Linear Gain - Standard Antennas Below 1000 MHz

R.G. FitzGerrell
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R.G. FitzGerrell

Electromagnetic Fields Division
Center for Electronics and Electrical Engineering
National Engineering Laboratory
National Bureau of Standards
Boulder, Colorado 80303
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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 $4\pi$ 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, \( Z_R \). It is obtained by calculating the intrinsic impedance, \( Z_I \), 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, \( Z_{MB} \), is obtained by calculating \( Z_{ML} \), 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, \( Z_{MB} \), is then multiplied by the reflection
coefficient of the ground evaluated at an elevation angle $\psi = 90$ 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, $\lambda$, are in meters. Upper-case variables, except $M$ and $N$, are the variable names actually used in program HVD6.

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

where

$$\beta = 2\pi/\lambda,$$

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

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 $RT$.

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

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

$$JWCT = jRT/30\lambda,$$

$$ZA = RABL+jXABL,$$

$$\text{Real}(ZA) = RABL = 60Ci(2\beta L)+30(2Ci(2\beta L)-Ci(4\beta L))\cos(2\beta L) + 30(Si(4\beta L)-2Si(2\beta L)\sin(2\beta L)),$$

and

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

In the preceding equations, $Si$ and $Ci$ (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,
\[ Z_R = Z_I, \]
and for monopoles,
\[ Z_R = Z_I/2. \]

For horizontal dipoles over ground,
\[ Z_R = Z_I + R_{90} \times Z_{MB}. \]

For vertical dipoles over ground,
\[ Z_R = Z_I + R_{90} \times Z_{MB}. \]

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, \( Z_{CHAR} \). Antenna factor is
\[ AF = 20 \log_{10} \left| \frac{(Z_{CHAR} + Z_R)}{Z_{CHAR}} \right| / \text{(effective length of antenna)} \] (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
\[ R = \frac{Z_R - Z_{CHAR}}{Z_R + Z_{CHAR}}, \] (7)
and the voltage standing-wave ratio is
\[ VSWR = \frac{1 + |R|}{1 - |R|}. \] (8)

The conjugate mismatch loss [7], expressed in decibels, is
\[ LOSS = 10 \log_{10} \left( \frac{1}{1 - |R|^2} \right). \] (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

\[
GAIN = 10 \log_{10}(\frac{120|E|^2}{\text{Real}(Z_R)})
\]  

(10)

where \(E\) is the effective length of a dipole over ground, multiplied by \(\pi/\lambda\).

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**

\[
E = |\tan(\beta L/2)| (e^{j\beta H \sin \psi} + R_H e^{-j\beta H \sin \psi})
\]  

(11)

**Vertical dipole over ground or monopole on perfect ground, \(E\)-plane**

\[
E = |(\cos(\beta L \sin \psi) - \cos(\beta L))/(\cos(\beta L \sin \psi))| (e^{j\beta H \sin \psi} + R_V e^{-j\beta H \sin \psi})
\]  

(12)

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

**Horizontal dipole over ground, \(E\)-plane**

\[
E = |(\cos(\beta L \cos \psi) - \cos(\beta L))/(\sin(\beta L))| (e^{j\beta H \sin \psi} - R_V e^{-j\beta H \sin \psi})
\]  

(13)

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

\[
R_V = ((\text{EPSN} - jX) \sin \psi - TSQ)/((\text{EPSN} - jX) \sin \psi + TSQ), \quad \text{and}
\]  

(14)

\[
R_H = (\sin \psi - TSQ)/(\sin \psi + TSQ),
\]  

(15)

where

\[X = 17.975 \text{ SIGMA/FREQ},\]

\[\text{FREQ} = \text{frequency, in MHz},\]

\[\text{SIGMA} = \sigma = \text{conductivity in millisiemens/m (abbreviated mS/m, and originally millimhos/m in past usage)},\]

\[\text{EPSN} = \varepsilon_r = \text{relative dielectric constant, and}\]

\[TSQ = (\text{EPSN} - jX - \cos^2 \psi)^{1/2}.\]
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 \( \leq 0.05 \text{ dB} \), with a value \( \leq 0.42 \text{ dB} \) on the outside. This result is for dipoles with \( 0.1\lambda \leq L \leq 0.25\lambda \) 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 \( 10^{-30} \text{ m} \). 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**

