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Gain Evaluation for an Idealized Curtain Array Antenna

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Gain Evaluation For an Idealized Curtain Array Antenna

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An expression for the gain of a curtain array antenna over a perfectly conducting, flat Earth with no mutual impedance between elements is derived in this report. A FORTRAN computer subroutine created to calculate the expression is described here. This subroutine considers interelement spacing and length of the individual elements, the spacing between the radiators and the reflecting screen behind the radiators, the antenna design and operating frequencies, and the number of elements in the array.

Key words: antenna gain; curtain array antenna; HF broadcast

1. BACKGROUND

High-frequency, curtain array antennas are being used more frequently in broadcast applications. We have developed a simple computer model for the curtain array antenna with a reflecting screen (as shown in Figure 1) to determine the directive gain for various slew angles. All dipoles in the array are uniformly spaced, identical, coplanar, and horizontal. The model assumes a flat, perfectly conducting Earth and a perfectly conducting reflector screen. There are no mutual impedance terms included in this model. We examined a 14 bay (wide), 8 stack (high), uniformly spaced, half-wavelength (at design frequency) dipole array for our computer subroutine. The subroutine can model an antenna operated at or near the design frequency and is applicable for other separations.

2. CURTAIN ARRAY RADIATION PATTERN

We begin by determining the radiation pattern for the antenna. Defining the coordinates as θ and ϕ , where θ is the vertical angle measured from the horizontal x-y plane, and ϕ is the azimuthal angle with respect to the antenna boresight (the x axis) as shown in Figure 2, the radiation pattern function (CCIR, 1984; Ma, 1974) is written as

$$F(\theta, \phi) = |\vec{E}(\theta, \phi)| = |\vec{f}\,\vec{f}_x\,\vec{f}_y\,\vec{f}_z| \qquad (1)$$

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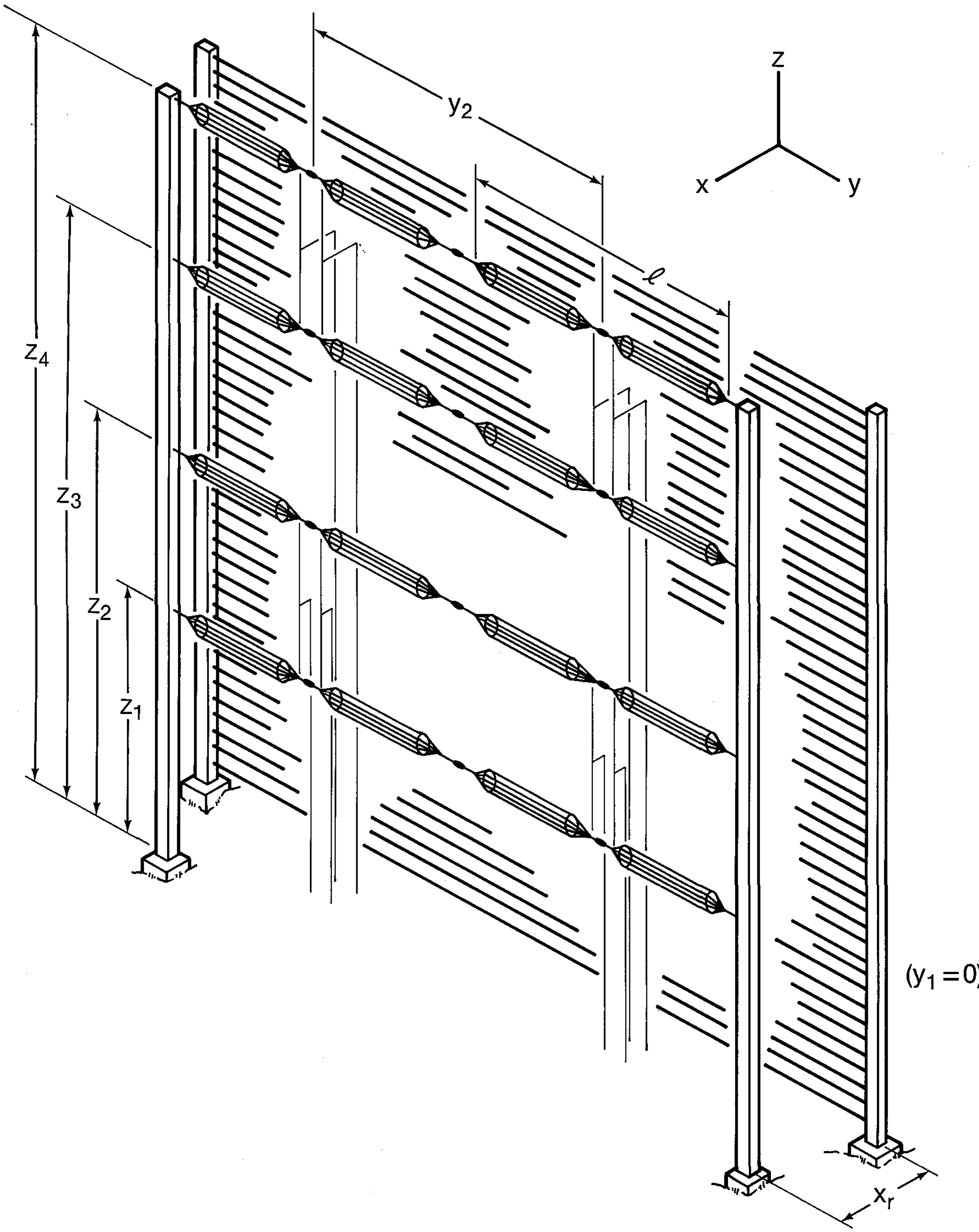

Figure 1. Curtain array with conducting screen (2 bays, 4 stacks).

where $\vec{f}$ is the elemental radiation characteristic for horizontal dipole antennas, $\vec{f}_z$ is the "height factor" or stack array factor, $\vec{f}_x$ is the array factor resulting from the presence of the reflector screen, and $\vec{f}_y$ is the "bay factor." The magnitude of the total electric field for this antenna in spherical coordinates is defined as

$$|\vec{E}(\theta, \phi)|^2 = \{|\vec{E}_\theta(\theta, \phi)|^2 + |\vec{E}_\phi(\theta, \phi)|^2\}. \qquad (2)$$

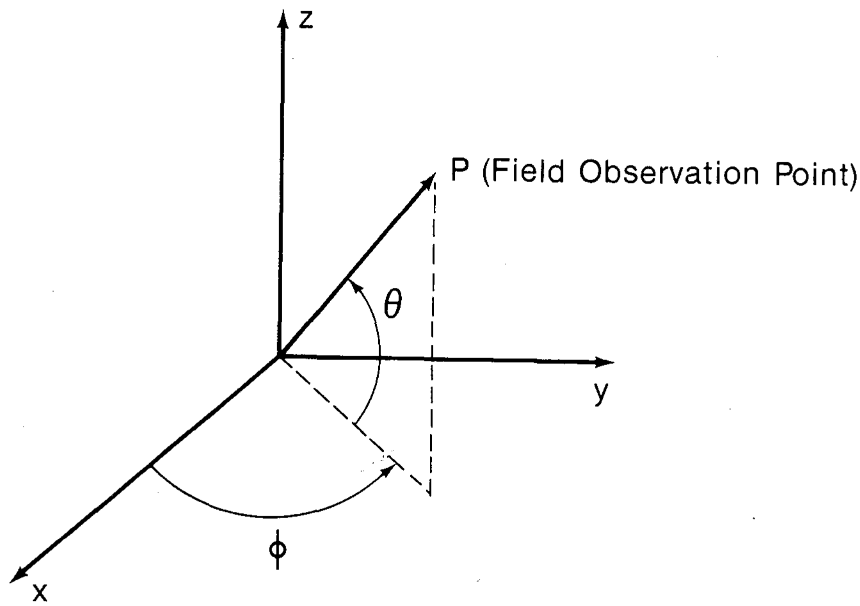

Figure 2. Coordinate variables definition.

The vector notation is used to avoid confusion with the magnitudes of the components.

Since the curtain array is made up of horizontal dipole elements, the element radiation characteristic (Ma and Walters, 1969) for a thin wire sinusoidal current distribution, given as

$$\vec{f} = \{\cos[(\beta \ell /2)\cos \psi] - \cos(\beta \ell /2)\}/\sin^2 \psi \qquad (3)$$

where ℓ is the length of the dipole, $\beta = 2\pi/\lambda$ (where λ is the wavelength), and $\cos \psi = \sin \phi \cos \theta$, is appropriate.

For the array oriented as shown in Figure 1, a height factor resulting from both the electric field components E_θ and E_ϕ (CCIR, 1984; Ma and

Walters, 1969) is used. For an m stack array the height factor is

$$\vec{f}_z = f_{z_\theta} \vec{a}_\theta + f_{z_\phi} \vec{a}_\phi$$

$$= \vec{a}_\theta \sin\theta \sin\phi \left\{ \sum_{i=1}^{m} C_i \exp(j[\beta z_i \sin\theta + \alpha_i]) \times \right.$$

$$\left. [1-R_v \exp(-2j\beta z_i \sin\theta)] \right\}$$

$$+ \vec{a}_\phi \cos\phi \left\{ \sum_{i=1}^{m} C_i \exp(j[\beta z_i \sin\theta + \alpha_i]) \times \right.$$

$$\left. [1 + R_h \exp(-2j\beta z_i \sin\theta)] \right\} \quad (4)$$

where C_i is the current magnitude ratio of the ith element, α_i is the phase of the ith dipole current, z_i is the height of the ith stack, R_h and R_v are the horizontal and vertical reflection coefficients, and $\vec{a}_\theta$ and $\vec{a}_\phi$ are the unit vectors in the θ and ϕ directions, respectively. For the perfectly conducting earth model, $R_h = -1$ and $R_v = +1$ so that

$$\vec{f}_z = \vec{a}_\theta \left\{ \sum_{i=1}^{m} 2jC_i \exp(j\alpha_i) \sin(\beta z_i \sin\theta) \right\} \sin\phi \sin\theta$$

$$+ \vec{a}_\phi \left\{ \sum_{i=1}^{m} 2j C_i \exp(j\alpha_i) \sin(\beta z_i \sin\theta) \right\} \cos\phi . \quad (5)$$

The "bay factor" or horizontal array factor (CCIR, 1984; Ma and Walters, 1969) is

$$f_y = \sum_{i=1}^{n} I_i \exp\{jS_i \cos\theta \sin\phi + jP_i\} \quad (6)$$

where I_i is the magnitude of the ith bay dipole current, $S_i = \beta y_i$ (where y_i is the distance between the first and the ith bay), and P_i is the phase of the ith bay dipole current. (If the antenna is operated at a frequency other than the design frequency, the phase term P_i is multiplied by a correction term, i.e., operating frequency divided by design frequency, to allow for the variation in the phase shift resulting from the feed line lengths being constant for the varied frequencies.)

The array factor resulting from the reflector presence is simply

$$\vec{f}_x = 2j \sin(\beta x_r \cos\theta \cos\phi) \quad (7)$$

(Ma and Walters, 1969) where x_r is the dipole to reflector spacing.

Now that $\vec{f}$, $\vec{f}_x$, $\vec{f}_y$, and $\vec{f}_z$ are defined, an expression for $F(\theta, \phi)$ is obtained from (1) so that now the gain may be found. The directive gain is by definition

$$G = 10 \log_{10} [4\pi |\vec{E}(\theta, \phi)|^2 / \int_0^{90} \int_{-90}^{90} |E(\theta, \phi)|^2 \cos\theta \, d\phi d\theta]. \quad (8)$$

The limits of integration in (8) are defined for a quarter sphere because the ground and reflector are considered perfectly conducting and infinite for this model. Substituting in the expression for $F(\theta, \phi)$, the gain may be written as

$$G = 10 \log_{10} [K F^2(\theta, \phi)] \quad (9)$$

where

$$K = 4\pi / \int_0^{90} \int_{-90}^{90} F^2(\theta, \phi) \cos\theta \, d\phi \, d\theta. \quad (10)$$

3. CURTAIN ARRAY DIRECTIVE GAIN SUBROUTINE

The subroutine GAIN is a FORTRAN subroutine to calculate the directive gain in the form of (9) for the curtain array antenna of the type shown in Figure 1 for arrays of up to 14 bays wide and 8 stacks high. The variables for the physical dimensions for the subroutine are shown in Figure 3. The overall dimensions shown in Figure 1 are computed as needed within the subroutine.

