7.6.3 METHOD TO DETERMINE THE OPTIMAL PARAMETERS OF THE ARECIBE 46.8-MHz ANTENNA SYSTEM

H. M. Ierkic, J. Rottger, J. B. Hagen, and R. K. Zimmerman

Arecibo Observatory
P.O. Box 995
Arecibo, Puerto Rico

INTRODUCTION

The spherical reflector at the Arecibo Observatory (AO) offers great advantages for the design of simple and inexpensive high performance steerable antennas at VHF. Light and small feeds have the added benefit that they can be quickly installed in the Arecibo platform causing almost no interruption to other experiments that may be in progress. Acceptable (primary) antennas are, for example, dipoles with reflectors, Yagis, loops etc. It is important to evaluate the performance of any given feed including the effects of the spherical reflector. In this paper, we will emphasize the optimization of two parameters, namely, the distance below the focal point of the reflector and the beam width of a 'point' feed. For the actual design of the feed at 46.8 MHz at the AO we had other requirements (e.g., best performance possible over a 10 MHz bandwidth around the carrier frequency for application in ionospheric modification experiments) independent of MST work. Details on the antenna mounting constraints and a comprehensive description of the new VHF radar can be found in ROTTGER et al. (1986).

DESIGN OF (PRIMARY) ARRAY

Numerical simulation codes were used to facilitate the exhaustive evaluation of the characteristics of the primary feeds, thus facilitating their design. The Numerical Electromagnetic Code (BURKE AND POGIO, 1981) obtains the solution of integral field equations that describe the currents flowing over wires and surfaces that the user has specified. The description of the program and the limitations that the approximations, implicit in the algorithms, create can be found in the reference above.

We modelled several types of feeds and decided on a simple dipole with a reflector. To minimize spillover out of the surface of the reflector by the illuminating feed after installation (for large zenith angles) and also to somewhat improve against clutter from the horizon, we decided to form an array of two feeds side by side separated by about half a wavelength. We call this array a twin Yagi feed. The numerical simulation provided us with the radiation pattern in the E and H planes and the impedance. The dimensions deemed appropriate are 3.8 m for the reflectors, 3.1 m for the driven elements with a separation of 1.5 m and with a radius for all the elements of 1.33 cm. The two antennas composing the array are separated by 3.2 m and fed with a parallel transmission of 100 Ω impedance. The radar system requires 50 Ω for optimum matching.

We summarize the performance of the array in the following table.

Table 1

F (MHz)	Gain (DB)	Beam width E	Beam width H	Impedance (Ω)
42	8.1	75.2	53.1	54 - i37
45	7.8	75.7	57.6	45 - i19
47	7.6	77.7	61.3	43 - i4
49	7.5	79.2	62.0	44 + i11
52	7.4	79.3	61.0	56 + i38

The actual environment where the array is installed in the platform includes the AO 430-MHz line feed. Care was taken to locate the array far enough (out of the Caustic region of influence of the line feed) to avoid interference (ROTTGER et al., 1986). Almost no perturbation of the array performance was found theoretically by modelling the AO feed with a set of wires.

PERFORMANCE OF (PRIMARY) ARRAY WITH THE AO SPHERICAL REFLECTOR

The problem of finding the gain of an antenna in front of a spherical reflector has been treated by many workers; we follow closely the development by CONDON (1969). To simplify the algebra, we assume that the (primary) array main lobe is rotationally symmetric and thus can be characterized by one angle only. This approximation simplifies the algebra and is enough for our purposes.

The far field due to the electric field distribution over an aperture can be written as

$$E(\phi) = 1/\lambda^2 \int_{\text{aperture}} E(x,y) \exp\left(\frac{i2\pi\chi\sin\phi}{\lambda}\right) dx\, dy \tag{1}$$

where

$E(x,y)$ = electric field on the plane immediately above the reflector surface.