.35

**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+JE 42.6593 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 = 1.7050**

**MISMATCH LOSS = .3395 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**

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**E-PLANE ELEVATION ANGLE IN DEGREES AND GAIN IN DB**

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Figure 5 a. Calculated gain versus elevation angle for a thin, λ/2 dipole in free space. λ=1 m
Figure 5b. Calculated gain versus elevation angle for a thin, \( \lambda/4 \) monopole fed against an infinite, perfectly conducting, plane ground. 
\( \lambda=1 \) m
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 \( \sigma = 10 \) mS/m and \( \varepsilon_r = 50 \) 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+JC 31.1427JOHMS
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 = 25.8498+JC 15.9547JOHMS
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

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16
Figure 6. Calculated gain versus elevation angle for a vertical dipole over imperfect ground with lower tip of dipole at ground level. 
\[ \lambda = 618 \, \text{m}; \, \sigma = 10 \, \text{mS/m}; \, \varepsilon_r = 50 \]
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, λ/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:

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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
? 1.
GROUND CONDUCTIVITY, MILLISIEMENS/M
? 20.
GROUND RELATIVE DIELECTRIC CONSTANT
? 5.
IMPEDANCE OF T-LINE ATTACHED TO ANTENNA, OHMS
? 100.
INPUT IMPEDANCE = 59.9441+JC-123.485130HMS
- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
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 = 9.6874+JC 15.232930HMS
USWR = 4.6582
MISMATCH LOSS = 2.3580 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.
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### E-PLANE ELEVATION ANGLE IN DEGREES AND GAIN IN DB

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### H-PLANE ELEVATION ANGLE IN DEGREES AND GAIN IN DB

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</table>
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
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 \( \frac{\lambda}{2} \) dipole positioned 2.6 \( \lambda \) 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**

? 9.172

**TYPE 1. FOR HORIZONTAL POLARIZATION, 0 FOR VERTICAL**

? 1.

**TYPE 1. FOR PERFECT GROUND, 0 FOR IMPERFECT GROUND**

? 0

**GROUND CONDUCTIVITY, MILLISIEMENS/M**

? 29.

**GROUND RELATIVE DIELECTRIC CONSTANT**

? 4.

**IMPEDANCE OF T-LINE ATTACHED TO ANTENNA, OHMS**

? 199.

**INPUT IMPEDANCE = 51.0038+JE 2.0276JOHMS**

**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 = -0.9154+JE -0.9953JOHMS**

**USWR = 1.9617**

**MISMATCH LOSS = 0.4839 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*

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**H-PLANE ELEVATION ANGLE IN DEGREES AND GAIN IN DB**

*VERTICAL POLARIZATION*

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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
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.

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<th>Frequency, MHz</th>
<th>Measured AF, dB</th>
<th>Calculated AF, dB</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.1</td>
<td>75.7</td>
<td>75.58</td>
</tr>
<tr>
<td>1.0</td>
<td>55.5</td>
<td>55.58</td>
</tr>
<tr>
<td>10.0</td>
<td>35.6</td>
<td>35.42</td>
</tr>
<tr>
<td>20.0</td>
<td>28.8</td>
<td>28.88</td>
</tr>
<tr>
<td>30.0</td>
<td>15.8</td>
<td>16.32</td>
</tr>
<tr>
<td>50.0</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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.