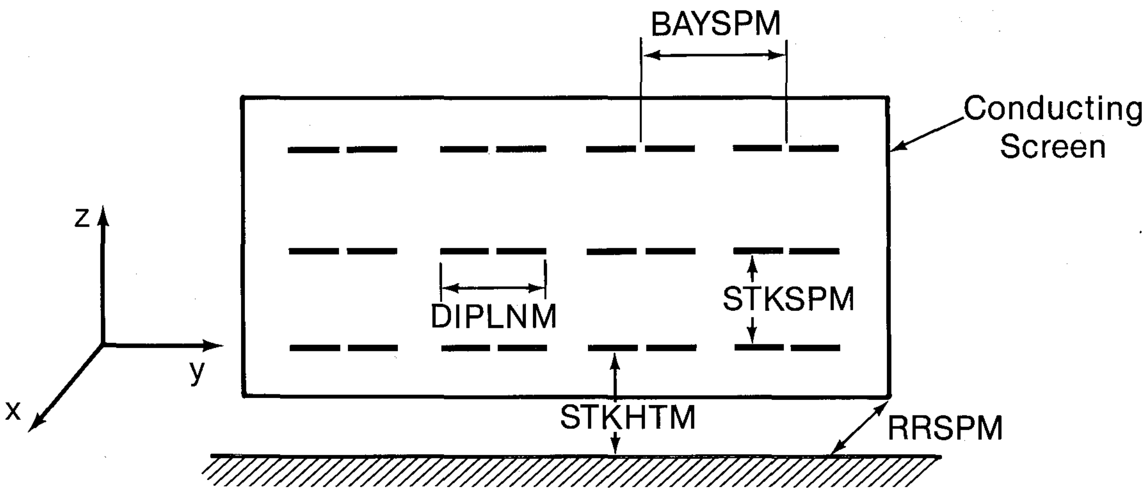

Figure 3. Gain subroutine input variables.

The call to the subroutine GAIN is

GAIN (XGAIN,FACTOR,IFLAG,THETAD,PHID)

where the parameters are defined as in Table 1. The user must also use the following common block to input to the subroutine the remaining necessary values (variables defined in Table 2):

COMMON / ANTDAT / NOSTAK, STKSPM, NUMBAY, BAYSPM, DIPLNM, RRSPM, STKHTM, STKRAT,BAYPHS,BAYPHS,BAYRAT, OFMHZ, DFMHZ

With values chosen for these parameters, the GAIN subroutine calculates the gain (9) using a double integration subroutine, DBLTRAP, to calculate the double integral of the K term of equation (10) and using the function F2 which straightforwardly calculates the F (θ, ϕ) of (1). DBLTRAP uses a nested trapezoidal rule summation to approximate the double integral using a step size of 1 degree. We found little variation in the first two significant digits of the gain when varying the step size to 0.5 degrees and to 2.0 degrees.

Table 1. Subroutine GAIN Parameter Definitions

Parameter Name	Variable Type	Parameter Representation
XGAIN	Real	Power gain in dBi calculated in subroutine
FACTOR	Real	Integration factor (K in eqn. (10)) that can be calculated in GAIN or passed in by user
IFLAG	Integer	Flag to determine if FACTOR is to be passed into GAIN or calculated in GAIN For IFLAG = 0, FACTOR is to be calculated For IFLAG = 1, FACTOR is passed into GAIN
THETAD	Real	Angle above the horizon in degrees where GAIN is to be calculated
PHID	Real	Antenna boresight azimuthal angle in degrees where GAIN is to be calculated

Table 2. Common Block ANTDAT Variable Definitions

Name	Type	Description
NOSTAK	Integer	Number of (vertical) stacks
STKSPM	Real	Spacing between stacks in meters
NUMBAY	Integer	Number of (horizontal) bays
BAYSPM	Real	Spacing between bays in meters
DIPLNM	Real	Dipole length in meters (set equal to half wavelength at design frequency)
RRSPM	Real	Spacing between radiators and reflecting screen in meters
STKHTM	Real	Height of lowest (first) stack above the ground in meters
STKRAT(14)	Real	Array of dimension 14 containing the relative stack current ratios
BAYPHS(14)	Real	Array of dimension 14 containing the relative phases of the bay currents in degrees
BAYRAT(14)	Real	Array of dimension 14 containing the relative bay current ratio
OFMHZ	Real	Antenna operating frequency in megahertz (i.e., 8.75 MHz is input as 8.75)
DFMHZ	Real	Antenna design frequency in megahertz

4. APPLICATION TO A PHYSICAL ANTENNA

Several of the variables can have restrictive limits placed on their values to match features of specific physical antennas. The dipoles for the antenna shown in Figure 4 have uniform spacing of a half-wavelength at design frequency between column centers and between each stack. The fifth and tenth bays are assumed to have zero current input (BAYRAT(5) = BAYRAT(10) = 0) since these are the support structures at those locations and there are no dipoles there. The height of the first stack off the ground is a multiple of a half-wavelength at design frequency.

With a phase delay in the input current to the individual dipole elements, the summing of the lesser maximum lobes and nulls combine to a new maximum lobe in a direction different from the original individual maximum. By controlling the phase delay, the direction of the maximum lobe can be rotated without physically moving the antenna. For our physical antenna we can rotate the direction of the maximum gain, i.e., slew the antenna, by introducing phase or magnitude differences in the vertical or horizontal elements current inputs. The current magnitudes for our antenna's vertical slews (the current ratio for the stacks--STKRAT) can only be +1, -1, and 0 for each dipole in that stack. There are a total of 11 combinations of vertical slew excitations or modes that we are interested in. These are shown in Table 3. The vertical current phases are all set to zero. The approximate current phases for the negative horizontal slew excitations are shown in Table 4. The current phases for the positive horizontal slews are simply obtained by multiplying the negative horizontal slew current phases by -1.

The CCIR (CCIR, 1984) defines a curtain array using a designation of HRS m/n/h(s) where m is the number of half-wave dipoles in each row (the number of bays); n is the number of rows spaced half a wavelength apart (the number of stacks); h is the height of the bottom row of dipoles above the ground in fractions of wavelength; and s is the slew of the azimuth of the main radiation lobe in degrees from the ϕ axis. Using the subroutine GAIN (listing in Appendix along with listings of a program CALLGAIN to call the subroutine GAIN, the subroutine DBLTRAP, and the function F2) in the ITS computer program called ANTE available in the TASERVICES on the Boulder computer; it is possible to generate gain arrays for various azimuthal angles and take-off angles.

Some of the resultant gain values are shown in Figures 5 - 12, for a standard HRS 4/6/0.5 curtain array, including a mode 10 with zero slew operated at and below design frequency, a mode 10 with +30 degree slew, and a mode 5 with zero slew.

Table 3. Vertical Slew Current Modes for a Physical Antenna

Mode Number	Stack Current Excitation Ratios for Stacks Numbered: 1 and 2	3 and 4	5 and 6	7 and 8
1	+1	0	0	0
4	+1	+1	0	0
5	+1	0	+1	0
6	0	+1	+1	0
7	+1	-1	0	0
8	+1	0	-1	0
9	0	+1	-1	0
10	+1	+1	+1	0
11	+1	+1	-1	0
12	+1	-1	+1	0
13	+1	-1	-1	0

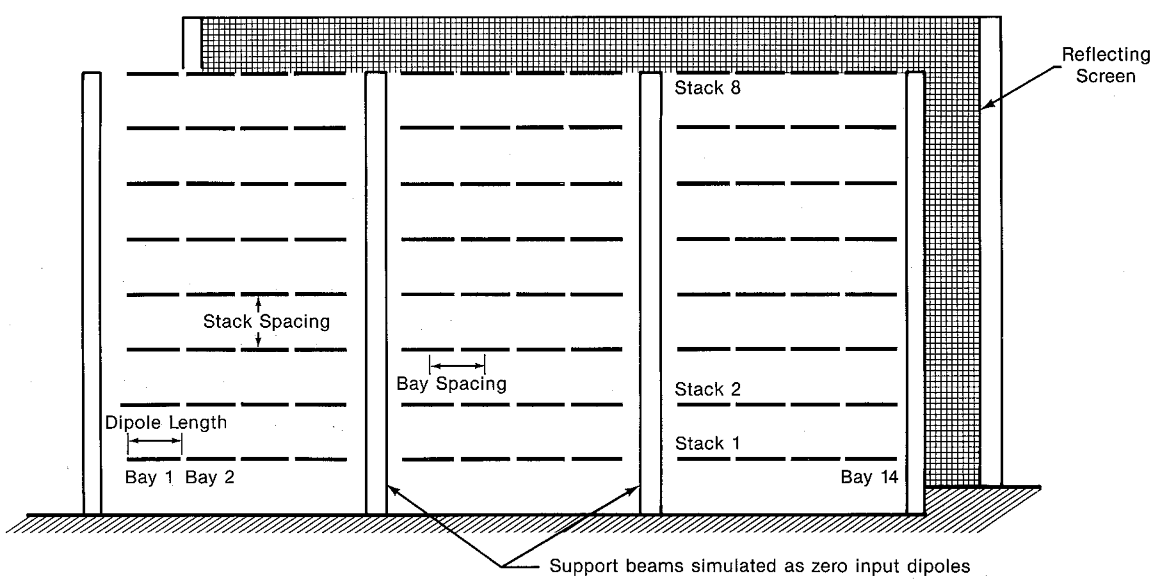

Figure 4. Physical antenna dimensions.

Table 4. Horizontal Slew Current Phases in Degrees
for a 14-Bay Curtain Antenna

Slew Angle	Bay Number 1	2	3	4	5	6	7	8	9	10	11	12	13	14
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
-5	0	0	31	31	0	77	77	109	109	0	155	155	186	186
-9	0	47	56	103	0	139	185	195	242	0	278	324	334	381
-13	0	47	81	128	0	200	246	281	327	0	399	446	480	527
-17	0	47	105	152	0	260	306	365	411	0	519	566	624	671
-21	0	47	129	176	0	318	365	447	494	0	636	683	765	812
-25	0	90	152	242	0	375	465	527	617	0	750	840	903	993
-30	0	90	180	270	0	444	534	624	714	0	888	978	1068	1158

5. DISCUSSION

Figures 5 and 6 show the HRS 4/6/0.5 (with zero horizontal slew) antenna gain results with a maximum gain of 23 dB at a takeoff angle of 7 degrees. As would be expected, the maximum gain and its takeoff angle for the maximum gain are moved when the operating frequency is no longer identical to the design frequency, as is seen when figures 5 and 6 are compared to figures 7 and 8 where the peak gain is 20 dB at 10 degrees.

Figures 9 and 10 show the gain for a slewed array (horizontal slew angle equals 30 degrees). The peak gain is moved away from the zero azimuth of figures 5 and 6 to near 30 degrees azimuth. The slight understeering to approximately 26 degrees is a result of the current phase angles being derived using a simple point source calculation.

Finally, in figures 11 and 12 (mode 5 excitation, see table 3), we see a change in the maximum gain to 20 dB at the takeoff angle to 6 degrees from that of figures 5 and 6 (mode 10 excitation) as would be expected.

The theoretical models used might further be improved by using a second order current expression in deriving the gain formulas or by including antenna

