)
 REAL L,L1,L2,L3,L4
 COMPLEX J,ZML
C*****************************************************
C*  COMPUTE ARGUMENTS FOR SINE AND COSINE INTEGRALS  *
C*****************************************************
 Y0=0.
 X0=2.*H
 IF(POLAR.EQ.0.) GO TO 1
 Y0=2.*H
 X0=0.
```

```
C***************************************************************
C*  X0 IS THE SEPARATION BETWEEN THE FEEDPOINTS OF THE VERTICAL  *
C*  DIPOLE AND ITS COLINEAR IMAGE.  Y0 IS THE SEPARATION BETWEEN *
C*  THE HORIZONTAL DIPOLE AND ITS IMAGE.                         *
C***************************************************************
 1 B=BETA
 Y02=Y0**2
 HL1=X0-2.*L
 HL2=X0-L
 HL3=X0
 HL4=X0+L
 HL5=X0+2.*L
 ARG(1)=B*(SQRT(Y02+HL1**2)+HL1)
 ARG(2)=B*(SQRT(Y02+HL2**2)+HL2)
 ARG(3)=B*(SQRT(Y02+HL3**2)+HL3)
 ARG(4)=B*(SQRT(Y02+HL4**2)+HL4)
 ARG(5)=B*(SQRT(Y02+HL5**2)+HL5)
 DO 10 I=1,5
 10 CALL SCI(ARG(I),SI(I),CI(I),CIN(I))
 IF(POLAR.EQ.0.) GO TO 20
C*******************************************************
C*  COMPUTE MUTUAL IMPEDANCE FOR HORIZONTAL POLARIZATION  *
C*******************************************************
 R12=30.*(COS(2.*B*L)*(CI(1)+CI(5)-2.*CI(2)-2.*CI(4)+2.*CI(3))
+         +SIN(2.*B*L)*(-SI(1)+SI(5)+2.*SI(2)-2.*SI(4))
+         +4.*CI(3)-2.*CI(2)-2.*CI(4))
 X12=30.*(COS(2.*B*L)*(-SI(1)-SI(5)+2.*SI(2)+2.*SI(4)-2.*SI(3))
+         +SIN(2.*B*L)*(-CI(1)+CI(5)+2.*CI(2)-2.*CI(4))
+         -4.*SI(3)+2.*SI(2)+2.*SI(4))
 ZML=R12+J*X12
 RETURN
C*****************************************************
C*  COMPUTE MUTUAL IMPEDANCE FOR VERTICAL POLARIZATION  *
C*****************************************************
 20 L1=ALOG(HL2/HL1)
 L2=ALOG(HL4/HL3)
 L3=ALOG(HL2/HL3)
 L4=ALOG(HL4/HL5)
 B1=B*HL1
 B2=B*HL3
 B3=B*HL5
 B4=B*HL2
 B5=B*HL4
 R12=15.*(COS(B1)*(CI(1)-CI(2)+L1)+SIN(B1)*(SI(1)-SI(2))+COS(B2)
+    *(CI(3)-CI(4)+L2)+SIN(B2)*(SI(3)-SI(4))+COS(B2)*(-CI(2)+CI(3)
+    +L3)+SIN(B2)*(-SI(2)+SI(3))+COS(B3)*(-CI(4)+CI(5)+L4)+SIN(B3)
+    *(-SI(4)+SI(5))+2.*COS(B*L)*COS(B4)*(-CI(2)+CI(3)+L3)+2.