<table>
<thead>
<tr>
<th>Frequency, MHz</th>
<th>Measured AF, dB</th>
<th>Calculated AF, dB</th>
</tr>
</thead>
<tbody>
<tr>
<td>400.0</td>
<td>20.6</td>
<td>20.41</td>
</tr>
<tr>
<td>500.0</td>
<td>22.6</td>
<td>22.48</td>
</tr>
<tr>
<td>550.0</td>
<td>21.9</td>
<td>23.26</td>
</tr>
<tr>
<td>600.0</td>
<td>22.4</td>
<td>24.10</td>
</tr>
<tr>
<td>650.0</td>
<td>23.8</td>
<td>24.74</td>
</tr>
<tr>
<td>700.0</td>
<td>25.9</td>
<td>25.48</td>
</tr>
<tr>
<td>800.0</td>
<td>26.2</td>
<td>26.64</td>
</tr>
<tr>
<td>900.0</td>
<td>27.0</td>
<td>27.76</td>
</tr>
<tr>
<td>1000.0</td>
<td>28.7</td>
<td>28.70</td>
</tr>
</tbody>
</table>
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 λ/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 λ/2 dipoles
+ + + + + -- calculated using the actual dipole dimensions
○ ○ ○ ○ ○ -- 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


Appendix -- Listing of Program HVD6

00100 PROGRAM HVD6(INPUT,OUTPUT,TAPE50)
00110C******************************************************************************
00120C* GAIN VERSUS ELEVATION ANGLE AND IMPEDANCE RELATED PARAMETERS *
00130C* FOR VERTICAL AND HORIZONTAL DIPOLES OVER GROUND AND MONOPOLES *
00140C* ON PERFECT GROUND..........R.G. FITZGERRELL (303) 497-3737 *
00150C* TAPE50 IS USED IN A PLOTTING PROCEDURE FILE. DELETE THE FOUR *
00160C* CALLS TO FILE AND SUBROUTINE FILE IF DESIRED. *
00170C******************************************************************************
00180 DIMENSION ARG(2),CI(2),CIN(2),SI(2)
00190 COMPLEX E,J,JWCT,R,RH,RV,RH90,RV90,TSQ,ZA,ZIND,ZINN,ZML,ZR,ZI,ZMB
00200 REAL KA,LAMBDA,L,L2,LOSS,NBL,MBL,MONO
00210C******************************************************************************
00220C* USER SPECIFIES ANTENNA GEOMETRY. ANTENNA ELEMENTS MAY *
00230C* HAVE A LINEAR TAPER OR A ZERO (1.E--30) RADIUS. *
00240C******************************************************************************
00250 10 FORMAT(*TYPE THE REQUESTED DATA AFTER EACH ?*)
00260 PRINT 10
00270 20 FORMAT(*FREQUENCY, MHZ*)
00280 PRINT 20
00290 30 FORMAT(F12.4)
00300 READ 30,FREQ
00310 40 FORMAT(*ANTENNA HALF-LENGTH < LAMBDA/2, M*)
00320 PRINT 40
00330 READ 30,L
00340 50 FORMAT(*ANTENNA RADII, FEEDPOINT THEN END, M*)
00350 PRINT 50
00360 READ 30,RB
00370 READ 30,RT
00380 IF(RT.EQ.0.)RT=1.E-30
00390 IF(RB.EQ.0.)RB=1.E-30
00400 60 FORMAT(*TYPE 1. FOR DIPOLE, 0 FOR MONOPOLE*)
00410 PRINT 60
00420 READ 30, MONO
00430 IF(MONO.EQ.0)POLAR=0.
00440 IF(MONO.EQ.0) GO TO 140
00450 70 FORMAT(*TYPE 1. FOR GROUND, 0 FOR FREE SPACE*)
00460 PRINT 70
00470 READ 30,GF
00480 IF(GF.EQ.0.)POLAR=1.
00490 IF(GF.EQ.0.) GO TO 140
00500 80 FORMAT(*DIPOLE FEED-POINT HEIGHT ABOVE GROUND, M*)
00510 PRINT 80
00520 READ 30, H
00530 IF(H.LE.L)POLAR=1.
00540 IF(H.LE.L) GO TO 95
00550 90 FORMAT(*TYPE 1. FOR HORIZONTAL POLARIZATION, 0 FOR VERTICAL*)
00560 PRINT 90
00570 READ 30, POLAR
00580 95 CONTINUE
00590 100 FORMAT(*TYPE 1. FOR PERFECT GROUND, 0 FOR IMPERFECT GROUND*)