Takeoff Angle

Azim	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36
0	***	11	16	19	21	22	23	23	22	22	20	19	16	13	9	3	-8	-15	-9	-14	-11	-1	5	8	10	11	12	12	12	11	9	7	4	0	-7	-23	-7
1	***	11	16	19	21	22	23	23	22	22	20	19	16	13	9	3	-8	-15	-9	-15	-11	-1	5	8	10	11	12	12	12	11	9	7	4	0	-7	-24	-7
2	***	11	16	19	21	22	23	23	22	22	20	19	16	13	9	3	-8	-15	-9	-15	-11	-1	4	8	10	11	12	12	11	11	9	7	4	0	-7	-24	-7
3	***	10	16	19	21	22	23	23	22	21	20	18	16	13	9	3	-8	-15	-9	-15	-11	-1	4	8	10	11	12	12	11	11	9	7	4	0	-8	-24	-7
4	***	10	16	19	21	22	23	23	22	21	20	18	16	13	9	3	-8	-15	-9	-15	-11	-1	4	7	10	11	11	12	11	10	9	7	4	0	-8	-24	-7
5	***	10	16	19	21	22	22	22	22	21	20	18	16	13	9	3	-8	-15	-9	-15	-12	-1	4	7	9	11	11	12	11	10	9	7	4	0	-8	-24	-8
6	***	10	16	19	21	22	22	22	22	21	20	18	16	13	8	2	-8	-15	-9	-15	-12	-1	4	7	9	11	11	11	11	10	9	7	4	0	-8	-24	-8
7	***	10	15	19	20	21	22	22	22	21	19	18	15	12	8	2	-9	-15	-10	-15	-12	-1	4	7	9	10	11	11	11	10	9	7	4	-1	-8	-24	-8
8	***	9	15	18	20	21	22	22	21	20	19	17	15	12	8	2	-9	-16	-10	-16	-12	-2	3	7	9	10	11	11	11	10	8	6	4	-1	-8	-24	-8
9	***	9	15	18	20	21	21	21	21	20	19	17	15	12	8	2	-9	-16	-10	-16	-13	-2	3	6	8	10	10	11	10	10	8	6	3	-1	-8	-25	-8
10	***	9	15	18	19	20	21	21	21	20	19	17	14	11	7	1	-10	-16	-10	-16	-13	-2	3	6	8	9	10	10	10	9	8	6	3	-1	-9	-25	-9
11	***	8	14	17	19	20	21	21	20	19	18	16	14	11	7	1	-10	-17	-11	-17	-13	-3	3	6	8	9	10	10	10	9	8	6	3	-2	-9	-25	-9
12	***	8	14	17	19	20	20	20	20	19	18	16	14	11	6	0	-10	-17	-11	-17	-14	-3	2	5	7	9	9	10	9	9	7	5	2	-2	-9	-25	-9
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15	***	6	12	15	17	18	18	19	18	17	16	14	12	9	5	-1	-12	-19	-13	-18	-15	-4	1	4	6	7	8	8	8	7	6	4	1	-3	-10	-26	-10
16	***	6	11	14	16	17	18	18	17	17	15	14	11	8	4	-2	-13	-19	-13	-19	-16	-5	0	3	6	7	8	8	8	7	5	4	1	-3	-11	-27	-11
17	***	5	11	14	15	17	17	17	17	16	15	13	11	8	4	-2	-13	-20	-14	-20	-16	-6	0	3	5	6	7	7	7	6	5	3	0	-4	-11	-27	-11
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22	***	0	5	9	10	12	12	12	12	11	10	8	6	3	-1	-7	-18	-24	-18	-24	-21	-10	-5	-1	1	2	3	4	3	3	2	0	-3	-7	-14	-30	-14
23	***	-2	4	7	9	10	11	11	11	10	9	7	5	2	-2	-8	-19	-26	-19	-25	-22	-11	-6	-2	0	2	2	3	3	2	1	-1	-4	-8	-15	-31	-15
24	***	-3	3	6	7	9	9	9	9	8	7	5	3	0	-4	-10	-20	-27	-21	-26	-23	-12	-7	-3	-1	0	1	2	2	1	0	-2	-5	-9	-16	-32	-15
25	***	-5	1	4	6	7	7	8	7	7	5	4	2	-1	-5	-11	-22	-28	-22	-28	-24	-13	-8	-5	-2	-1	0	1	1	0	-1	-3	-6	-10	-17	-33	-16
26	***	-7	-2	2	3	5	5	5	5	4	3	2	0	-3	-7	-13	-24	-30	-24	-29	-26	-15	-10	-6	-4	-2	-1	-1	-1	-1	-2	-4	-7	-11	-18	-34	-17
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28	***	-14	-8	-5	-3	-2	-1	-1	-1	-1	-2	-4	-6	-8	-12	-18	-28	-35	-28	-34	-30	-19	-13	-10	-7	-5	-4	-4	-4	-4	-5	-7	-9	-13	-20	-36	-19
29	***	-20	-14	-11	-9	-8	-7	-6	-6	-6	-7	-8	-10	-13	-16	-21	-32	-38	-31	-36	-32	-21	-16	-12	-9	-7	-6	-5	-5	-6	-6	-8	-10	-14	-21	-37	-20
30	***	-68	-49	-39	-32	-27	-23	-21	-19	-18	-17	-17	-18	-19	-22	-27	-37	-43	-36	-40	-36	-25	-19	-15	-12	-10	-8	-8	-7	-7	-8	-10	-12	-16	-23	-38	-21
31	***	-21	-16	-13	-11	-11	-11	-11	-13	-15	-18	-22	-27	-37	-58	-44	-49	-52	-44	-47	-42	-30	-23	-19	-16	-13	-11	-10	-10	-10	-10	-12	-14	-17	-24	-40	-23
32	***	-16	-10	-7	-5	-4	-4	-5	-5	-7	-8	-11	-14	-18	-23	-31	-44	-53	-52	-69	-60	-41	-32	-26	-21	-18	-16	-14	-13	-13	-13	-14	-16	-19	-26	-41	-24
33	***	-13	-7	-4	-2	-1	-1	-1	-2	-3	-4	-7	-9	-13	-18	-24	-36	-44	-39	-47	-45	-38	-37	-45	-38	-28	-23	-20	-18	-17	-17	-17	-19	-22	-28	-43	-26
34	***	-11	-5	-2	0	1	1	1	1	0	-2	-4	-7	-10	-15	-21	-32	-40	-35	-41	-39	-30	-26	-25	-25	-28	-35	-39	-28	-24	-22	-22	-22	-25	-31	-46	-28
35	***	-9	-3	0	1	2	3	3	2	1	0	-2	-5	-8	-13	-19	-30	-37	-32	-38	-36	-26	-22	-19	-19	-19	-20	-23	-28	-40	-36	-30	-28	-30	-35	-49	-31
36	***	-8	-2	1	3	4	4	4	3	2	1	-1	-3	-7	-11	-17	-29	-36	-30	-36	-33	-23	-19	-16	-15	-15	-15	-17	-19	-22	-27	-37	-48	-38	-41	-54	-35
37	***	-7	-1	2	3	4	5	5	4	3	2	0	-2	-6	-10	-16	-27	-34	-29	-35	-32	-22	-17	-14	-13	-12	-13	-13	-15	-17	-20	-25	-31	-42	-63	-62	-40
38	***	-7	-1	2	4	5	5	5	5	4	3	1	-2	-5	-9	-15	-26	-33	-28	-34	-31	-21	-16	-13	-11	-11	-11	-11	-12	-14	-17	-20	-25	-32	-43	-67	-58
39	***	-6	0	3	4	5	6	6	5	5	3	1	-1	-4	-9	-15	-26	-33	-27	-33	-30	-20	-15	-12	-10	-9	-9	-10	-11	-12	-15	-18	-22	-28	-37	-56	-44
40	***	-6	0	3	5	6	6	6	6	5	4	2	-1	-4	-8	-14	-25	-32	-26	-32	-29	-19	-14	-11	-9	-9	-8	-9	-9	-11	-13	-16	-20	-25	-34	-52	-38
41	***	-6	0	3	5	6	6	6	6	5	4	2	0	-4	-8	-14	-25	-32	-26	-32	-29	-18	-13	-11	-9	-8	-7	-8	-8	-10	-12	-14	-18	-23	-32	-49	-34
42	***	-6	0	3	5	6	7	7	6	5	4	2	0	-3	-8	-14	-25	-32	-26	-32	-28	-18	-13	-10	-8	-7	-7	-7	-8	-9	-11	-13	-17	-22	-30	-47	-32
43	***	-6	0	3	5	6	7	7	6	5	4	2	0	-3	-7	-14	-24	-31	-25	-31	-28	-18	-13	-10	-8	-7	-6	-6	-7	-8	-10	-13	-16	-21	-29	-46	-31
44	***	-6	0	3	5	6	7	7	6	5	4	2	0	-3	-7	-13	-24	-31	-25	-31	-28	-18	-13	-9	-8	-6	-6	-6	-7	-8	-10	-12	-15	-20	-28	-45	-29
45	***	-6	0	3	5	6	6	6	6	5	4	2	0	-3	-7	-13	-24	-31	-25	-31	-28	-17	-12	-9	-7	-6	-6	-6	-6	-7	-9	-11	-15	-19	-27	-44	-28
46	***	-6	0	3	5	6	6	6	6	5	4	2	0	-3	-8	-14	-24	-31	-25	-31	-28	-17	-12	-9	-7	-6	-6	-6	-6	-7	-9	-11	-14	-19	-27	-43	-28
47	***	-6	0	3	4	6	6	6	6	5	4	2	0	-4	-8	-14	-25	-31	-25	-31	-28	-17	-12	-9	-7	-6	-5	-5	-6	-7	-9	-11	-14	-19	-26	-43	-27
48	***	-7	-1	2	4	5	6	6	5	5	3	2	-1	-4	-8	-14	-25	-32	-26	-31	-28	-18	-12	-9	-7	-6	-5	-5	-6	-7	-8	-11	-14	-18	-26	-43	-27
49	***	-7	-1	2	4	5	5	5	5	4	3	1	-1	-4	-8	-14	-25	-32	-26	-32	-28	-18	-13	-9	-7	-6	-6	-5	-6	-7	-8	-11	-14	-18	-26	-42	-26
50	***	-7	-2	1	3	4	5	5	5	4	3	1	-1	-4	-9	-14	-25	-32	-26	-32	-29	-18	-13	-10	-8	-6	-6	-6	-6	-7	-8	-10	-14	-18	-26	-42	-26
51	***	-8	-2	1	3	4	5	5	4	3	2	0	-2	-5	-9	-15	-26	-32	-26	-32	-29	-18	-13	-10	-8	-6	-6	-6	-6	-7	-8	-11	-14	-18	-26	-42	-26
52	***	-8	-3	0	2	3	4	4	4	3	2	0	-2	-5	-9	-15	-26	-33	-27	-32	-29	-18	-13	-10	-8	-7	-6	-6	-6	-7	-8	-11	-14	-18	-26	-42	-26
53	***	-9	-3	0	2	3	3	4	3	2	1	0	-3	-6	-10	-16	-26	-33	-27	-33	-29	-19	-14	-10	-8	-7	-6	-6	-6	-7	-9	-11	-14	-18	-26	-42	-26
54	***	-10	-4	-1	1	2	3	3	3	2	1	-1	-3	-6	-10	-16	-27	-34	-28	-33	-30	-19	-14	-11	-9	-7	-6	-6	-7	-7	-9	-11	-14	-18	-26	-42	-26
55	***	-10	-4	-1	1	2	2	2	2	1	0	-2	-4	-7	-11	-17	-27	-34	-28	-34	-30	-20	-14	-11	-9	-8	-7	-7	-7	-8	-9	-11	-14	-18	-26	-42	-26
56	***	-11	-5	-2	0	1	2	2	1	1	-1	-2	-4	-7	-11	-17	-28	-35	-29	-34	-31	-20	-15	-11	-9	-8	-7	-7	-7	-8	-9	-11	-14	-18	-26	-42	-26
57	***	-12	-6	-3	-1	0	1	1	1	0	-1	-3	-5	-8	-12	-18	-29	-35	-29	-35	-31	-21	-15	-12	-10	-8	-8	-7	-7	-8	-10	-12	-14	-19	-26	-42	-26
58	***	-13	-7	-4	-2	-1	0	0	0	-1	-2	-4	-6	-9	-13	-19	-29	-36	-30	-35	-32	-21	-16	-12	-10	-9	-8	-8	-8	-9	-10	-12	-15	-19	-26	-43	-26
59	***	-13	-8	-5	-3	-1	-1	-1	-1	-2	-3	-4	-7	-9	-13	-19	-30	-37	-30	-36	-32	-22	-16	-13	-11	-9	-8	-8	-8	-9	-10	-12	-15	-19	-27	-43	-27
60	***	-14	-9	-5	-4	-2	-2	-2	-2	-3	-4	-5	-7	-10	-14	-20	-31	-37	-31	-37	-33	-22	-17	-14	-11	-10	-9	-9	-9	-9	-11	-13	-15	-20	-27	-43	-27

Figure 5. Power gain for HRS 4/6/0.5 curtain array antenna for mode 10 excitation and horizontal slew = 0, designed and operated at 8.75 MHz.

Takeoff Angle

Azim	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36
0			16	19		22	23		22	22		19	16	13											10							7	4				
1																																					
2																							4														
3		10																																			
4																								7						10							
5							22	22																													
6																																					
7											19															10											
8																																					
9																											10		10								
10					19										7	1												10									
11										19		16																									
12																									7						7						
13		7	13	16		19			19				13	10																							
14							19	19															1	4								4					
15											16															7				7			1				
16					16										4																						
17										16		13															7	7	7								
18		4	10	13		16	16	16	16				10	7											4						4						
19											13													1													
20					13					13		10			1											4				4		1					
21		1	7	10		13	13	13	13				7	4													4	4	4								
22					10						10														1												
23			4	7		10				10		7																			1						
24					7						7																1			1							
25			1	4		7	7		7	7		4																1	1								
26										4																											
27					1						1																										
28																																					
29																																					
30																																					
31																																					
32																																					
33																																					
34						1	1	1	1																												
35					1					1																											
36				1		4	4	4			1																										
37									4																												
38					4					4		1																									
39																																					
40											4																										
41																																					
42							7	7																													
43																																					
44																																					
45																																					
46																																					
47					4																																
48																																					
49										4		1																									
50				1		4																															
51									4																												
52							4	4																													
53											1																										
54					1																																
55										1																											
56						1			1																												
57							1	1																													
58																																					
59																																					
60																																					

Figure 6. Power gain for HRS 4/6/0.5 curtain array antenna for mode 10 excitation and horizontal slew = 0, designed and operated at 8.75MHz.