+    *COS(B*L)*SIN(B4)*(-SI(2)+SI(3))+2.*COS(B*L)*COS(B5)*(CI(3)
+    -CI(4)+L2)+2.*COS(B*L)*SIN(B5)*(SI(3)-SI(4)))
```

```
03220 X12=15.*(COS(B1)*(-SI(1)+SI(2))+SIN(B1)*(CI(1)-CI(2)-L1)+COS(B2)
03230+    *(-SI(3)+SI(4))+SIN(B2)*(CI(3)-CI(4)-L2)+COS(B2)*(SI(2)
03240+    -SI(3))+SIN(B2)*(-CI(2)+CI(3)-L3)+COS(B3)*(SI(4)-SI(5))
03250+    +SIN(B3)*(-CI(4)+CI(5)-L4)+2.*COS(B*L)*COS(B4)*(SI(2)
03260+    -SI(3))+2.*COS(B*L)*SIN(B4)*(-CI(2)+CI(3)-L3)+2.*COS(B*L)
03270+    *(-SI(3)+SI(4))+2.*COS(B*L)*SIN(B5)*(CI(3)-CI(4)-L2))
03280 ZML=R12+J*X12
03290 RETURN
03300 END
03310C***************************************************************
03320       SUBROUTINE SCI(ARG,SI,CI,CIN)
03330C*     COMPUTES THE SINE, COSINE, AND MODIFIED COSINE INTEGRALS *
03340C***************************************************************
03350 DIMENSION T(42),S(20),C(20)
03360 K=1
03370 T(1)=1.0
03380 DO 10 M=1,42
03390 K=K+1
03400 10 T(K)=M*T(K-1)
03410 IF(ARG.GT.1.) GO TO 25
03420C****************************************
03430C*  COMPUTE THE INTEGRALS FOR 0<ARG<1   *
03440C****************************************
03450 DO 20 N=1,20
03460 20 S(N)=((-1)**N)*(ARG**(2*N+1))/((2*N+1)*T(2*N+2))
03470 SI=ARG+S(1)+S(2)+S(3)+S(4)+S(5)+S(6)+S(7)+S(8)+S(9)+S(10)
03480+      +S(11)+S(12)+S(13)+S(14)+S(15)+S(16)+S(17)+S(18)+S(19)+S(20)
03490 DO 30 N=1,20
03500 30 C(N)=((-1)**N)*(ARG**(2*N))/((2*N)*T(2*N+1))
03510 SA=C(1)+C(2)+C(3)+C(4)+C(5)+C(6)+C(7)+C(8)+C(9)+C(10)+C(11)
03520+   +C(12)+C(13)+C(14)+C(15)+C(16)+C(17)+C(18)+C(19)+C(20)
03530 CI=0.577215665+ALOG(ARG)+SA
03540 CIN=-SA
03550 GO TO 40
03560C*********************************************
03570C*  COMPUTE THE INTEGRALS FOR 1<ARG<INFINITY  *
03580C*********************************************
03590 25 FZ=(ARG**8+38.027264*(ARG**6)+265.187033*(ARG**4)
03600+      +335.67732*(ARG**2)+38.102495)/(ARG*((ARG**8)
03610+      +40.021433*(ARG**6)+322.624911*(ARG**4)
03620+      +570.23628*(ARG**2)+157.105423))
03630 GZ=(ARG**8+42.242855*(ARG**6)+302.757865*(ARG**4)
03640+   +352.018498*(ARG**2)+21.821899)/((ARG**2)*((ARG**8)
03650+   +48.196927*(ARG**6)+482.485984*(ARG**4)+1114.978885
03660+   *(ARG**2)+449.690326))
03670 SI=1.570796327-FZ*COS(ARG)-GZ*SIN(ARG)
03680 CI=FZ*SIN(ARG)-GZ*COS(ARG)
03690 CIN=-CI+0.5772157+ALOG(ARG)
03700 40 RETURN
03710 END
```

```
03720C***************************************************************
03730       SUBROUTINE FILE(ENC,ENC2,L,POLAR,SIGMA,PSI,GAIN)
03740C*     WRITES DATA ON TAPE50 FOR PLOTTING USING PROCEDURE FILE 4T *
03750C***************************************************************
03760 N=AINT(10./ENC+80./(ENC+ENC2))
03770 10 FORMAT(I5)
03780 20 FORMAT(2F10.3)
03790 30 FORMAT(F10.3)
03800 40 FORMAT(E9.3)
03810 IF(ENC.GT.0) WRITE(50,10)N
03820 IF(ENC.GT.0) WRITE(50,30)L
03830 IF(ENC.GT.0) WRITE(50,30)POLAR
03840 IF(ENC.GT.0) WRITE(50,40)SIGMA
03850 IF(ENC.LT.0) WRITE(50,20)PSI,GAIN
03860 RETURN
03870 END
```

Note: If file TAPE50 is not wanted, delete line 00100, calls to FILE in lines 01800, 02160, 02440, and 02540, and the entire Subroutine FILE.

U. S. GOVERNMENT PRINTING OFFICE: 1986—671-745/45,198 REGION NO. 8

NBS-114A (REV. 2-80)

U.S. DEPT. OF COMM. BIBLIOGRAPHIC DATA SHEET *(See instructions)*	1. PUBLICATION OR REPORT NO. NBS/TN-1098	2. Performing Organ. Report No.	3. Publication Date May 1986

4. TITLE AND SUBTITLE

Linear Gain-Standard Antennas Below 1000 MHz

5. AUTHOR(S)

R. G. FitzGerrell

6. PERFORMING ORGANIZATION *(If joint or other than NBS, see instructions)*

NATIONAL BUREAU OF STANDARDS
DEPARTMENT OF COMMERCE
WASHINGTON, D.C. 20234

7. Contract/Grant No.

8. Type of Report & Period Covered

9. SPONSORING ORGANIZATION NAME AND COMPLETE ADDRESS *(Street, City, State, ZIP)*

10. SUPPLEMENTARY NOTES

☐ Document describes a computer program; SF-185, FIPS Software Summary, is attached.