00600 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
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 ANTÉNNA, 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* COMPUTE SELF-IMPEDANCE, ZI, USING SCHELKUNOFF'S EQN. 13-108 *
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))
NB=60.*(SI(1)-SIN(B))
RABL=60.*(CIN(1)+30.*(2.*CIN(1)-CIN(2))*COS(B)+30.*SI(2))
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********************************************************************
01150 IF(SIGMA.EQ.0.AND.MONO.EQ.1.)ZR=ZI
01160 IF(MONO.EQ.0.)ZR=ZI/2.
01170 IF(MONO.EQ.0.OR.SIGMA.EQ.0.) GO TO 240
01180 CALL MUTUAL(BETA,H,J,L,ZML,POLAR)
01190 ZMB=ZML/(SIN(BL)**2)
01200 IF(H.GE.0.1*L) GO TO 230
01210 H=0.0001*LAMBDA
01220 POLAR1=1.0
01230 CALL MUTUAL(BETA,H1,J,L,ZML,POLAR1)
01240 ZMB=ZML/(SIN(BL)**2)
01250 C***************************************************************
01260 C* THE ABOVE 5 LINES HELP PREVENT NEGATIVE VALUES OF ZR FOR *
01270 C* DIPOLES NEAR THE GROUND BECAUSE SCHELKUNOFF'S ZI DOES NOT *
01280 C* CONVERGE TO THAT OBTAINED USING SUBROUTINE MUTUAL. *
01290 C***************************************************************
01300 C* COMPUTE REFLECTION COEFFICIENTS FOR PSI=90 DEG *
01310 C***************************************************************
01320 230 RV90=((EPSN-J*X)-CSQRT(EPSN-J*X))/((EPSN-J*X)+CSQRT(EPSN-J*X))
01330 RH90=(1.-CSQRT(EPSN-J*X))/(1.+CSQRT(EPSN-J*X))
01340 IF(POLAR.EQ.1.AND.MONO.EQ.1.)ZR=ZI+RH90*ZMB
01350 IF(POLAR.EQ.0.AND.MONO.EQ.1.)ZR=ZI+RV90*ZMB
01360 240 CONTINUE
01370 250 FORMAT(*INPUT IMPEDANCE =*F12.4*+J[*F12.4*]OHMS*)
01380 PRINT 250,ZR
01390 PRINT 170
01400 260 FORMAT(*ENTER NEW HALF-LENGTH, OR ENTER 0*)
01410 PRINT 260
01420 READ 30,L2
01430 IF(L2.GT.0) L=L2
01440 IF(L2.GT.0) GO TO 200
01450 C*****************************************************************
01460 C* COMPUTE ANTENNA FACTOR; MUTUAL IMPEDANCE; VSWR; MISMATCH LOSS*
01470 C* ANTENNA FACTOR=VOLTAGE DIVIDER FACTOR/EFFECTIVE LENGTH *
01480 C*****************************************************************
01490 IF(MONO.EQ.0.)AF=(CABS(ZCHAR+ZR)/ZCHAR)/ABS((1./BETA)*TAN(BL/2.))
01500 IF(MONO.EQ.1.)AF=(CABS(ZCHAR+ZR)/ZCHAR)/ABS((2./BETA)*TAN(BL/2.))
01510 PRINT 170
01520 300 FORMAT(*ANTENNA FACTOR ASSUMING A *F6.2*-OHM RECEIVER*)
01530 310 FORMAT(*AND A 1:1 BALUN ARE EMPLOYED =*F8.2* DB*)
01540 320 FORMAT(*AND TRANSMISSION LINE ARE EMPLOYED =*F8.2* DB*)
01550 PRINT 300,ZCHAR
01560 IF(MONO.EQ.1.) PRINT 310, 20.*ALOG10(AF)
01570 IF(MONO.EQ.0.) PRINT 320, 20.*ALOG10(AF)
01580 330 FORMAT(*MUTUAL IMPEDANCE DUE TO THE DIPOLE'S IMAGE*/
01590 *IN THE GROUND =*F12.4*+J[*F12.4*]OHMS*)
01600 IF(SIGMA.GT.0.) ID=SIGMA
01610 R=(ZCHAR-ZR)/(ZCHAR)
01620 VSRR=(1.+CABS(R))/(|1.-CABS(R)|)
01630 340 FORMAT(*VSWR =*F12.4*)
01640 PRINT 340,VSRR
01650 LOSS=10.0*ALOG10(|1./(1.-CABS(R)*R))|
01660 350 FORMAT(*MISMATCH LOSS =*F12.4* DB*)
01670 PRINT 350,LOSS
01680 PRINT 170
* COMPUTE GAIN VERSUS ELEVATION OR EXIT PROGRAM. *
* ******************************************************