Takeoff Angle

Azim	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36
0	-99	5	11	14	16	18	19	20	20	20	20	20	20	19	18	17	16	14	12	10	7	4	0	-7	-21	-17	-12	-13	-18	-24	-10	-4	-1	2	4	5	6
1	-99	5	11	14	16	18	19	20	20	20	20	20	20	19	18	17	16	14	12	10	7	4	0	-7	-21	-17	-12	-13	-18	-24	-10	-4	-1	2	4	5	6
2	-99	5	11	14	16	18	19	20	20	20	20	20	20	19	18	17	16	14	12	10	7	4	0	-7	-21	-17	-12	-13	-18	-24	-10	-5	-1	2	4	5	6
3	-99	5	11	14	16	18	19	19	20	20	20	20	19	19	18	17	16	14	12	10	7	4	-1	-7	-21	-17	-12	-13	-18	-25	-10	-5	-1	2	4	5	6
4	-99	5	11	14	16	18	19	19	20	20	20	20	19	19	18	17	16	14	12	10	7	4	-1	-7	-21	-17	-12	-13	-18	-25	-10	-5	-1	2	3	5	6
5	-99	5	11	14	16	18	19	19	20	20	20	20	19	19	18	17	15	14	12	10	7	4	-1	-7	-21	-17	-12	-13	-18	-25	-10	-5	-1	2	3	5	6
6	-99	5	10	14	16	17	18	19	20	20	20	20	19	19	18	17	15	14	12	10	7	4	-1	-7	-21	-17	-12	-13	-18	-25	-11	-5	-1	1	3	5	6
7	-99	4	10	14	16	17	18	19	20	20	20	19	19	18	18	17	15	14	12	10	7	4	-1	-7	-22	-17	-13	-13	-18	-25	-11	-5	-1	1	3	5	6
8	-99	4	10	13	16	17	18	19	19	20	20	19	19	18	17	16	15	14	12	9	7	3	-1	-7	-22	-18	-13	-13	-18	-25	-11	-5	-1	1	3	5	6
9	-99	4	10	13	15	17	18	19	19	19	19	19	19	18	17	16	15	13	12	9	7	3	-1	-8	-22	-18	-13	-13	-19	-25	-11	-5	-1	1	3	4	6
10	-99	4	10	13	15	17	18	19	19	19	19	19	19	18	17	16	15	13	11	9	6	3	-1	-8	-22	-18	-13	-13	-19	-25	-11	-5	-2	1	3	4	5
11	-99	4	10	13	15	17	18	18	19	19	19	19	18	18	17	16	15	13	11	9	6	3	-2	-8	-22	-18	-13	-14	-19	-25	-11	-5	-2	1	3	4	5
12	-99	3	9	13	15	16	17	18	19	19	19	19	18	17	17	16	14	13	11	9	6	3	-2	-8	-22	-18	-13	-14	-19	-26	-11	-6	-2	1	3	4	5
13	-99	3	9	12	14	16	17	18	18	18	18	18	18	17	16	15	14	13	11	8	6	2	-2	-8	-23	-18	-14	-14	-19	-26	-12	-6	-2	0	2	4	5
14	-99	3	9	12	14	16	17	18	18	18	18	18	18	17	16	15	14	12	10	8	6	2	-2	-9	-23	-19	-14	-14	-20	-26	-12	-6	-2	0	2	4	5
15	-99	3	8	12	14	15	17	17	18	18	18	18	17	17	16	15	14	12	10	8	5	2	-2	-9	-23	-19	-14	-14	-20	-26	-12	-6	-3	0	2	3	4
16	-99	2	8	11	14	15	16	17	17	18	18	17	17	16	16	15	13	12	10	8	5	2	-3	-9	-23	-19	-14	-15	-20	-27	-12	-7	-3	0	2	3	4
17	-99	2	8	11	13	15	16	17	17	17	17	17	17	16	15	14	13	11	10	7	5	1	-3	-10	-24	-20	-15	-15	-20	-27	-13	-7	-3	-1	1	3	4
18	-99	1	7	11	13	14	15	16	17	17	17	17	16	16	15	14	13	11	9	7	4	1	-3	-10	-24	-20	-15	-15	-21	-27	-13	-7	-3	-1	1	3	4
19	-99	1	7	10	12	14	15	16	16	16	16	16	16	15	14	13	12	11	9	7	4	1	-4	-10	-24	-20	-15	-16	-21	-27	-13	-7	-4	-1	1	2	3
20	-99	1	7	10	12	14	15	15	16	16	16	16	15	15	14	13	12	10	8	6	4	0	-4	-11	-25	-21	-16	-16	-21	-28	-13	-8	-4	-1	1	2	3
21	-99	0	6	9	12	13	14	15	15	16	16	15	15	14	14	13	11	10	8	6	3	0	-5	-11	-25	-21	-16	-16	-22	-28	-14	-8	-4	-2	0	2	3
22	-99	0	6	9	11	13	14	14	15	15	15	15	15	14	13	12	11	9	8	5	3	-1	-5	-11	-25	-21	-16	-17	-22	-28	-14	-8	-5	-2	0	1	3
23	-99	-1	5	8	11	12	13	14	14	15	15	14	14	13	13	12	10	9	7	5	2	-1	-5	-12	-26	-22	-17	-17	-22	-29	-15	-9	-5	-2	0	1	2
24	-99	-1	4	8	10	12	13	13	14	14	14	14	14	13	12	11	10	8	7	4	2	-2	-6	-12	-26	-22	-17	-18	-23	-29	-15	-9	-5	-3	-1	1	2
25	-99	-2	4	7	9	11	12	13	13	14	14	13	13	12	12	11	9	8	6	4	1	-2	-6	-13	-27	-23	-18	-18	-23	-30	-15	-10	-6	-3	-1	0	2
26	-99	-3	3	7	9	10	11	12	13	13	13	13	12	12	11	10	9	7	6	3	1	-3	-7	-13	-27	-23	-18	-18	-24	-30	-16	-10	-6	-4	-2	0	1
27	-99	-3	3	6	8	10	11	12	12	12	12	12	12	11	10	9	8	7	5	3	0	-3	-7	-14	-28	-24	-19	-19	-24	-31	-16	-10	-7	-4	-2	0	1
28	-99	-4	2	5	7	9	10	11	11	12	12	11	11	11	10	9	8	6	4	2	0	-4	-8	-14	-28	-24	-19	-20	-25	-31	-17	-11	-7	-4	-2	-1	0
29	-99	-5	1	5	7	8	9	10	11	11	11	11	10	10	9	8	7	6	4	2	-1	-4	-9	-15	-29	-25	-20	-20	-25	-32	-17	-11	-8	-5	-3	-1	0
30	-99	-5	0	4	6	8	9	9	10	10	10	10	10	9	8	7	6	5	3	1	-2	-5	-9	-16	-30	-25	-20	-21	-26	-32	-18	-12	-8	-5	-3	-2	-1
31	-99	-6	0	3	5	7	8	9	9	9	9	9	9	8	8	7	6	4	2	0	-2	-6	-10	-16	-30	-26	-21	-21	-26	-33	-18	-12	-9	-6	-4	-2	-1
32	-99	-7	-1	2	4	6	7	8	8	9	9	8	8	8	7	6	5	3	2	0	-3	-6	-11	-17	-31	-27	-22	-22	-27	-33	-19	-13	-9	-6	-4	-3	-2
33	-99	-8	-2	1	3	5	6	7	7	8	8	8	7	7	6	5	4	3	1	-1	-4	-7	-11	-18	-32	-27	-22	-22	-28	-34	-20	-14	-10	-7	-5	-3	-2
34	-99	-9	-3	0	2	4	5	6	6	7	7	7	6	6	5	4	3	2	0	-2	-5	-8	-12	-18	-32	-28	-23	-23	-28	-35	-20	-14	-10	-8	-6	-4	-3
35	-99	-10	-4	-1	1	3	4	5	5	6	6	6	5	5	4	3	2	1	-1	-3	-5	-9	-13	-19	-33	-29	-24	-24	-29	-35	-21	-15	-11	-8	-6	-4	-3
36	-99	-11	-5	-2	0	2	3	4	4	5	5	5	4	4	3	2	1	0	-2	-4	-6	-10	-14	-20	-34	-30	-25	-25	-30	-36	-22	-16	-12	-9	-7	-5	-4
37	-99	-13	-7	-3	-1	1	2	3	3	3	4	3	3	3	2	1	0	-1	-3	-5	-7	-10	-15	-21	-35	-30	-25	-25	-30	-37	-22	-16	-12	-10	-7	-6	-4
38	-99	-14	-8	-5	-2	-1	0	1	2	2	2	2	2	2	1	0	-1	-2	-4	-6	-8	-11	-16	-22	-36	-31	-26	-26	-31	-38	-23	-17	-13	-10	-8	-6	-5
39	-99	-15	-10	-6	-4	-2	-1	0	0	1	1	1	1	0	0	-1	-2	-3	-5	-7	-9	-13	-17	-23	-37	-32	-27	-27	-32	-38	-24	-18	-14	-11	-9	-7	-6
40	-99	-17	-11	-8	-6	-4	-3	-2	-1	-1	-1	-1	-1	-1	-2	-3	-4	-5	-6	-8	-11	-14	-18	-24	-38	-33	-28	-28	-33	-39	-25	-19	-15	-12	-9	-8	-6
41	-99	-19	-13	-10	-8	-6	-5	-4	-3	-3	-2	-2	-2	-3	-3	-4	-5	-6	-8	-10	-12	-15	-19	-25	-39	-34	-29	-29	-34	-40	-26	-19	-15	-12	-10	-8	-7
42	-99	-21	-15	-12	-10	-8	-7	-6	-5	-5	-4	-4	-4	-5	-5	-6	-7	-8	-9	-11	-13	-16	-20	-26	-40	-35	-30	-30	-35	-41	-27	-20	-16	-13	-11	-9	-8
43	-99	-24	-18	-15	-13	-11	-9	-8	-8	-7	-7	-7	-7	-7	-7	-8	-8	-10	-11	-13	-15	-18	-22	-28	-41	-37	-31	-31	-36	-42	-27	-21	-17	-14	-12	-10	-8
44	-99	-28	-22	-19	-16	-14	-13	-12	-11	-10	-10	-9	-9	-9	-9	-10	-11	-12	-13	-14	-17	-19	-23	-29	-43	-38	-33	-32	-37	-43	-29	-22	-18	-15	-13	-11	-9
45	-99	-34	-28	-24	-22	-20	-18	-16	-15	-14	-14	-13	-13	-12	-12	-13	-13	-14	-15	-17	-19	-21	-25	-31	-44	-39	-34	-34	-38	-44	-30	-23	-19	-16	-14	-12	-10
46	-99	-54	-46	-40	-36	-32	-29	-26	-23	-21	-20	-19	-18	-17	-16	-16	-16	-17	-18	-19	-21	-23	-27	-33	-46	-41	-36	-35	-40	-46	-31	-24	-20	-17	-15	-13	-11
47	-99	-37	-32	-29	-27	-27	-27	-29	-31	-38	-48	-33	-28	-25	-23	-22	-21	-21	-21	-22	-24	-26	-29	-35	-48	-43	-37	-37	-41	-47	-32	-26	-21	-18	-16	-14	-12
48	-99	-31	-25	-22	-20	-19	-19	-19	-19	-20	-22	-24	-27	-33	-54	-36	-30	-28	-27	-27	-28	-29	-32	-37	-50	-45	-39	-39	-43	-49	-34	-27	-23	-19	-17	-15	-13
49	-99	-28	-22	-19	-17	-16	-15	-15	-15	-15	-16	-17	-19	-21	-24	-27	-33	-49	-41	-35	-34	-34	-36	-41	-53	-48	-41	-41	-45	-50	-35	-28	-24	-20	-18	-16	-14
50	-99	-26	-20	-17	-15	-13	-13	-12	-12	-12	-13	-14	-15	-16	-18	-21	-24	-27	-33	-42	-56	-44	-43	-46	-57	-51	-44	-43	-47	-52	-37	-30	-25	-22	-19	-17	-15
51	-99	-24	-19	-15	-13	-12	-11	-11	-10	-10	-11	-11	-12	-14	-15	-17	-19	-22	-26	-30	-36	-46	-78	-55	-63	-55	-48	-46	-49	-54	-39	-32	-27	-23	-20	-18	-16
52	-99	-23	-18	-14	-12	-11	-10	-9	-9	-9	-9	-10	-11	-12	-13	-15	-17	-19	-22	-26	-30	-36	-44	-57	-86	-64	-53	-50	-53	-57	-41	-34	-29	-25	-22	-19	-17
53	-99	-23	-17	-14	-11	-10	-9	-8	-8	-8	-8	-9	-10	-11	-12	-13	-15	-18	-20	-23	-27	-32	-38	-47	-66	-71	-66	-57	-57	-60	-44	-36	-31	-27	-23	-21	-18
54	-99	-22	-16	-13	-11	-9	-8	-8	-7	-7	-8	-8	-9	-10	-11	-12	-14	-16	-19	-22	-25	-30	-35	-43	-60	-59	-60	-96	-65	-65	-47	-39	-33	-29	-25	-22	-20
55	-99	-22	-16	-13	-10	-9	-8	-7	-7	-7	-7	-8	-8	-9	-10	-12	-13	-15	-18	-20	-24	-28	-33	-41	-57	-55	-53	-57	-74	-75	-53	-43	-36	-31	-27	-24	-21
56	-99	-21	-16	-12	-10	-9	-8	-7	-7	-7	-7	-7	-8	-9	-10	-11	-13	-14	-17	-19	-23	-27	-32	-39	-55	-52	-49	-52	-61	-76	-65	-48	-40	-34	-29	-26	-23
57	-99	-21	-15	-12	-10	-8	-7	-7	-6	-6	-6	-7	-7	-8	-9	-11	-12	-14	-16	-19	-22	-26	-31	-38	-53	-50	-47	-49	-57	-67	-60	-63	-45	-37	-32	-28	-25
58	-99	-21	-15	-12	-10	-8	-7	-7	-6	-6	-6	-7	-7	-8	-9	-10	-12	-14	-16	-18	-21	-25	-30	-37	-52	-49	-45	-47	-54	-63	-52	-53	-61	-43	-36	-31	-27
59	-99	-21	-15	-12	-10	-8	-7	-7	-6	-6	-6	-7	-7	-8	-9	-10	-12	-13	-15	-18	-21	-25	-30	-37	-51	-48	-44	-46	-52	-61	-49	-47	-50	-58	-41	-34	-29
60	-99	-21	-15	-12	-10	-8	-7	-7	-6	-6	-6	-7	-7	-8	-9	-10	-11	-13	-15	-18	-21	-24	-29	-36	-51	-47	-43	-45	-51	-59	-47	-43	-43	-48	-52	-39	-32