11. ABSTRACT *(A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here)*

Gain and antenna parameters related to input impedance are calculated using a computer program called HVD6. This program uses well documented equations to compute these parameters for gain-standard antennas used in relative-gain or gain-transfer measurements at frequencies below 1000 MHz. The utility of this program is that it calculates gain patterns and input impedances for linear dipoles above perfect or imperfectly conducting plane ground and in free space, and for monopoles on perfectly conducting plane ground. Examples are included to illustrate the use of the program. Uncertainties in the calculated parameters are estimated to be less than those of the measured parameters.

12. KEY WORDS *(Six to twelve entries; alphabetical order; capitalize only proper names; and separate key words by semicolons)*

antenna gain; dipole antennas; gain standards; monopole antennas

13. AVAILABILITY

☒ Unlimited
☐ For Official Distribution. Do Not Release to NTIS
☒ Order From Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402.
☐ Order From National Technical Information Service (NTIS), Springfield, VA. 22161

14. NO. OF PRINTED PAGES

44

15. Price

USCOMM-DC 6043-P80

NBS Technical Publications

Periodical

Journal of Research—The Journal of Research of the National Bureau of Standards reports NBS research and development in those disciplines of the physical and engineering sciences in which the Bureau is active. These include physics, chemistry, engineering, mathematics, and computer sciences. Papers cover a broad range of subjects, with major emphasis on measurement methodology and the basic technology underlying standardization. Also included from time to time are survey articles on topics closely related to the Bureau's technical and scientific programs. Issued six times a year.

Nonperiodicals

Monographs—Major contributions to the technical literature on various subjects related to the Bureau's scientific and technical activities.

Handbooks—Recommended codes of engineering and industrial practice (including safety codes) developed in cooperation with interested industries, professional organizations, and regulatory bodies.

Special Publications—Include proceedings of conferences sponsored by NBS, NBS annual reports, and other special publications appropriate to this grouping such as wall charts, pocket cards, and bibliographies.

Applied Mathematics Series—Mathematical tables, manuals, and studies of special interest to physicists, engineers, chemists, biologists, mathematicians, computer programmers, and others engaged in scientific and technical work.

National Standard Reference Data Series—Provides quantitative data on the physical and chemical properties of materials, compiled from the world's literature and critically evaluated. Developed under a worldwide program coordinated by NBS under the authority of the National Standard Data Act (Public Law 90-396). NOTE: The Journal of Physical and Chemical Reference Data (JPCRD) is published quarterly for NBS by the American Chemical Society (ACS) and the American Institute of Physics (AIP). Subscriptions, reprints, and supplements are available from ACS, 1155 Sixteenth St., NW, Washington, DC 20056.

Building Science Series—Disseminates technical information developed at the Bureau on building materials, components, systems, and whole structures. The series presents research results, test methods, and performance criteria related to the structural and environmental functions and the durability and safety characteristics of building elements and systems.

Technical Notes—Studies or reports which are complete in themselves but restrictive in their treatment of a subject. Analogous to monographs but not so comprehensive in scope or definitive in treatment of the subject area. Often serve as a vehicle for final reports of work performed at NBS under the sponsorship of other government agencies.

Voluntary Product Standards—Developed under procedures published by the Department of Commerce in Part 10, Title 15, of the Code of Federal Regulations. The standards establish nationally recognized requirements for products, and provide all concerned interests with a basis for common understanding of the characteristics of the products. NBS administers this program as a supplement to the activities of the private sector standardizing organizations.

Consumer Information Series—Practical information, based on NBS research and experience, covering areas of interest to the consumer. Easily understandable language and illustrations provide useful background knowledge for shopping in today's technological marketplace.

Order the **above** *NBS publications from: Superintendent of Documents, Government Printing Office, Washington, DC 20402.*

Order the **following** *NBS publications—FIPS and NBSIR's—from the National Technical Information Service, Springfield, VA 22161.*

Federal Information Processing Standards Publications (FIPS PUB)—Publications in this series collectively constitute the Federal Information Processing Standards Register. The Register serves as the official source of information in the Federal Government regarding standards issued by NBS pursuant to the Federal Property and Administrative Services Act of 1949 as amended, Public Law 89-306 (79 Stat. 1127), and as implemented by Executive Order 11717 (38 FR 12315, dated May 11, 1973) and Part 6 of Title 15 CFR (Code of Federal Regulations).

NBS Interagency Reports (NBSIR)—A special series of interim or final reports on work performed by NBS for outside sponsors (both government and non-government). In general, initial distribution is handled by the sponsor; public distribution is by the National Technical Information Service, Springfield, VA 22161, in paper copy or microfiche form.

U.S. Department of Commerce
National Bureau of Standards
Gaithersburg, MD 20899

Official Business
Penalty for Private Use $300

U.S.MAIL

POSTAGE AND FEES PAID
U S DEPARTMENT OF COMMERCE
COM-215

FIRST CLASS