χ = path length difference
ϕ = zenith angle

We rewrite this equation in terms of polar coordinates (Figure 1) to take advantage of the rotational symmetry of the radiation pattern.

$$G(\phi) = \left|\frac{2\pi}{\lambda^2} \int_{o}^{rm} E(r)\, J_o\left(\frac{2\pi r}{\lambda} \sin\phi\right) \cos\frac{2\pi\varepsilon}{\lambda}\, r dr\right|^2 \tag{2}$$

$$+ \left|\frac{2\pi}{\lambda 2} \int_{o}^{rm} E(r)\, J_o\left(\frac{2\pi r}{\lambda} \sin\phi\right) \sin\frac{2\pi\varepsilon}{\lambda}\, r dr\right|^2$$

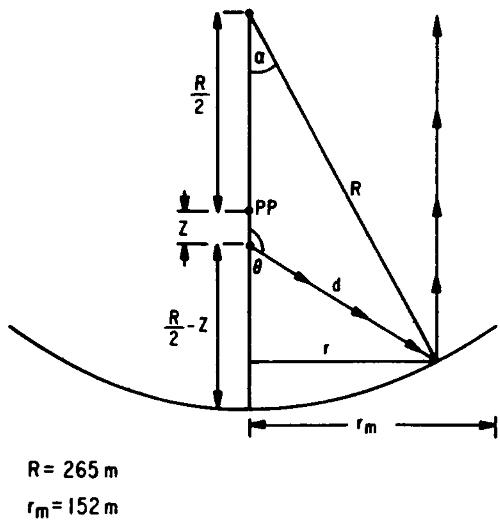

Figure 1. Geometry involved in the computation of the antenna gain (adapted from CONDON, 1969).

where

$\varepsilon(r)$ = path length error of array reflected from a sphere.

r_m = radius of the aperture of the reflecting surface.

Equation (2) can be readily evaluated once the primary antenna pattern is specified since the rest of the quantities depend only on the geometry. Following CONDON (1969), we have assumed that the primary pattern can be fitted with a cosine square type of function. This simplification makes it possible to characterize an antenna by its beam width alone.

Using this procedure, we have computed the values of antenna aperture shown in Table 2 for several beam widths and distances z to the paraxial surface. Note from this table that for the array previously discussed with an average beam width of about 70°, the maximum aperture is 43000 m^2 when $z = 9.3$ m. The radiation diagram corresponding to this antenna is shown in Figure 2. The half-power beam width (found from the figure) is 1.6° with a sidelobe 2.6° off axis suppressed by about 17 dB. For comparison, the figure also shows the diagram for the array in front of a parabolic reflector.

CONCLUSIONS AND FUTURE DEVELOPMENTS

A straightforward procedure has been proposed to design and install simple antennas in the AO platform facing the spherical reflector.

Further work will include relaxation of some of the constraints used in this note (e.g., rotational symmetry, cosine square primary pattern, etc.). We are also planning to design antennas that will allow us to monitor the same scattering volume at two frequencies (i.e., concentrical to the 430-MHz line feed).

Table 2

Antenna aperture (x $10^{-4} m^2$)
Beam width (degrees)

z (meters)