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 TO 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
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)
EFLH=ABS(TAN(BL/2.))
E=EFLH*(CEXP(J*BH*SNPSI)+RH*(CEXP(-J*BH*SNPSI)))
E2=120.*CABS(E*E)/REAL(ZR)
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
02230 PRINT 545
02240 PSI=0
02250C**********************************************************************
02260C* VERTICAL POLARIZATION *
02270C**********************************************************************
02280 550 PSI=PSI+ENC
02290 IF (PSI.LT.10.1) GO TO 560
02300 PSI=PSI+ENC2
02310 IF (PSI.GT.90.) GO TO 580
02320 560 PSIRAD=0.01745329252*PSI
02330 SNPSI=SIN(PSIRAD)
02340 CNPSI=COS(PSIRAD)
02350 TSQ=CSQRT(EPSN-J*X-(CNPSI**2))
02360 RV=((EPSN-J*X)*SNPSI)-TSQ)/(((EPSN-J*X)*SNPSI)+TSQ)
02370 IF(POLAR.EQ.1.) GO TO 570
02380 E=EFLV*(CEXP(J*BH*SNPSI)+RV*(CEXP(-J*BH*SNPSI)))
02390 E2=120.0*CABS(E*E)/REAL(ZR)
02400 IF(E2.EQ.0.) E2=1.E-12
02410 GAIN=10.0*ALOG10(E2)
02430 PRINT 520,PSI,GAIN
02450 GO TO 550
02460C**********************************************************************
02470C* VERTICAL POLARIZATION FOR A HORIZONTAL DIPOLE *
02480C**********************************************************************
02490 570 EFLVH=ABS(COS(BL*SNPSI)-COS(BL))/(SNPSI*SIN(BL))
02500 E=EFLVH*(CEXP(J*BH*SNPSI)-RV*(CEXP(-J*BH*SNPSI)))
02510 E2=120.0*CABS(E*E)/REAL(ZR)
02520 GAIN=10.0*ALOG10(E2)
02530 PRINT 520,PSI,GAIN
02550 GO TO 550
02560 580 PRINT 170
02570 END
02580C**********************************************************************
02590 SUBROUTINE MUTUAL(BETA,H,J,L,ZML,POLAR)
02600C* COMPUTES MUTUAL IMPEDANCES BETWEEN DIPOLES IN ECHELON *
02610C**********************************************************************
02620 DIMENSION ARG(5),SI(5),CI(5),CIN(5)
02630 REAL L,L1,L2,L3,L4
02640 COMPLEX J,ZML
02650C**********************************************************************
02660C* COMPUTE ARGUMENTS FOR SINE AND COSINE INTEGRALS *
02670C**********************************************************************
02680 Y0=0.
02690 X0=2.*H
02700 IF(POLAR.EQ.0.) GO TO 1
02710 Y0=2.*H
02720 X0=0.
02730C******************************************************************************
02740C* XO IS THE SEPARATION BETWEEN THE FEEDPOINTS OF THE VERTICAL *
02750C* DIPOLE AND ITS COLINEAR IMAGE. YO IS THE SEPARATION BETWEEN *
02760C* THE HORIZONTAL DIPOLE AND ITS IMAGE. *
02770C******************************************************************************