Figure 7. Power gain for HRS 4/6/0.5 curtain array antenna with mode 10 excitation, horizontal slew = 0, designed at 8.75 MHz, and operated at 6.07 MHz.

Takeoff Angle

Azim	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36
0					16		19				20			19			16			10	7	4													4		
1																																					
2																																					
3								19					19																								
4																																					
5																																					
6			10																															1			
7		4										19																									
8				13					19							16																					
9										19	19							13																		4	
10																																					
11																																					
12						16																															
13															16																						
14																			10																		
15																																					4
16							16							16			13																				
17					13															7		1													1		
18		1	7					16					16								4																
19				10					16	16	16	16				13																					
20																		10																			
21						13																															
22															13																					1	
23							13							13			10		7																		
24			4		10			13												4																	
25				7					13			13	13								1																
26						10				13	13					10		7																			1
27															10																						
28					7		10												4																		
29			1					10					10	10			7																				
30				4					10	10	10	10				7				1																	
31						7												4																			
32					4		7								7																						
33				1				7	7				7	7			4		1																		
34						4				7	7	7				4																					
35					1		4								4			1																			
36								4	4				4	4			1																				
37						1					4					1																					
38								1							1																						
39										1	1	1	1																								
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Figure 8. Power gain for HRS 4/6/0.5 curtain array antenna with mode 10 excitation, horizontal slew = 0, designed at 8.75 MHz, and operated at 6.07 MHz.

Takeoff Angle

Azim	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36
0	***	***	***	***	***	***	***	***	***	***	***	***	***	***	***	***	***	***	***	***	***	***	***	***	***	***	***	***	***	***	***	***	***	***	***	***	***
1	***	-16	-10	-7	-5	-4	-4	-4	-4	-5	-6	-8	-11	-14	-18	-24	-35	-42	-36	-42	-38	-28	-23	-20	-18	-17	-16	-16	-16	-17	-19	-21	-24	-28	-36	-52	-36
2	***	-10	-4	-1	1	2	2	2	2	1	0	-2	-4	-8	-12	-18	-29	-36	-30	-35	-32	-22	-17	-14	-12	-10	-10	-10	-10	-11	-12	-15	-18	-22	-30	-46	-30
3	***	-6	0	3	4	6	6	6	6	5	3	2	-1	-4	-8	-14	-25	-32	-26	-32	-29	-18	-13	-10	-8	-7	-6	-6	-6	-7	-9	-11	-14	-18	-26	-42	-26
4	***	-3	2	5	7	8	9	9	8	7	6	4	2	-1	-5	-11	-22	-29	-23	-29	-26	-15	-10	-7	-5	-4	-3	-3	-4	-5	-6	-8	-11	-16	-23	-39	-23
5	***	-1	4	7	9	10	11	11	10	9	8	6	4	1	-3	-9	-20	-27	-21	-27	-24	-13	-8	-5	-3	-2	-1	-1	-2	-3	-4	-6	-9	-14	-21	-37	-21
6	***	0	6	9	11	12	12	12	12	11	10	8	6	3	-2	-8	-19	-25	-20	-25	-22	-12	-7	-3	-1	0	0	0	0	-1	-2	-5	-8	-12	-20	-36	-20
7	***	2	7	10	12	13	14	14	13	13	11	9	7	4	0	-6	-17	-24	-18	-24	-21	-10	-5	-2	0	1	2	2	1	0	-1	-3	-6	-10	-18	-34	-18
8	***	3	9	12	14	15	15	15	15	14	12	11	8	5	1	-5	-16	-23	-17	-23	-20	-9	-4	-1	1	2	3	3	3	2	0	-2	-5	-9	-17	-33	-17
9	***	4	10	13	15	16	16	16	16	15	14	12	9	6	2	-4	-15	-22	-16	-22	-18	-8	-3	0	2	3	4	4	4	3	1	-1	-4	-8	-16	-32	-16
10	***	5	11	14	15	17	17	17	17	16	14	13	10	7	3	-3	-14	-21	-15	-21	-18	-7	-2	1	3	4	5	5	5	4	2	0	-3	-7	-15	-31	-15
11	***	6	11	14	16	17	18	18	17	17	15	13	11	8	4	-2	-13	-20	-14	-20	-17	-6	-1	2	4	5	6	6	5	5	3	1	-2	-6	-14	-30	-14
12	***	6	12	15	17	18	19	19	18	17	16	14	12	9	5	-2	-12	-19	-13	-19	-16	-5	0	3	5	6	7	7	6	5	4	2	-1	-6	-13	-30	-13
13	***	7	13	16	18	19	19	19	19	18	17	15	12	9	5	-1	-12	-19	-13	-19	-15	-5	0	3	5	7	7	7	7	6	4	2	-1	-5	-13	-29	-13
14	***	8	13	16	18	19	20	20	19	18	17	15	13	10	6	0	-11	-18	-12	-18	-15	-4	1	4	6	7	8	8	7	7	5	3	0	-4	-12	-28	-12
15	***	8	14	17	19	20	20	20	20	19	18	16	14	10	6	0	-11	-18	-12	-17	-14	-4	1	4	6	8	8	8	8	7	6	3	1	-4	-12	-28	-12
16	***	9	14	17	19	20	21	21	20	19	18	16	14	11	7	1	-10	-17	-11	-17	-14	-3	2	5	7	8	9	9	8	8	6	4	1	-3	-11	-27	-11
17	***	9	15	18	20	21	21	21	21	20	19	17	14	11	7	1	-10	-17	-11	-17	-13	-3	2	5	7	9	9	9	9	8	6	4	1	-3	-11	-27	-11
18	***	9	15	18	20	21	21	21	21	20	19	17	15	12	7	1	-10	-16	-10	-16	-13	-2	3	6	8	9	10	10	9	8	7	5	2	-3	-10	-26	-10
19	***	10	15	18	20	21	22	22	21	20	19	17	15	12	8	2	-9	-16	-10	-16	-13	-2	3	6	8	9	10	10	10	9	7	5	2	-2	-10	-26	-10
20	***	10	15	19	20	21	22	22	22	21	19	18	15	12	8	2	-9	-16	-10	-16	-12	-2	3	6	8	10	10	10	10	9	7	5	2	-2	-10	-26	-10
21	***	10	16	19	21	22	22	22	22	21	20	18	15	12	8	2	-9	-16	-10	-16	-12	-2	3	7	9	10	10	11	10	9	8	6	3	-2	-9	-25	-9
22	***	10	16	19	21	22	22	22	22	21	20	18	16	12	8	2	-9	-15	-9	-15	-12	-2	4	7	9	10	11	11	10	9	8	6	3	-1	-9	-25	-9
23	***	10	16	19	21	22	22	22	22	21	20	18	16	13	8	2	-8	-15	-9	-15	-12	-1	4	7	9	10	11	11	10	10	8	6	3	-1	-9	-25	-9
24	***	10	16	19	21	22	22	22	22	21	20	18	16	13	9	3	-8	-15	-9	-15	-12	-1	4	7	9	10	11	11	11	10	8	6	3	-1	-9	-25	-9
25	***	10	16	19	21	22	23	23	22	21	20	18	16	13	9	3	-8	-15	-9	-15	-12	-1	4	7	9	10	11	11	11	10	8	6	3	-1	-9	-25	-9
26	***	10	16	19	21	22	23	23	22	21	20	18	16	13	9	3	-8	-15	-9	-15	-12	-1	4	7	9	10	11	11	11	10	9	6	4	-1	-8	-25	-8
27	***	10	16	19	21	22	23	23	22	21	20	18	16	13	9	3	-8	-15	-9	-15	-12	-1	4	7	9	10	11	11	11	10	9	7	4	-1	-8	-24	-8
28	***	10	16	19	21	22	22	22	22	21	20	18	16	13	9	3	-8	-15	-9	-15	-12	-1	4	7	9	10	11	11	11	10	9	7	4	-1	-8	-24	-8
29	***	10	16	19	21	22	22	22	22	21	20	18	16	13	9	3	-8	-15	-9	-15	-12	-1	4	7	9	10	11	11	11	10	9	7	4	-1	-8	-24	-8
30	***	10	16	19	21	22	22	22	22	21	20	18	16	13	8	2	-8	-15	-9	-15	-12	-1	4	7	9	10	11	11	11	10	9	7	4	-1	-8	-24	-8
31	***	10	16	19	20	22	22	22	22	21	20	18	16	12	8	2	-9	-15	-9	-15	-12	-1	4	7	9	10	11	11	11	10	9	7	4	-1	-8	-24	-8
32	***	10	15	18	20	21	22	22	22	21	19	18	15	12	8	2	-9	-16	-10	-15	-12	-1	4	7	9	10	11	11	11	10	8	6	4	-1	-8	-24	-8
33	***	9	15	18	20	21	22	22	21	20	19	17	15	12	8	2	-9	-16	-10	-16	-12	-2	4	7	9	10	11	11	11	10	8	6	3	-1	-8	-24	-8
34	***	9	15	18	20	21	21	21	21	20	19	17	15	12	8	2	-9	-16	-10	-16	-12	-2	3	7	9	10	11	11	10	10	8	6	3	-1	-8	-25	-8
35	***	9	15	18	20	21	21	21	21	20	19	17	15	12	7	2	-9	-16	-10	-16	-13	-2	3	6	8	10	10	11	10	10	8	6	3	-1	-9	-25	-8
36	***	9	14	17	19	20	21	21	21	20	18	17	14	11	7	1	-10	-16	-10	-16	-13	-2	3	6	8	10	10	10	10	9	8	6	3	-1	-9	-25	-9
37	***	8	14	17	19	20	21	21	20	19	18	16	14	11	7	1	-10	-17	-11	-16	-13	-2	3	6	8	9	10	10	10	9	8	6	3	-1	-9	-25	-9
38	***	8	14	17	19	20	20	20	20	19	18	16	14	11	7	1	-10	-17	-11	-17	-13	-3	2	6	8	9	10	10	10	9	8	6	3	-1	-9	-25	-9
39	***	7	13	16	18	19	20	20	19	19	17	16	13	10	6	0	-11	-17	-11	-17	-14	-3	2	5	7	9	10	10	9	9	7	5	3	-2	-9	-25	-9
40	***	7	13	16	18	19	19	19	19	18	17	15	13	10	6	0	-11	-18	-12	-17	-14	-3	2	5	7	9	9	10	9	8	7	5	2	-2	-9	-25	-9
41	***	7	12	15	17	18	19	19	19	18	17	15	13	10	5	0	-11	-18	-12	-18	-14	-4	1	5	7	8	9	9	9	8	7	5	2	-2	-10	-26	-9
42	***	6	12	15	17	18	18	19	18	17	16	14	12	9	5	-1	-12	-18	-12	-18	-15	-4	1	4	7	8	9	9	9	8	7	5	2	-2	-10	-26	-10
43	***	6	11	14	16	17	18	18	18	17	16	14	12	9	5	-1	-12	-19	-13	-19	-15	-4	1	4	6	8	8	9	8	8	6	4	2	-3	-10	-26	-10
44	***	5	11	14	16	17	17	17	17	16	15	13	11	8	4	-2	-13	-19	-13	-19	-16	-5	0	4	6	7	8	8	8	7	6	4	1	-3	-10	-26	-10
45	***	5	10	13	15	16	17	17	17	16	15	13	11	8	4	-2	-13	-20	-14	-19	-16	-5	0	3	5	7	8	8	8	7	6	4	1	-3	-11	-27	-10
46	***	4	10	13	15	16	16	16	16	15	14	12	10	7	3	-3	-14	-20	-14	-20	-17	-6	-1	3	5	6	7	7	7	6	5	3	1	-4	-11	-27	-11
47	***	3	9	12	14	15	16	16	15	15	13	12	9	7	2	-3	-14	-21	-15	-20	-17	-6	-1	2	4	6	7	7	7	6	5	3	0	-4	-11	-27	-11
48	***	3	8	11	13	14	15	15	15	14	13	11	9	6	2	-4	-15	-21	-15	-21	-18	-7	-2	2	4	5	6	7	6	6	4	3	0	-4	-12	-28	-11
49	***	2	8	11	13	14	14	14	14	13	12	10	8	5	1	-5	-15	-22	-16	-22	-18	-7	-2	1	3	5	6	6	6	5	4	2	-1	-5	-12	-28	-12
50	***	1	7	10	12	13	14	14	13	13	11	10	8	5	1	-5	-16	-23	-17	-22	-19	-8	-3	1	3	4	5	6	5	5	4	2	-1	-5	-12	-28	-12
51	***	0	6	9	11	12	13	13	13	12	11	9	7	4	0	-6	-17	-23	-17	-23	-19	-8	-3	0	2	4	5	5	5	4	3	1	-1	-5	-13	-29	-12
52	***	0	5	9	10	12	12	12	12	11	10	8	6	3	-1	-7	-17	-24	-18	-23	-20	-9	-4	0	2	3	4	5	4	4	3	1	-2	-6	-13	-29	-13
53	***	-1	5	8	10	11	11	11	11	10	9	8	5	3	-1	-7	-18	-25	-18	-24	-21	-10	-4	-1	1	3	4	4	4	3	2	0	-2	-6	-14	-30	-13
54	***	-2	4	7	9	10	10	11	10	10	8	7	5	2	-2	-8	-19	-25	-19	-25	-21	-10	-5	-2	1	2	3	4	3	3	2	0	-3	-7	-14	-30	-14
55	***	-3	3	6	8	9	10	10	9	9	8	6	4	1	-3	-9	-19	-26	-20	-25	-22	-11	-6	-2	0	2	3	3	3	2	1	-1	-3	-7	-15	-30	-14
56	***	-4	2	5	7	8	9	9	9	8	7	5	3	0	-4	-10	-20	-27	-21	-26	-23	-12	-6	-3	-1	1	2	2	2	2	1	-1	-4	-8	-15	-31	-14
57	***	-5	1	4	6	7	8	8	8	7	6	4	2	-1	-5	-10	-21	-28	-21	-27	-23	-12	-7	-4	-1	0	1	2	2	1	0	-2	-4	-8	-16	-31	-15
58	***	-6	0	3	5	6	7	7	7	6	5	3	1	-2	-5	-11	-22	-28	-22	-28	-24	-13	-8	-4	-2	0	1	1	1	1	0	-2	-5	-9	-16	-32	-15
59	***	-7	-1	2	4	5	6	6	6	5	4	2	0	-3	-6	-12	-23	-29	-23	-28	-25	-14	-8	-5	-3	-1	0	1	1	0	-1	-3	-5	-9	-17	-32	-16
60	***	-8	-2	1	3	4	5	5	5	4	3	1	-1	-3	-7	-13	-24	-30	-24	-29	-26	-15	-9	-6	-3	-2	-1	0	0	-1	-2	-3	-6	-10	-17	-33	-16

