Computation of RF Boresight Direction From Reflector Distortions

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The direction of the radio-frequency (RF) boresight as computed by use of the RMS and Radiation programs is calculated by (1) using the same NASTRAN-computed distortion data and (2) searching for the maximum gain location of the focus. For small gravity distortions of the 64-m antenna, the values compare within 0.000004 rad (0.0003 deg).

I. Introduction

The direction of the RF boresight of the 64-m antenna may be calculated using the distortion data of the reflector structure. As shown in Refs. 1 and 2, best-fitting of the distortion data with the RMS program combined with the deflection data of the RF phase center provides one answer by ray-tracing. A direction answer may also be output from the Radiation program (Ref. 3), where the same distortion data may be input. The Radiation program integrates the illumination function over the antenna aperture, taking into account the pathlength and surface phasing error caused by the distortion at each point on the surface, and outputs a far-field radiation pattern. A rigorous comparison of the two outputs should provide an insight into the accuracy of the RF boresight calculation using the more versatile RMS program.

In the RMS best-fitting process, it is obvious that in fitting the almost circular shape of the paraboloid to a set of distortions, the accuracy of the rotated position of the best fit paraboloid used in ray-tracing is vulnerable to the quality of the distortion data. In this report, the distortion data were computed by the NASTRAN computing program using the 1/2 models as described in Ref. 1. The two sets used were for the standard and the modified reflector structure.

The reflection factor was first upgraded with the use of X-band propagation constant in the Radiation program. The description of the method of including the pathlength errors by offsets is included. Then the RF boresight direction is computed using X-band with the Radiation program and compared to the answer using the RMS program. An additional comparison is made using the Radiation program to search for the position of the RF phase center which produces the maximum gain. This position should be the same as the position of the focus of the best fit paraboloid.

II. Reflection Factor

Since specific illumination taper of the RF feed can be input to the JPL Radiation program, this method of determining the reflection factor was used, although general solutions are available in the literature. The phase center was laterally displaced by effectively moving the paraboloid laterally.

In addition to the distortion data, which in this series of computations were set to zero error, a Y-offset dimension was input to the Radiation program. This Y-offset was then added to the coordinates of each node defining a perfect paraboloid. The algorithm in the Radiation program then computes the pathlength error at each node. The number of nodes includes one at the center, followed by 24 nodes in the first row and 48 nodes for 8 more rows for a total of 409 nodes.

Figure 1 defines the algorithm where the basic assumption is made that the deflected surface remains parallel to the original tangent at the undeformed node. Then from the normal vector **NT** of the offset or the distortion vector **NR**, vector **NS**, which is equal to vector **NU**, may be computed. Vector **NV** equals **NS** $\times \cos\psi$. Thus the pathlength error equals **NS** plus **NV** or **NU** $(1 + \cos\psi)$.

The illumination taper curve shown in Fig. 2 was assumed to be symmetric about the axis of revolution, although in the tricone setup the pattern is known to be slightly asymmetric. As compared to the reflector factor using a uniform illumination, the factor increase with a taper is from 0.83+ to 0.84+.

Figure 3 illustrates the ray-tracing picture when the reflector is moved laterally, with the computed answers delineated in Table 1.

III. Boresight Direction Using the RMS Program

The results described in Ref. 1 will be used with corrections for the change in the reflection factor of 0.83 used in Ref. 1 to 0.8419 computed for X-band and for an error discovered for the X-rotation value for the modified case: −0.0002818 corrected to −0.0002815. The results are shown in Table 2 and illustrated in Fig. 4, the symbols being defined as follows:

C = undeformed paraboloid vertex

C_3 = best fit paraboloid vertex

F = undeformed paraboloid focus point

F_3 = RF phase center

F_4 = best fit paraboloid focus point

The same illumination taper values shown in Fig. 1 were input into the RMS program, in which the surface areas of a normal dish assignable to each node are computed and multiplied by the illumination factor, resulting in a weighting factor for each node during the best fitting calculation.

IV. Maximum Gain Direction From Radiation Program

As shown in Fig. 4, by effectively moving the focus F_4 of the best fit paraboloid on F, the undeformed focus in the Radiation program, the Radiation program should output the minimum gain loss or the maximum gain of the RF pattern with a boresight direction corresponding to angle θ of the axis of the best fit paraboloid. A search for the maximum gain angle θ was made by varying the Y-offset WW. Effectively, the focus F_4 was moved to position F using the Z-offset value from the RMS output. The results of this effort are shown in Table 3.

V. Conclusions

The calculated boresight direction matches with 0.000004 rad (0.0003 deg) when the comparisons are made between the RMS and Radiation program methods. When the comparison is made by the search for the maximum gain method, the difference using the distortion data from the standard configuration appears for unknown reasons to be too large, while there is a close match with the modified configuration.