02780 1 B=BETA
02790 Y02=Y0**2
02800 HL1=XO-2.*L
02810 HL2=XO-L
02820 HL3=XO
02830 HL4=XO+L
02840 HL5=XO+2.*L
02850 ARG(1)=B*(SQRT(Y02+HL1**2)+HL1)
02860 ARG(2)=B*(SQRT(Y02+HL2**2)+HL2)
02870 ARG(3)=B*(SQRT(Y02+HL3**2)+HL3)
02880 ARG(4)=B*(SQRT(Y02+HL4**2)+HL4)
02890 ARG(5)=B*(SQRT(Y02+HL5**2)+HL5)
02900 DO 10 I=1,5
02910 10 CALL SCI(ARG(I),SI(I),CI(I),CIN(I))
02920 IF(POLAR.EQ.O.) GO TO 20
02930C******************************************************************************
02940C* COMPUTE MUTUAL IMPEDANCE FOR HORIZONTAL POLARIZATION *
02950C******************************************************************************
02960 R12=30.*(COS(2.*B*L)*(CI(1)+CI(5)-2.*CI(2)-2.*CI(4)+2.*CI(3))
02970+ +SIN(2.*B*L)*(-SI(1)+SI(5)+2.*SI(2)-2.*SI(4))
02980+ +4.*CI(3)-2.*CI(2)-2.*CI(4))
02990 X12=30.*(COS(2.*B*L)*(-SI(1)-SI(5)+2.*SI(2)+2.*SI(4)-2.*SI(3))
03000+ +SIN(2.*B*L)*(-CI(1)+CI(5)+2.*CI(2)-2.*CI(4))
03010+ -4.*SI(3)+2.*SI(2)+2.*SI(4))
03020 ZML=R12+J*X12
03030 RETURN
03040C******************************************************************************
03050C* COMPUTE MUTUAL IMPEDANCE FOR VERTICAL POLARIZATION *
03060C******************************************************************************
03070 20 L1=ALOG(HL2/HL1)
03080 L2=ALOG(HL4/HL3)
03090 L3=ALOG(HL2/HL3)
03100 L4=ALOG(HL4/HL5)
03110 B1=B*HL1
03120 B2=B*HL3
03130 B3=B*HL5
03140 B4=B*HL2
03150 B5=B*HL4
03160 R12=15.*(COS(B1)*(CI(1)-CI(2)+L1)+SIN(B1)*(SI(1)-SI(2))+COS(B2)
03170+ *(CI(3)-CI(4)+L2)+SIN(B2)*(SI(3)-SI(4))+COS(B3)*(-CI(2)+CI(3)
03180+ +L3)+SIN(B3)*(-SI(2)+SI(3))+COS(B4)*(-CI(4)+CI(5)+L4)+SIN(B3)
03190+ *(L3)+SIN(B3)*(-SI(2)+SI(3))+COS(B4)*(-CI(4)+CI(5)+L4)+SIN(B3)
03200+ *(L3)+SIN(B3)*(-SI(2)+SI(3))+COS(B4)*(-CI(4)+CI(5)+L4)+SIN(B3)
03210+ *(L3)+SIN(B3)*(-SI(2)+SI(3))+COS(B4)*(-CI(4)+CI(5)+L4)+SIN(B3)
03220+ *(L3)+SIN(B3)*(-SI(2)+SI(3))+COS(B4)*(-CI(4)+CI(5)+L4)+SIN(B3)
\[ 03220 \quad \text{X12=15.} \times (\cos(B1)\times (-\text{SI}(1)+\text{SI}(2))+\sin(B1)\times (\text{CI}(1)-\text{CI}(2)-L1)+\cos(B2) \]
\[ 03230+ \times (-\text{SI}(3)+\text{SI}(4))+\sin(B2)\times (\text{CI}(3)-\text{CI}(4)-L2)+\cos(B2)\times (\text{SI}(2) \]
\[ 03240+ + (\text{SI}(3))+2. \times \cos(B*L)\times \sin(B4)\times (\text{CI}(2)+\text{CI}(3)-L3)+2. \times \cos(B*L) \]
\[ 03250+ \times (-\text{SI}(3)+\text{SI}(4))+2. \times \cos(B*L)\times \sin(B5)\times (\text{CI}(3)-\text{CI}(4)-L2)) \]
\[ 03280 \quad \text{ZML=R12+J*X12} \]
\[ 03290 \quad \text{RETURN} \]
\[ 03300 \quad \text{END} \]