Figure 9. Power gain for HRS 4/6/0.5 curtain array antenna with mode 10 excitation, horizontal slew = 30 degrees, designed and operated at 8.75 MHz.

Takeoff Angle

Azim	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36
0																																					
1																																					
2					1					1																											
3					4																																
4					7					7		4																									
5			4	7		10			10				4	1																							
6											10																										
7			7	10		13			13	13			7	4												1			1								
8															1										1												
9		4	10	13		16	16	16	16																		4	4	4		1						
10										16			10	7										1		4				4							
11					16							13			4										4							1					
12											16																										
13		7					19	19																			7	7			4						
14			13	16		19			19				13													7			7								
15														10									1	4						7							
16					19					19		16																									
17																									7							4	1				
18															7	1																					
19																																					
20											19																	10			7						
21																											10										
22																																					
23																													10								
24							22	22																													
25																																					
26																																					
27																																					
28																																					
29																																					
30		10	16	19		22	22	22	22				16	13									4	7		10				10		7	4				
31																																					
32											19																										
33																																					
34																													10								
35															7												10										
36					19											1												10									
37										19		16																									
38																																					
39		7	13	16		19			19				13	10											7						7						
40							19	19																													
41																							1														
42											16													4													
43					16																											4					
44										16		13			4											7				7			1				
45			10	13		16																															
46		4					16	16	16				10	7													7	7	7								
47											13														4												
48					13																										4						
49										13		10			1									1													
50		1	7	10		13			13																	4											
51							13	13					7	4																4		1					
52					10						10																4		4								
53										10															1			4									
54			4	7		10	10		10			7																									
55								10					4	1																	1						
56					7						7															1											
57			1	4		7				7		4															1			1							
58							7	7	7				1															1	1								
59					4						4																										
60				1		4				4		1																									

Figure 10. Power gain for HRS 4/6/0.5 curtain array antenna with mode 10 excitation, horizontal slew = 30 degrees, designed and operated at 8.75 MHz.