F =	47.0 MHZ										
Z/HPBW	50.0	55.00	60.00	65.00	70.00	75.00	80.00	85.00	90.00	95.00	100.00
0.5	2.60	2.53	2.21	1.96	1.75	1.57	1.41	1.28	1.17	1.07	0.98
0.8	2.64	2.60	2.29	2.03	1.80	1.62	1.45	1.32	1.20	1.10	1.01
1.0	2.68	2.67	2.37	2.09	1.86	1.67	1.50	1.36	1.23	1.13	1.04
1.3	2.71	2.73	2.45	2.16	1.93	1.72	1.55	1.40	1.27	1.16	1.07
1.5	2.75	2.80	2.53	2.24	1.99	1.78	1.60	1.45	1.32	1.20	1.10
1.8	2.78	2.86	2.61	2.31	2.06	1.84	1.66	1.50	1.36	1.25	1.15
2.0	2.81	2.93	2.70	2.39	2.13	1.91	1.72	1.56	1.42	1.29	1.19
2.3	2.83	2.99	2.78	2.47	2.21	1.98	1.78	1.62	1.47	1.35	1.24
2.5	2.86	3.04	2.86	2.55	2.28	2.05	1.85	1.68	1.53	1.40	1.29
2.8	2.88	3.10	2.95	2.64	2.36	2.13	1.93	1.75	1.60	1.47	1.35
3.0	2.90	3.15	3.03	2.72	2.45	2.21	2.00	1.82	1.67	1.53	1.41
3.3	2.91	3.20	3.11	2.81	2.53	2.29	2.08	1.90	1.74	1.61	1.48
3.5	2.93	3.24	3.19	2.90	2.62	2.38	2.17	1.99	1.82	1.68	1.56
3.8	2.93	3.28	3.27	2.98	2.71	2.47	2.26	2.07	1.91	1.76	1.64
4.0	2.94	3.32	3.34	3.07	2.81	2.57	2.36	2.17	2.00	1.85	1.72
4.3	2.95	3.35	3.41	3.16	2.90	2.67	2.45	2.26	2.09	1.94	1.81
4.5	2.95	3.38	3.48	3.25	3.00	2.77	2.56	2.37	2.19	2.04	1.90
4.8	2.94	3.40	3.54	3.33	3.10	2.87	2.66	2.47	2.30	2.14	2.00
5.0	2.94	3.42	3.60	3.42	3.19	2.97	2.77	2.58	2.40	2.24	2.10
5.3	2.93	3.44	3.66	3.50	3.29	3.08	2.88	2.69	2.51	2.35	2.21
5.5	2.92	3.45	3.70	3.58	3.39	3.19	2.99	2.80	2.63	2.46	2.31
5.8	2.91	3.45	3.75	3.66	3.48	3.29	3.10	2.92	2.74	2.58	2.43
6.0	2.89	3.45	3.79	3.73	3.57	3.40	3.21	3.03	2.86	2.69	2.54
6.3	2.87	3.45	3.82	3.80	3.66	3.50	3.33	3.15	2.98	2.81	2.66
6.5	2.85	3.44	3.84	3.86	3.75	3.60	3.44	3.27	3.09	2.93	2.77
6.8	2.83	3.43	3.86	3.92	3.84	3.70	3.55	3.38	3.21	3.05	2.89
7.0	2.80	3.41	3.88	3.97	3.92	3.80	3.66	3.50	3.33	3.16	3.00
7.3	2.77	3.38	3.88	4.02	3.99	3.89	3.76	3.61	3.44	3.28	3.12
7.5	2.74	3.36	3.88	4.06	4.06	3.98	3.86	3.71	3.56	3.39	3.23
7.8	2.71	3.32	3.87	4.09	4.12	4.06	3.96	3.82	3.66	3.50	3.34
8.0	2.68	3.29	3.85	4.12	4.18	4.14	4.05	3.92	3.77	3.61	3.45
8.3	2.64	3.25	3.83	4.13	4.22	4.21	4.13	4.01	3.86	3.71	3.55
8.5	2.60	3.20	3.80	4.14	4.26	4.27	4.21	4.10	3.96	3.81	3.65
8.8	2.56	3.15	3.77	4.14	4.29	4.32	4.27	4.17	4.04	3.89	3.74
9.0	2.51	3.10	3.72	4.13	4.32	4.37	4.33	4.24	4.12	3.98	3.82
9.3	2.47	3.05	3.67	4.12	4.33	4.40	4.39	4.31	4.19	4.05	3.90
9.5	2.42	2.99	3.61	4.09	4.33	4.43	4.43	4.36	4.25	4.11	3.97
9.8	2.38	2.93	3.55	4.05	4.32	4.44	4.46	4.40	4.30	4.17	4.02
10.0	2.33	2.86	3.48	4.01	4.31	4.45	4.48	4.43	4.34	4.21	4.07
10.3	2.28	2.79	3.41	3.95	4.28	4.44	4.48	4.45	4.36	4.25	4.11
10.5	2.23	2.73	3.33	3.89	4.24	4.42	4.48	4.46	4.38	4.27	4.14
10.8	2.18	2.65	3.24	3.82	4.19	4.39	4.46	4.45	4.38	4.28	4.15
11.0	2.13	2.58	3.15	3.74	4.13	4.35	4.44	4.44	4.38	4.28	4.16
11.3	2.07	2.50	3.06	3.65	4.06	4.29	4.40	4.41	4.36	4.27	4.15
11.5	2.02	2.43	2.96	3.56	3.98	4.23	4.34	4.36	4.32	4.24	4.13
11.8	1.97	2.35	2.86	3.45	3.89	4.15	4.28	4.31	4.28	4.20	4.10
12.0	1.91	2.27	2.76	3.34	3.79	4.07	4.20	4.24	4.22	4.15	4.06
12.3	1.86	2.19	2.66	3.23	3.69	3.97	4.12	4.17	4.15	4.09	4.00
12.5	1.80	2.11	2.55	3.11	3.57	3.86	4.02	4.08	4.07	4.02	3.93
12.8	1.75	2.03	2.44	2.98	3.45	3.74	3.91	3.98	3.98	3.93	3.85
13.0	1.69	1.95	2.33	2.85	3.32	3.62	3.79	3.87	3.87	3.84	3.77
13.3	1.64	1.87	2.22	2.72	3.18	3.48	3.66	3.75	3.76	3.73	3.67
13.5	1.59	1.79	2.11	2.59	3.04	3.34	3.53	3.62	3.64	3.62	3.56
13.8	1.53	1.72	2.00	2.45	2.89	3.20	3.38	3.48	3.51	3.49	3.44
14.0	1.48	1.64	1.89	2.31	2.74	3.04	3.23	3.33	3.37	3.36	3.32

