Optimization of Small Reflector Antennas for Radio Astronomy

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***Abstract*—This paper reports simulated and analytical results for 3.8 m symmetric and offset reflector geometries using a wideband feed and concludes that a significant improvement in performance can be obtained using the offset geometry. These performance improvements are a reduction of spillover noise from 28K to 16 K, and an improvement in the sensitivity figure of merit (A_{eff}/T_{sys}) from 0.07 to 0.09 m^2/K. Further performance improvement in offset design were achieved using a ground shield, which reduced the spillover noise to 11 K, and adding a dielectric rod within the wideband feed, which illuminated the antenna to improve sensitivity figure of merit from 0.09 to 0.12m^2/K. The use of a mesh material for the offset reflector surface was also investigated. Using these optimizations, arrays of small offset reflectors can be used in future radio astronomy.**

I. Introduction

Arrays of small reflector antennas have gained recent interest in radio astronomy for their potential to drive new discoveries at a fraction of the cost of conventional instruments. Optimization of small reflectors is important to reduce the number and size of array elements for a given sensitivity. The conventional symmetric prime focus antenna shown in Fig. 1 (a) is described by the aperture diameter D of the reflector and the focal length F [1]. Four circular struts are also included to support the feed structure. The offset parabolic reflector antenna shown in Fig. 1 (b) is described by parameters F, D, θo, and the offset height H. The reflector is a section of a parent parabolic reflector.

The optics angle of offset design is given by:

$$\Theta_0 = \arctan\left(\frac{2fD}{4f^2+H(D+H)}\right) \qquad (1)$$

The offset parabolic reflector antenna has attracted significant research attention due to its promise of higher performance. To illuminate the aperture of the antenna, high efficiency wide band horn feeds are often used [2]. Placing a dielectric material within the feed horn has shown to be a promising method for improving the sensitivity figure of merit of the antenna feed system [3].

An outline of this paper is as follows: 1) Symmetric versus offset reflector antennas design, 2) Spillover versus elevation angle, 3) Ground shield for offset antenna, 4) Solid versus reflector mesh surfaces for offset antenna, and 5) Introduction of dielectric rod to wide band feed.

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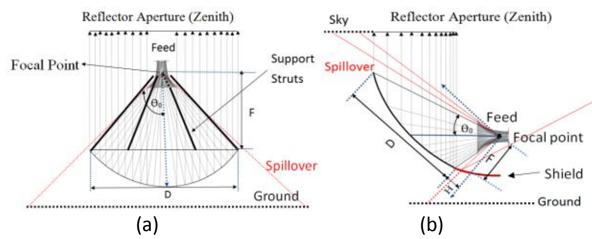


Fig. 1: (a) Symmetric prime-focus reflector geometry including four struts/ feed blockage, and (b) Offset reflector geometry.

II. Symmetric versus offset reflector antenna design

The main design parameter of the reflector system is the optics angle θ_o of the feed. In this work, a wide band Quad Ridge Flared Horn (QRFH) feed antenna [2] with approximately -10 dB taper at a half-angle of 52^0 is used to illuminate a 3.8 m small reflector antenna over the 0.7 to 2 GHz band with an optics angle equal to 52^0. This angle was chosen as it provides a reasonable F/D for both offset and symmetric antennas. Having defined the optics angle θ_o, equation (1) is used to design the offset antenna with D = 3.8 m, F= 1.14 m and H = 0.5 m. For the prime-focus reflector, the values used were D = 3.8 m and F = 1.9 m. Computed far field patterns of the QRFH antenna were used to illuminate the 3.8 m reflector system at 1.5 GHz. The key performance parameter of a reflector system is the sensitivity figure of merit (FOM), which is given by:

$$\text{FoM} = \frac{\text{Aeff}}{\text{Tsys}} = \frac{\text{Ap } \acute{\eta}_{\text{Total}}}{\text{Tsky+ Tsp+ Trec}} \qquad (2)$$

For this design, operating at 1.5 GHz, Tsky is 5K and Trec is assumed to 55K.

Table 1 compares the performance of symmetric and offset reflector antennas using the QRFH feed antenna. The main difference is that offset design has much lower spillover noise compared to axisymmetric case. The corresponding relative reduction in sensitivity is the result of the combined effect of the aperture efficiency loss and larger Tsp. As can be seen, Fig.2 shows the feed blockage and scattering effects from struts in axisymmetric antenna.

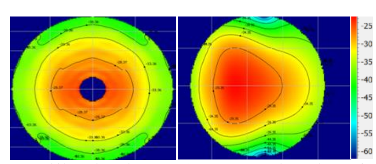


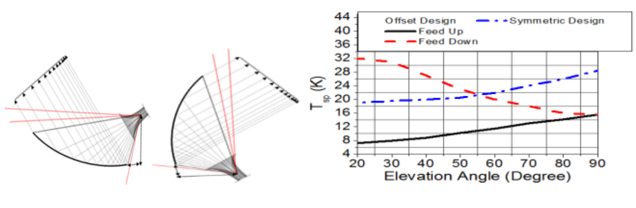
Fig. 2: Reflector illumination (a)) Symmetric prime-focus antenna with four struts and a central feed and (b) Offset reflector antenna.