Takeoff Angle

Azim	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36
0	***	9	14	17	19	20	20	20	19	18	16	13	9	2	-10	-13	-13	-12	1	8	12	15	17	18	19	20	20	20	19	18	17	15	12	8	1	-15	2
1	***	9	14	17	19	20	20	20	19	18	16	13	9	2	-10	-13	-13	-12	1	8	12	15	17	18	19	20	20	20	19	18	17	15	12	8	1	-15	2
2	***	9	14	17	19	20	20	20	19	18	16	13	9	2	-10	-13	-13	-12	1	8	12	15	17	18	19	20	20	20	19	18	17	15	12	8	1	-15	2
3	***	9	14	17	19	20	20	20	19	18	15	13	8	2	-10	-14	-13	-12	1	8	12	15	17	18	19	20	20	20	19	18	17	15	12	8	1	-15	2
4	***	8	14	17	19	20	20	20	19	17	15	12	8	2	-10	-14	-13	-12	1	7	12	15	17	18	19	20	20	20	19	18	17	15	12	8	1	-15	2
5	***	8	14	17	19	20	20	19	19	17	15	12	8	2	-10	-14	-13	-13	1	7	11	14	16	18	19	20	20	20	19	18	17	15	12	8	1	-15	2
6	***	8	14	17	18	19	20	19	18	17	15	12	8	2	-11	-14	-13	-13	1	7	11	14	16	18	19	19	20	19	19	18	16	14	12	8	0	-15	2
7	***	8	14	16	18	19	19	19	18	17	15	12	8	1	-11	-14	-14	-13	1	7	11	14	16	18	19	19	19	19	19	18	16	14	12	7	0	-15	1
8	***	8	13	16	18	19	19	19	18	17	14	12	7	1	-11	-15	-14	-13	0	7	11	14	16	17	18	19	19	19	18	17	16	14	11	7	0	-16	1
9	***	7	13	16	18	18	19	18	18	16	14	11	7	1	-11	-15	-14	-13	0	6	10	13	16	17	18	19	19	19	18	17	16	14	11	7	0	-16	1
10	***	7	13	16	17	18	18	18	17	16	14	11	7	1	-12	-15	-14	-14	0	6	10	13	15	17	18	18	19	18	18	17	16	14	11	7	0	-16	1
11	***	6	12	15	17	18	18	18	17	15	13	11	6	0	-12	-16	-15	-14	-1	6	10	13	15	16	17	18	18	18	18	17	15	13	11	6	-1	-16	1
12	***	6	12	15	16	17	18	17	16	15	13	10	6	0	-13	-16	-15	-15	-1	5	9	12	14	16	17	18	18	18	17	16	15	13	10	6	-1	-17	0
13	***	5	11	14	16	17	17	17	16	15	12	10	5	-1	-13	-16	-16	-15	-2	5	9	12	14	16	17	17	17	17	17	16	14	13	10	6	-1	-17	0
14	***	5	11	14	15	16	16	16	15	14	12	9	5	-1	-14	-17	-16	-16	-2	4	8	11	14	15	16	17	17	17	16	15	14	12	9	5	-2	-17	0
15	***	4	10	13	15	16	16	16	15	13	11	8	4	-2	-14	-18	-17	-16	-3	4	8	11	13	15	16	16	17	16	16	15	14	12	9	5	-2	-18	-1
16	***	4	9	12	14	15	15	15	14	13	11	8	4	-2	-15	-18	-17	-17	-3	3	7	10	12	14	15	16	16	16	15	14	13	11	9	5	-3	-18	-1
17	***	3	9	12	13	14	14	14	13	12	10	7	3	-3	-16	-19	-18	-17	-4	3	7	10	12	13	15	15	15	15	15	14	13	11	8	4	-3	-19	-2
18	***	2	8	11	12	13	14	13	13	11	9	6	2	-4	-16	-20	-19	-18	-5	2	6	9	11	13	14	15	15	15	14	13	12	10	8	4	-4	-19	-2
19	***	1	7	10	12	12	13	12	12	10	8	5	1	-5	-17	-20	-20	-19	-5	1	5	8	10	12	13	14	14	14	14	13	11	10	7	3	-4	-20	-3
20	***	0	6	9	11	11	12	12	11	9	7	5	0	-6	-18	-21	-21	-20	-6	0	4	7	10	11	12	13	13	13	13	12	11	9	6	2	-5	-20	-3
21	***	-1	5	8	9	10	11	10	10	8	6	3	-1	-7	-19	-22	-22	-21	-7	-1	4	7	9	10	12	12	13	13	12	11	10	8	6	2	-5	-21	-4
22	***	-2	4	7	8	9	9	9	8	7	5	2	-2	-8	-20	-23	-23	-22	-8	-2	3	6	8	9	11	11	12	12	11	10	9	7	5	1	-6	-22	-5
23	***	-4	2	5	7	8	8	8	7	6	4	1	-3	-9	-21	-25	-24	-23	-9	-3	1	4	7	8	10	10	11	11	10	10	8	7	4	0	-7	-22	-5
24	***	-5	1	4	5	6	7	6	6	4	2	0	-4	-11	-23	-26	-25	-24	-11	-4	0	3	6	7	9	9	10	10	9	9	7	6	3	-1	-8	-23	-6
25	***	-7	-1	2	3	4	5	5	4	3	1	-2	-6	-12	-24	-28	-27	-26	-12	-6	-1	2	4	6	7	8	9	9	8	8	6	5	2	-2	-9	-24	-7
26	***	-9	-4	-1	1	2	3	2	2	0	-1	-4	-8	-14	-26	-29	-28	-28	-14	-7	-3	0	3	5	6	7	7	7	7	6	5	4	1	-3	-10	-25	-8
27	***	-12	-6	-3	-1	0	0	0	-1	-2	-4	-7	-10	-16	-28	-32	-30	-30	-16	-9	-5	-1	1	3	4	5	6	6	6	5	4	2	0	-4	-11	-26	-9
28	***	-16	-10	-7	-5	-4	-4	-4	-4	-5	-7	-10	-13	-19	-31	-34	-33	-32	-18	-11	-7	-3	-1	1	3	4	4	4	4	4	3	1	-1	-5	-12	-27	-10
29	***	-22	-16	-13	-11	-10	-9	-9	-10	-10	-12	-14	-18	-23	-35	-38	-36	-35	-21	-14	-9	-6	-3	-1	0	2	2	3	3	2	1	0	-3	-6	-13	-28	-11
30	***	-70	-51	-41	-34	-29	-26	-24	-22	-21	-22	-23	-25	-30	-41	-44	-42	-40	-26	-18	-13	-9	-6	-4	-2	-1	0	0	1	0	-1	-2	-4	-8	-14	-29	-12
31	***	-23	-18	-15	-13	-13	-13	-14	-16	-19	-22	-28	-35	-47	-77	-61	-54	-50	-33	-25	-19	-14	-11	-8	-6	-4	-3	-2	-2	-2	-3	-4	-6	-9	-16	-31	-14
32	***	-18	-12	-9	-8	-7	-7	-7	-9	-11	-13	-17	-22	-29	-42	-47	-49	-51	-42	-47	-37	-26	-19	-15	-12	-9	-7	-6	-5	-5	-5	-6	-8	-11	-18	-33	-15
33	***	-14	-9	-6	-4	-4	-3	-4	-5	-7	-9	-12	-17	-24	-37	-41	-41	-41	-29	-24	-22	-22	-25	-34	-28	-19	-15	-12	-10	-9	-9	-9	-11	-14	-20	-35	-17
34	***	-12	-7	-4	-2	-1	-1	-2	-3	-4	-7	-10	-14	-21	-34	-38	-37	-37	-25	-19	-16	-14	-14	-14	-16	-19	-27	-31	-20	-16	-14	-14	-15	-17	-23	-37	-19
35	***	-11	-5	-2	-1	0	0	0	-1	-3	-5	-8	-12	-19	-32	-35	-35	-35	-22	-16	-13	-10	-9	-9	-9	-10	-12	-15	-20	-33	-28	-22	-20	-22	-27	-40	-22
36	***	-10	-4	-1	0	1	1	1	0	-2	-4	-7	-11	-18	-30	-34	-33	-33	-20	-14	-10	-8	-7	-6	-6	-6	-7	-9	-11	-15	-20	-29	-40	-30	-33	-45	-25
37	***	-9	-3	0	1	2	2	2	1	-1	-3	-6	-10	-17	-29	-33	-32	-32	-19	-13	-9	-6	-5	-4	-3	-4	-4	-5	-7	-9	-13	-17	-23	-34	-54	-54	-31
38	***	-9	-3	0	2	3	3	2	2	0	-2	-5	-9	-16	-28	-32	-31	-31	-18	-12	-8	-5	-3	-2	-2	-2	-2	-3	-5	-7	-9	-13	-17	-24	-35	-58	-48
39	***	-8	-2	1	2	3	3	3	2	1	-2	-5	-9	-15	-28	-31	-31	-30	-17	-11	-7	-4	-2	-1	-1	-1	-1	-2	-3	-5	-7	-10	-14	-20	-29	-47	-35
40	***	-8	-2	1	3	3	4	3	2	1	-1	-4	-8	-15	-27	-31	-30	-30	-16	-10	-6	-4	-2	-1	0	0	0	-1	-2	-3	-5	-8	-12	-17	-26	-43	-28
41	***	-8	-2	1	3	4	4	4	3	1	-1	-4	-8	-14	-27	-30	-30	-29	-16	-10	-6	-3	-1	0	1	1	1	0	-1	-2	-4	-7	-10	-15	-23	-40	-25
42	***	-7	-2	1	3	4	4	4	3	1	-1	-4	-8	-14	-27	-30	-29	-29	-16	-9	-5	-3	-1	1	1	2	2	1	0	-1	-3	-6	-9	-14	-22	-38	-23
43	***	-7	-2	1	3	4	4	4	3	1	-1	-4	-8	-14	-27	-30	-29	-29	-15	-9	-5	-2	0	1	2	2	2	2	1	-1	-2	-5	-8	-13	-21	-37	-21
44	***	-8	-2	1	3	4	4	4	3	1	-1	-4	-8	-14	-27	-30	-29	-29	-15	-9	-5	-2	0	1	2	2	2	2	1	0	-2	-4	-7	-12	-20	-36	-20
45	***	-8	-2	1	3	4	4	4	3	1	-1	-4	-8	-14	-27	-30	-29	-29	-15	-9	-5	-2	0	1	2	3	3	2	1	0	-1	-4	-7	-11	-19	-35	-19
46	***	-8	-2	1	2	3	4	3	3	1	-1	-4	-8	-14	-27	-30	-29	-29	-15	-9	-5	-2	0	1	2	3	3	2	2	1	-1	-3	-6	-11	-19	-35	-18
47	***	-8	-2	1	2	3	3	3	2	1	-1	-4	-8	-14	-27	-30	-29	-29	-15	-9	-5	-2	0	1	2	3	3	3	2	1	-1	-3	-6	-11	-18	-34	-18
48	***	-8	-3	0	2	3	3	3	2	1	-1	-4	-8	-15	-27	-30	-30	-29	-16	-9	-5	-2	0	1	2	3	3	3	2	1	-1	-3	-6	-10	-18	-34	-17
49	***	-9	-3	0	2	2	3	2	2	0	-2	-5	-9	-15	-27	-31	-30	-29	-16	-9	-5	-2	0	1	2	3	3	3	2	1	-1	-3	-6	-10	-18	-34	-17
50	***	-9	-4	-1	1	2	2	2	1	0	-2	-5	-9	-15	-28	-31	-30	-30	-16	-10	-5	-3	0	1	2	3	3	3	2	1	-1	-3	-6	-10	-17	-33	-17
51	***	-10	-4	-1	1	2	2	2	1	-1	-3	-5	-9	-16	-28	-31	-31	-30	-16	-10	-6	-3	-1	1	2	2	3	2	2	1	-1	-3	-6	-10	-17	-33	-17
52	***	-10	-5	-2	0	1	1	1	0	-1	-3	-6	-10	-16	-28	-32	-31	-30	-17	-10	-6	-3	-1	1	2	2	2	2	2	1	-1	-3	-6	-10	-17	-33	-17
53	***	-11	-5	-2	0	1	1	1	0	-2	-4	-6	-10	-17	-29	-32	-31	-31	-17	-11	-6	-3	-1	0	1	2	2	2	1	0	-1	-3	-6	-10	-17	-33	-17
54	***	-11	-6	-3	-1	0	0	0	-1	-2	-4	-7	-11	-17	-29	-33	-32	-31	-18	-11	-7	-4	-2	0	1	2	2	2	1	0	-1	-3	-6	-10	-17	-33	-17
55	***	-12	-6	-3	-2	-1	0	-1	-1	-3	-5	-7	-12	-18	-30	-33	-32	-32	-18	-12	-7	-4	-2	0	1	1	2	1	1	0	-1	-3	-6	-10	-18	-33	-17
56	***	-13	-7	-4	-2	-1	-1	-1	-2	-3	-5	-8	-12	-18	-31	-34	-33	-32	-19	-12	-8	-5	-2	-1	0	1	1	1	1	0	-2	-4	-6	-10	-18	-33	-17
57	***	-14	-8	-5	-3	-2	-2	-2	-3	-4	-6	-9	-13	-19	-31	-34	-33	-33	-19	-13	-8	-5	-3	-1	0	1	1	1	0	-1	-2	-4	-7	-11	-18	-34	-17
58	***	-14	-9	-6	-4	-3	-3	-3	-4	-5	-7	-10	-14	-20	-32	-35	-34	-33	-20	-13	-9	-6	-3	-2	-1	0	0	0	0	-1	-2	-4	-7	-11	-18	-34	-17
59	***	-15	-10	-7	-5	-4	-3	-4	-4	-6	-8	-10	-14	-20	-33	-36	-35	-34	-20	-14	-9	-6	-4	-2	-1	0	0	0	0	-1	-3	-4	-7	-11	-18	-34	-17
60	***	-16	-11	-8	-6	-5	-4	-5	-5	-7	-8	-11	-15	-21	-33	-36	-35	-35	-21	-14	-10	-7	-5	-3	-2	-1	0	0	-1	-2	-3	-5	-7	-11	-19	-34	-17

Figure 11. Power gain for HRS 4/6/0.5 curtain array antenna for mode 5 excitation with horizontal slew = 0, designed and operated at 8.75 MHz.

Takeoff Angle

Azim	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36
0					19				19		16	13							1						19		20		19						1		
1																																					
2																																					
3																																					
4																				7																	
5								19															16														
6						19																				19		19			16						
7				16			19							1													19							7			1
8			13										7																								
9		7								16											10	13															
10																																					
11											13													16								13					
12					16				16			10																		16			10				
13																																					
14						16	16	16												4					16				16								
15		4	10	13						13			4										13			16		16									
16																					7	10					16				13						
17					13				13		10	7												13										4			
18						13		13																						13		10					
19		1	7	10			13			10			1							1			10		13								7				
20											7										4	7				13	13	13	13								
21						10		10	10															10							10						
22			4	7						7																				10		7		1			
23					7				7		4	1									1	4	7		10	10			10				4				
24			1	4			7			4														7			10	10			7						
25						4			4		1												4		7												
26					1																					7	7	7	7			4	1				
27																							1		4						4						
28																								1		4	4	4	4	4		1					
29																															1						
30																													1								
31																																					
32																																					
33																																					
34																																					
35																																					
36						1	1	1																													
37					1				1																												
38																																					
39				1						1																											
40							4																														
41						4		4																	1	1	1										
42																								1				1									
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55																										1		1									
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Figure 12. Power gain for HRS 4/6/0.5 curtain array antenna for mode 5 excitation with horizontal slew = 0, designed and operated at 8.75 MHz.

losses and ground losses. These would make the formulas more complicated and thereby increase the computer time necessary to complete the gain calculations.