03310C******************************************************************************************
03320 \quad \text{SUBROUTINE SCI(ARG,SI,CI,CIN)}
03330C* COMPUTES THE SINE, COSINE, AND MODIFIED COSINE INTEGRALS *
03340C******************************************************************************************
03350 \quad \text{DIMENSION T(42),S(20),C(20)}
03360 \quad K=1
03370 \quad T(1)=1.0
03380 \quad DO 10 M=1,42
03390 \quad K=K+1
03400 \quad T(K)=M*T(K-1)
03410 \quad IF(ARG.GT.1.) GO TO 25
03420C**********************************************************************************
03430C* COMPUTE THE INTEGRALS FOR 0<ARG<1 *
03440C**********************************************************************************
03450 \quad DO 20 N=1,20
03460 \quad S(N)=((-1)**N)*(ARG**(2*N+1))/((2*N+1)*T(2*N+2))
03470 \quad SI=ARG*S(1)+S(2)+S(3)+S(4)+S(5)+S(6)+S(7)+S(8)+S(9)+S(10)
03490 \quad DO 30 N=1,20
03500 \quad C(N)=((-1)**N)*(ARG**(2*N))/((2*N)*T(2*N+1))
03510 \quad SA=C(1)+C(2)+C(3)+C(4)+C(5)+C(6)+C(7)+C(8)+C(9)+C(10)+C(11)
03530 \quad CI=0.577215665+ALOG(ARG)+SA
03540 \quad CIN=-SA
03550 \quad GO TO 40
03560C******************************************************************************************
03570C* COMPUTE THE INTEGRALS FOR 1<ARG<INFINITY *
03580C******************************************************************************************
03590 \quad DO 25 N=1,20
03600 \quad FZ=(ARG**8+38.027264*(ARG**6)+265.187033*(ARG**4)
03610+ \quad +335.67732*(ARG**2)+38.102495)/(ARG*((ARG**8)
03620+ \quad +40.021433*(ARG**6)+322.624911*(ARG**4)
03630+ \quad +570.23628*(ARG**2)+157.105423))
03640 \quad GZ=(ARG**8+42.242855*(ARG**6)+302.757865*(ARG**4)
03650+ \quad +352.018498*(ARG**2)+21.821899)/(ARG**2)*(ARG**8)
03660+ \quad +48.196927*(ARG**6)+482.485984*(ARG**4)+1114.978885
03670 \quad +((ARG**2)+449.690326))
03680 \quad SI=1.570796327-FZ*\cos(ARG)-GZ*\sin(ARG)
03690 \quad CI=FZ*\sin(ARG)-GZ*\cos(ARG)
03690 \quad CIN=-CI+0.5772157+ALOG(ARG)
03700 \quad GO TO 40
03710 \quad END
SUBROUTINE FILE(ENC,ENC2,L,POLAR,SIGMA,PSI,GAIN)

* WRITES DATA ON TAPE50 FOR PLOTTING USING PROCEDURE FILE 4T *

N=AINT(10./ENC+80./(ENC+ENC2))

10 FORMAT(I5)
20 FORMAT(2F10.3)
30 FORMAT(F10.3)
40 FORMAT(E9.3)

IF(ENC.GT.0) WRITE(50,10)N
IF(ENC.GT.0) WRITE(50,30)L
IF(ENC.GT.0) WRITE(50,30)POLAR
IF(ENC.GT.0) WRITE(50,40)SIGMA
IF(ENC.LT.0) WRITE(50,20)PSI,GAIN
RETURN
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.
Linear Gain-Standard Antennas Below 1000 MHz

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.
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 20036.

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.

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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.

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