TABLE.1. Symmetric versus Offset reflector Antenna at 1.5 GHz using QRFH

Parameters	Symmetric Antenna	Offset Antenna
$\acute{\eta}_{Total}$ (%)	0.523	0.54
$T_{sp\ total}$ (K) (Zenith)	28.4K	15.7K
X-Pol	−12	-11.2
SLL1st	−22.8	-23.2
FOM (m^2/K)	0.07	0.09

III. SPILLOVER VERSUS ELEVATION ANGLE

Spillover noise temperature varies with elevation angle due to the fraction of the feed beam which is receptive to the warm earth and changes in atmospheric noise with elevation angle. The sky and ground temperature distribution reported in [4] is used to calculate the variation in spillover temperature with elevation angle. In the symmetric case at zenith, close to 100% of the spillover is hitting the ground and hence, Tsp reaches its maximum of 28.4 K. Tsp decreases as the reflector system moves toward the horizon because a portion of spillover power is hitting the sky. In the offset case at zenith, Tsp is 15.6 K. Off zenith, the spillover noise is very dependent on whether the feed is above (high) or below (low) the reflector, as shown in Fig.3. At some angle near the horizon (approximately 15^0) ground radiation enters the main beam making astronomical observation useless.



(a) (b) (c)

Fig. 3: (a) Feed up at 45^0, (b) Feed down at 45^0, and (c) Spillover versus elevation angle.

IV. GROUND SHIELD FOR OFFSET ANTENNA

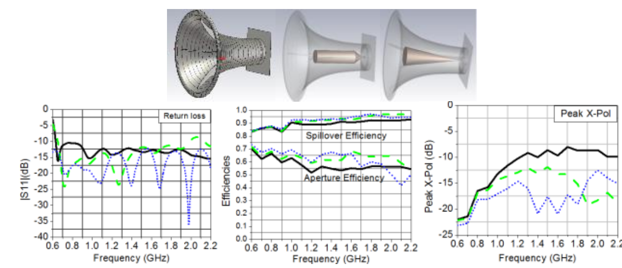
The purpose of ground shield is to block the spillover radiation from the warm ground and replace it with less noise power from the cold sky. This will be accomplished by a shield reflector [5], which will cover the horizon and the line of sight from the feed to the ground, as shown in Fig.1. The spillover noise temperature reduces from 15.7K to10.9K as the shield diameter increases from 0 to 1.2m. The position and angle of the shield is optimized to reduce the effect of the directed spillover power on the side lobes.

V. SOLID VERSUS MESH SURFACES FOR OFFEST ANTENNA

The reflector manufactured of wire mesh is often used as a surface of reflector antennas in radio astronomy due to their light weight, reduced wind effects, and less cost, as compared to the solid surface. The transmission loss equation obtained from [6] is used to compute the transmission loss through a mesh. At wavelength, λ = 20 cm, mesh size = 1cmχ1cm, and wire diameter = 1mm; the transmission loss = -19.5 dB and the FOM = 0.084. As the mesh size increases to 2cmχ2cm, the mesh transmission loss increases to -10.1dB. The corresponding mesh leakage temperature [10] is added to the total system temperature.

VI. INTRODUCTION OF DIELECTRIC ROD TO WIDE BAND FEED.

The performance of the horn feed antennas can be improved by modifying the feed to include dielectric materials when compared with those of an unloaded horn antennas [3]. Cone and spear dielectric shapes were added to a Caltech wide band QRFH feed antenna, as shown in Fig. 4. The simulation shows that the input reflection coefficient at over most of the frequency range is improved. The change in aperture efficiency can be explained due to excitation of higher order modes. The spillover efficiency is improved due to focalization of the radiated energy into a narrower beam.



(a) (b) (c)

Fig. 4: QRFH feed antenna performance with dielectric over 0.7-2 GHz; solid line: QRFH feed without dielectric, dashed green line: QRFH feed with spear dielectric shape, and dotted blue line: QRFH feed with cone dielectric shape.

The computed far field pattern of QRFH feed loaded with cone dielectric at 1.5GHz was used to illuminate the 3.8-m reflector offset antenna using the GRASP program. Significant improvements have been obtained in the aperture efficiency by almost 13%, spillover temperature by 4.7K, cross polarization by -7 dB relative to the peak, and a figure of merit improvement by almost 25%.

ACKNOWLEDGEMENT

I would like to thank Clifton Quan, Stephen Smith, and Andrew Janzen for their valuable comments on this work.

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