6. REFERENCES

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APPENDIX: Source Code for FORTRAN Subroutines GAIN and DBLTRAP, Program CALLGAIN, and Function F2

```
      SUBROUTINE GAIN(XGAIN,FACTOR,IFLAG,THETAD,PHID)
C*****************************************************************
C SUBROUTINE TO CALCULATE THE GAIN OF A CURTAIN ANTENNA ........
C*****************************************************************
C
C       DOCUMENTED IN NTIA REPORT     , N. A. KUESTER
C
C       XGAIN    -  POWER GAIN IN dBi CACLULATED WITHIN THE
C                     SUBROUTINE
C       FACTOR   -  INTEGRATION FACTOR WHICH CAN BE CALCULATED IN
C                     GAIN OR PASSED IN BY THE USER
C       IFLAG    -  FLAG TO DETERMINE IF FACTOR IS TO BE PASSED
C                     INTO GAIN OR CALCULATED WITHIN GAIN
C                     IFLAG = 0, FACTOR IS TO BE CALCULATED
C                     IFLAG = 1, FACTOR IS PASSED IN
C       THETAD   -  ANGLE ABOVE THE HORIZON IN DEGREES
C       PHID     -  ANTENNA BORESIGHT AZIMUTHAL ANGLE IN
C                     DEGREES
C       NOSTAK   -  NUMBER OF (VERTICAL) STACKS
C       STKSPM   -  SPACING BETWEEN STACKS IN METERS
C       NUMBAY   -  NUMBER OF (HORIZONTAL) BAYS
C       BAYSPM   -  SPACING BETWEEN BAYS IN METERS
C       DIPLNM   -  DIPOLE LENGTH IN METERS
C       RRSPM    -  SPACING BETWEEN RADIATORS AND REFLECTING
C                     SCREEN IN METERS
C       STKHTM   -  HEIGHT OF LOWEST STACK IN METERS
C       STKRAT   -  ARRAY CONTAINING THE RELATIVE STACK CURRENT
C                     RATIOS
C       BAYPHS   -  ARRAY CONTAINING THE RELATIVE PHASES OF THE
C                     BAY CURRENTS IN DEGREES
C       BAYRAT   -  ARRAY CONTAINING THE RELATIVE BAY CURRENT
C                     RATIOS
C       OFMHZ    -  ANTENNA OPERATING FREQUENCY IN MEGAHERTZ
C       DFMHZ    -  ANTENNA DESIGN FREQUENCY IN MEGAHERTZ
C
C       THIS SUBROUTINE USES THE SUBROUTINE DBLTRAP
C
      COMMON/CONST/ PI,VOFL,PI2,PIO2,D2R,R2D
      DIMENSION BAYRAT(14),STKRAT(14),BAYPHS(14)
      COMMON/ANTDAT/NOSTAK,STKSPM,NUMBAY,BAYSPM,DIPLNM,RRSPM,
     1  STKHTM,STKRAT,BAYPHS,BAYRAT,OFMHZ,DFMHZ
      COMMON/FWAVE/EIL,XR,C,R,PS,A,Y,Z,WAVE,BETA
      DIMENSION C(8),R(14),PS(14),A(8),Y(14),Z(8)
C CONSTANTS
      WAVE = VOFL /OFMHZ
      BETA = PI2 / WAVE
      EL = DIPLNM * BETA
      Y(1) = 0.0
      H = STKHTM * BETA
      XR = RRSPM * BETA
      DO 30 I = 1,NOSTAK
```

```
          Z(I) = STKSPM * BETA *FLOAT(I-1) + H
          A(I) = 0.0
          C(I) = STKRAT(I)
 30     CONTINUE
        DO 40 I = 1,NUMBAY
           PS(I) = D2R * BAYPHS(I) * OFMHZ / DFMHZ
           R(I) = BAYRAT(I)
           IF (I.EQ.1) GO TO 40
           Y(I) = BETA * FLOAT(i-1) * BAYSPM
  40   CONTINUE
       EIL = EL / 2.0
       IF (IFLAG .GT. 0) GO TO 200
         TSTEPD = 1.0
         PSTEPD = 1.0
         TZD = 0.0
         PZD = -90.0
         TFD = 90.0
         PFD = 90.0
         CALL DBLTRAP(DINTGL,TSTEPD,PSTEPD,TZD,PZD,TFD,PFD)
         FACTOR = 4.0 * PI / DINTGL
 200   CONTINUE
       THETA = THETAD * D2R
       PHI = PHID * D2R
       XGAIN = F2 (THETA,PHI)
       IF (XGAIN . EQ .0.0) XGAIN = 1.E-10
       XGAIN = 10 * ALOG10(ABS(XGAIN * FACTOR))
 901   FORMAT(T1,E9.3,T11,E9.3,T22,E9.3)
 1000  FORMAT(E10.4)
  999  FORMAT(6F7.2)
       RETURN
       END
C*****************************************************************
      SUBROUTINE DBLTRAP(DINTGL,TSTEPD,PSTEPD,TZD,PZD,TFD,PFD)
C*****************************************************************
C     SUBROUTINE TO CALCULATE A DOUBLE INTEGRAL IN THETA AND PHI
C       USING A SIMPLE TRAPIZOIDAL RULE APPROXIATION.  THE
C       INTEGRAND IS CALCULATED IN THE FUNCION F2.
C
C     DINTGL   -  INTEGRATION RESULT CALCULATED IN DBLTRAP
C     TSTEPD   -  THETA STEP SIZE IN DEGREES
C     PSTEPD   -  PHI STEP SIZE IN DEGREES
C     TZD      -  THETA LOWER LIMIT OF INTEGRATION IN DEGREES
C     PZD      -  PHI LOWER LIMIT OF INTEGRATION IN DEGREES
C     TFD      -  THETA UPPER LIMIT OF INTEGRATION IN DEGREES
C     PFD      -  PHI UPPER LIMIT OF INTEGRATION IN DEGREES
C
      EXTERNAL FUNCTION F2
      COMMON/CONST/ PI,VOFL,PI2,PIO2,D2R,R2D
      THETAZ = TZD * D2R
      PHIZ = PZD * D2R
      PSTEP = PSTEPD * D2R
      TSTEP = TSTEPD * D2R
      THETAF = TFD * D2R
```

```
      PHIF = PFD *D2R
      TINT = 0.0
      T = THETAZ
      NTSTEPS = INT(ABS((THETAF - THETAZ) / TSTEP))
      NPSTEPS = INT(ABS((PHIF - PHIZ) / PSTEP))
      DO 80 IP1 = 1,NTSTEPS+1
        I = IP1 - 1
        P = PHIZ + PSTEP
        PINT = 0.0
        DO 90 J = 1,NPSTEPS-1
          PINT = PINT + F2(T,P)
          P = P + PSTEP
   90   CONTINUE
        PINT = PINT * PSTEP
        PINT = PINT + (PSTEP/2.) * (F2(T,P) + F2(T,PHIZ))
        IF (I.EQ.0 .OR. I.EQ.NTSTEPS) GO TO 91
        TINT = TINT + TSTEP * PINT *COS(T)
        GO TO 92
   91   TINT = TINT + TSTEP * PINT * COS(T) / 2.0
   92   CONTINUE
        T = T + TSTEP
   80 CONTINUE
      DINTGL =  TINT
      RETURN
      END
C*****************************************************************
      FUNCTION F2(THETA,PHI)
C*****************************************************************
C
C     FUNCTION TO CALCULATE THE INTEGRAND OF EQUATION (10), NTIA
C       REPORT      , N. A. KUESTER,  FOR USE IN CALCULATING THE
C       GAIN OF CURTAIN ARRAY ANTENNAS.
C
C     THETA  -  TAKEOFF ANGLE IN RADIANS
C     PHI    -  AZIMUTHAL ANGLE IN RADIANS
C     F2     -  RETURNED VALUE OF INTEGRAND
C
      COMPLEX FY, FZTHETA, FZPHI
      COMMON/CONST/ PI,VOFL,PI2,PIO2,D2R,R2D
      COMMON/ANTDAT/NOSTAK,STKSPM,NUMBAY,BAYSPM,DIPLNM,RRSPM,
     1  STKHTM,STKRAT,BAYPHS,BAYRAT,OFMHZ,DFMHZ
      DIMENSION C(8),R(14),PS(14),A(8),Y(14),Z(8)
      COMMON/FWAVE/EIL,XR,C,R,PS,A,Y,Z,WAVE,BETA
      DIMENSION BAYRAT(14),STKRAT(14),BAYPHS(14)
         PHID = PHI * R2D
         THETAD = THETA * R2D
         CPHI = COS(PHI)
         SPHI = SIN(PHI)
         CTHETA = COS(THETA)
         STHETA = SIN(THETA)
         SEIL = SIN(EIL)
         CEIL = COS(EIL)
         CPSI = CTHETA * SPHI
```

```
      SPSI = SQRT(1. - CPSI * CPSI)
      IF( ABS( SPSI ) .LE. 1.0E-6 ) SPSI = 1.0E-6
      EF = (COS(EIL * CPSI) - CEIL) / (SPSI * SPSI)
      FY = CMPLX(0.,0.)
      DO 50 I  = 1,Numbay
      ARG = Y(I) * CTHETA * SPHI + PS(I)
 50   FY = FY + R(I) * CMPLX(COS(ARG),SIN(ARG))
C     IF ANTENNA IS A SINGLE DIPOLE WITH NO REFLECTOR,
C       THEN FX =1.
      IF (XR .GT. 1.E20) THEN
          FX = 1.0
      ELSE
          FX =  SIN( XR * CTHETA * CPHI)
      END IF
      FZPHI = CMPLX(0.,0.)
      DO 60 I =1,nostak
          FZPHI = FZPHI +  C(I) * SIN(Z(i)* STHETA) *
     1                       CMPLX(COS(A(I)),SIN(A(I)))
 60   CONTINUE
      FZTHETA = FZPHI * STHETA * SPHI
      FZPHI = FZPHI * CPHI
      F2 = EF * EF  * FX * FX  *  FY * CONJG(FY)
     1    * (FZTHETA * CONJG(FZTHETA)  +  FZPHI * CONJG(FZPHI))
   RETURN
   END
```

```
C****************************************************************
      BLOCK DATA CONSTANTS
C****************************************************************
      COMMON/CONST/ PI,VOFL,PI2,PIO2,D2R,R2D
      DATA PI,PI2,PIO2 / 3.14159265359, 6.283185308, 1.570796327/
      DATA D2R,R2D,VOFL / .017453293,57.2957795, 2.997925E2/
      END
C****************************************************************
      PROGRAM CALLGAIN
C****************************************************************
C PROGRAM TO USE GAIN SUBROUTINE FOR CURTAIN ANTENNA
C****************************************************************
C
C     INPUT FILE IS DGAIN
C     OUTPUT FILE IS OGAIN
C
C     INPUT VARIABLES ARE INPUT IN THE FOLLOWING ORDER:
C           NOSTAK, NUMBAY    - READ IN USING 2I2 FORMAT
C           STKSTM, BAYSPM, DIPLNM, RRSPM, STKHTM, OFMHZ, DFMHZ
C                             - READ IN USING 7F7.2 FORMAT
C           STKRAT(I)         - READ IN USING F7.2 (NOTE: MUST
C                               INPUT THE NUMBER OF STACKS TIMES)
C           BAYRAT(I), BAYPHS(I)
C                             - READ IN USING 2F7.2 (NOTE: MUST
C                               INPUT THE NUMBER OF BAYS TIMES)
C           PHID, THETAD      - READ IN USING 2F7.2 FORMAT
C
C     XGAIN    -  POWER GAIN IN dBi CACLULATED WITHIN THE
C                   SUBROUTINE
C     FACTOR   -  INTEGRATION FACTOR WHICH CAN BE CALCULATED IN
C                   GAIN OR PASSED IN BY THE USER
C     IFLAG    -  FLAG TO DETERMINE IF FACTOR IS TO BE PASSED
C                   INTO GAIN OR CALCULATED WITHIN GAIN
C                   IFLAG = 0, FACTOR IS TO BE CALCULATED
C                   IFLAG = 1, FACTOR IS PASSED IN
C     THETAD   -  ANGLE ABOVE THE HORIZON IN DEGREES
C     PHID     -  ANTENNA BORESIGHT AZIMUTHAL ANGLE IN
C                   DEGREES
C     NOSTAK   -  NUMBER OF (VERTICAL) STACKS
C     STKSPM   -  SPACING BETWEEN STACKS IN METERS
C     NUMBAY   -  NUMBER OF (HORIZONTAL) BAYS
C     BAYSPM   -  SPACING BETWEEN BAYS IN METERS
C     DIPLNM   -  DIPOLE LENGTH IN METERS
C     RRSPM    -  SPACING BETWEEN RADIATORS AND REFLECTING
C                   SCREEN IN METERS
C     STKHTM   -  HEIGHT OF LOWEST STACK IN METERS
C     STKRAT   -  ARRAY CONTAINING THE RELATIVE STACK CURRENT
C                   RATIOS
C     BAYPHS   -  ARRAY CONTAINING THE RELATIVE PHASES OF THE
C                   BAY CURRENTS IN DEGREES
C     BAYRAT   -  ARRAY CONTAINING THE RELATIVE BAY CURRENT
C                   RATIOS
```

```
C      OFMHZ    -   ANTENNA OPERATING FREQUENCY IN MEGAHERTZ
C      DFMHZ    -   ANTENNA DESIGN FREQUENCY IN MEGAHERTZ
C
       COMMON/CONST/ PI,VOFL,PI2,PIO2,D2R,R2D
       DIMENSION BAYRAT(14),STKRAT(14),BAYPHS(14)
       COMMON/ANTDAT/NOSTAK,STKSPM,NUMBAY,BAYSPM,DIPLNM,RRSPM,
      1  STKHTM,STKRAT,BAYPHS,BAYRAT,OFMHZ,DFMHZ
       OPEN(UNIT=50,FILE='DGAIN',IOSTAT=IOS,ERR=99)
       open(unit=60,file='OGAIN',iostat=ioso,err=98)
       READ(50,998) NOSTAK,NUMBAY
       WRITE(60,997) NOSTAK,NUMBAY
 997   FORMAT(' NOSTAK=',I2,'  NUMBAY=',I2)
 998   FORMAT(3I2)
       READ(50,999)STKSPM,BAYSPM,DIPLNM,RRSPM,STKHTM,OFMHZ,DFMHZ
       WRITE(60,900)STKSPM,BAYSPM,DIPLNM,RRSPM,STKHTM,OFMHZ,DFMHZ
 900   FORMAT('STKSPM=',G10.4,' BAYSPM=',G10.4,' DIPLNM=',G10.4,
      1 ' RRSPM=',G10.4,' STKHTM=',G10.4,' OFMHZ=',G10.4,' DFMHZ='
      2 ,G10.4)
       DO 30 I = 1,NOSTAK
          READ(50,999) STKRAT(I)
          WRITE(60,913) I,STKRAT(I)
 913      FORMAT(' STKRAT(',I2,')=',F7.2)
 30     CONTINUE
        DO 40 I = 1,NUMBAY
           READ(50,999) BAYRAT(I),BAYPHS(I)
           WRITE(60,914) I,BAYRAT(I),I,BAYPHS(I)
 914       FORMAT(' BAYRAT(',I2,')=',F7.2,' BAYPHS(',I2,')=',F7.2)
  40   CONTINUE
       IFLAG = 0
       READ (50,999) PHID,THETAD
       PHI = PHID * D2R
       WRITE(60,902)
       XGAIN = 0.
       CALL GAIN(XGAIN,FACTOR,IFLAG,THETAD,PHID)
       WRITE(60,901) THETAD,PHID,XGAIN
 901   FORMAT(T1,G9.3,T11,G9.3,T22,G9.3,'DB')
 902   FORMAT(T3,'THETA',T15,'PHI',T30,'GAIN')
 1000  FORMAT(E10.4)
  999  FORMAT(7F7.2)
       CLOSE(50)
       CLOSE(60)
  98   write(1,44) ioso
  99   write(1,44) ios
  44   FORMAT(' ERROR ENCOUNTERED ',I6)
       STOP
       END
```

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

An expression for the gain of a curtain array antenna over a perfectly conducting, flat Earth with no mutual impedance between elements is derived in this report. A FORTRAN computer subroutine created to calculate the expression is described here. This subroutine considers interelement spacing and length of the individual elements, the spacing between the radiators and the reflecting screen behind the radiators, the antenna design and operating frequencies, and the number of elements in the array.

16. Key Words *(Alphabetical order, separated by semicolons)*

antenna gain; curtain array antenna; HF broadcast

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