References

1. Katow, M. S., "64-m-Diameter Antenna: Computation of RF Boresight Direction," in *The Deep Space Network Progress Report*, Technical Report 32-1526, Vol. XIV, pp 68–72, Jet Propulsion Laboratory, Pasadena, Calif., Apr. 15, 1973.
2. Katow, M. S., and Schmele, L. W., "Antenna Structures: Evaluation Techniques of Reflector Distortions," in *Supporting Research and Advanced Development*, Space Programs Summary 37-40, Vol. IV, pp. 176–184, Jet Propulsion Laboratory, Pasadena, Calif., Sept. 30, 1968.
3. Bathker, D., "Radiation Pattern Programs," in *Computer Programs for Antenna Feed System Design and Analysis*, Technical Report 32-479, Vols. I and II, edited by A. Ludwig, Jet Propulsion Laboratory, Pasadena, Calif., Apr. 15, 1967.

Table 1. Reflection factors

Radio frequency	Propagation constant	Offset, cm	(in.)	Incidence angle, rad	Reflection angle, rad	Reflection factor
S-band, 2300 MHz	1.22089	2.54	(1.0)	0.0537	0.0420	0.8417
		5.08	(2.0)	0.1074	0.09045	0.8424
		7.62	(3.0)	0.1610	0.1359	0.8441
		10.16	(4.0)	0.2147	0.1817	0.8463
X-band, 8448 MHz	4.49749	2.54	(1.0)	0.0537	0.0452	0.8417
		5.08	(2.0)	0.1074	0.09035	0.8412
		7.62	(3.0)	0.1610	0.13555	0.8419
		10.16	(4.0)	0.2147	0.18075	0.8419

Table 2. Computed RF boresight directions

Program	Deflection			64-m antenna: gravity distortion at zenith look, aligned at 45° elevation angle, offsets					
	Symbol		Description	Standard structure			Modified/new braces		
	Angular	Linear		Angle, rad	Linear cm	(in.)	Angle, rad	Linear cm	(in.)
RMS	–	OP	RF phase center	–	3.058	−1.204	–	−2.644	−1.041
	α	NN	Incidence angle	0.002559	6.939	2.732	0.002921	7.920	3.118
	β	–	Reflection angle	0.002154	5.842	2.300	0.002459	6.668	2.625
	θ	MM	Best fit paraboloid (X-rotation)	−0.002612	7.081	2.788	−0.002815	7.633	3.005
	δ		RF boresight direction	0.000458	1.239	0.488	0.000356	0.965	0.380
	–	VV	Best fit paraboloid (vertex Y-offset)	–	−10.962	−4.316	–	−12.909	−5.082
	–	CC	Best fit paraboloid (vertex Z-offset)	–	−0.616	−0.243	–	−0.600	−0.237
	–	WW	Best fit paraboloid (focus point)	–	3.881	1.528	–	5.276	2.077
	–	C_3F_3	Best fit paraboloid (focal length)	–	2711.618	1067.566	–	2711.625	1067.569
Radiation	δ	–	RF boresight direction	0.000460	–	–	0.000352	–	–
		CF	Undeformed focal length	–	2710.926	1067.294	–	2710.926	1067.294
	–	–	Y-offset	–	3.058	−1.204	–	−2.644	−1.041
	–	–	Z-offset	–	−.616	−0.243	–	−0.600	−0.237
Difference	δ		RF boresight direction	0.000002			0.000004		

Table 3. Maximum gain direction

Data description	Maximum gain angle θ							
	Radiation, X-band					RMS		
	Y-offset, cm	(in.)	Z-offset cm	(in.)	θ, rad	Y-offset cm	(in.)	θ (X-rotation), rad
Standard	3.772 ($\pm$0.025)	1.485 ($\pm$0.010)	0.617	−0.243	0.002580 ($\pm$0.000009)	3.879	1.527	0.002612
Modified	5.276 ($\pm$0.008)	2.077 ($\pm$0.003)	0.602	−0.237	0.002814 ($\pm$0.000002)	5.276	2.077	0.002815