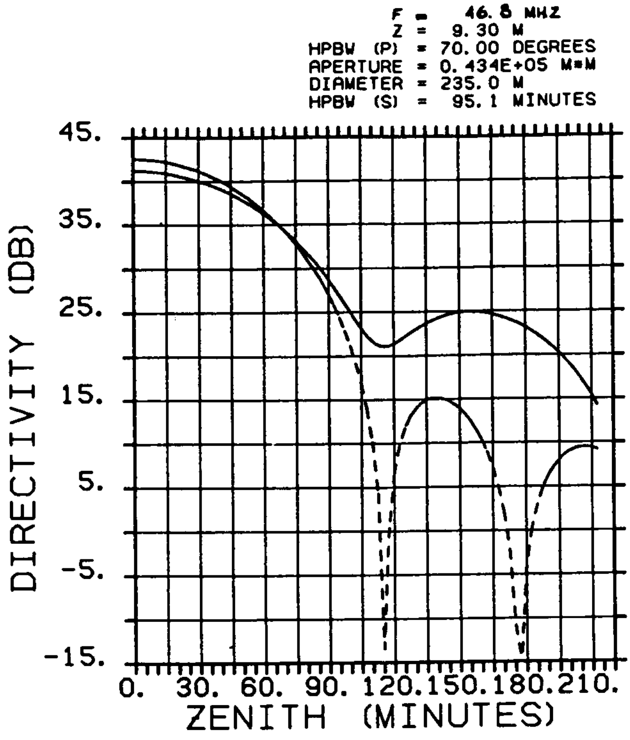

Figure 2. Radiation pattern for AO array in front of spherical reflector (solid line) and parabolic reflector (dashed line). Primary beam width is 70° and distance z from paraxial surface 9.3 meters.

REFERENCES

Burke, G. J., and A. J. Pogio (1981), Numerical electromagnetic code, Lawrence Livermore Laboratory, Technical Document 116, 1-3.

Condon, J. J. (1969), Theory of point fed spherical reflectors, Cornell-Sydney University Astronomy Center, CSUAC 182.

Rottger, J., H. M. Ierkic, R. K. Zimmerman, and J. B. Hagen (1986), Investigations of the lower and middle atmosphere at the Arecibo Observatory and a description of the new VHF radar project, this volume.