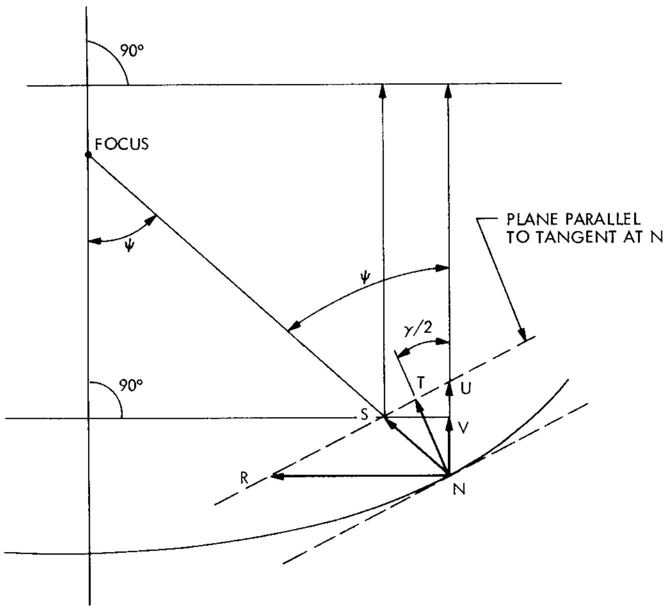
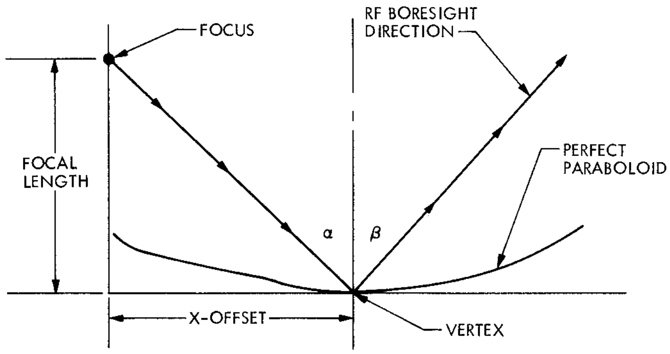


Fig. 1. Pathlength error definition



$$\text{REFLECTION FACTOR} = \frac{\text{BORESIGHT ANGLE}}{\tan^{-1}\left(\dfrac{\text{X-OFFSET}}{\text{FOCAL LENGTH}}\right)} = \frac{\beta}{\alpha}$$

Fig. 3. RF boresight direction due to lateral offset

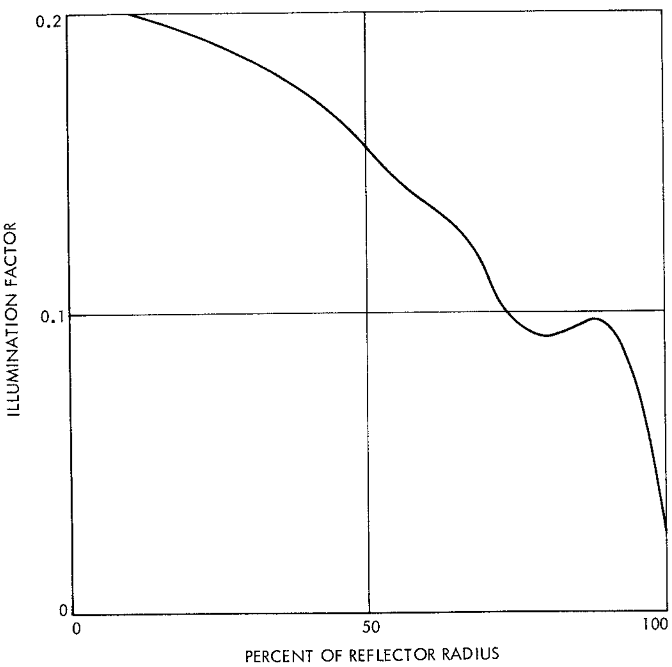


Fig. 2. 64-m-antenna RF feed illumination taper

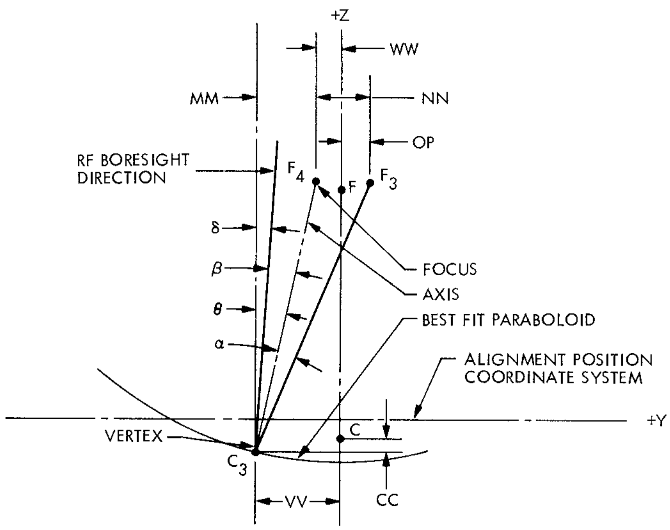


Fig. 4. RF ray tracing on the best fit paraboloid