

The Influence of Panel Gaps on the System Noise Temperature of the FAST

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Abstract A Five-hundred-meter Aperture Spherical Telescope (FAST), the largest single dish in the world, is proposed to be built in one of the karst depressions in Guizhou province. The main spherical reflector is to consist of about two thousand small panels, which can be adjusted to fit a paraboloid in real time. There are many slit-like gaps across the aperture due to manufacturing error, thermal effects and deviations between a sphere and a paraboloid. The influence of the energy leakage of the narrow gaps on the system noise temperature of the FAST reflector is discussed in this paper.

Key words: telescopes – methods: analytical – energy leakage

1 INTRODUCTION

The FAST is an Arecibo-type telescope with a number of innovations, which is to be built in the unique karst area of Southwest China (Nan Rendong et al. 1996). Some basic parameters of the FAST have been tentatively suggested such as, curvature radius $R = 300$ m, opening angle $\theta = 120^\circ$, and frequency range from 300 MHz to 5 GHz. Based on the fact that the central part of a spherical surface deviates little from a paraboloid as a proper focal length is chosen, a novel design for a giant spherical reflector has been proposed (Qiu Yuhai 1998). It is necessary to divide the giant main reflector into about 2000 spherical hexagons with diagonal dimensions of 10–15 m to approximate a paraboloid. The focal length is set to be $0.467 R$ in the real configuration with the illuminated aperture 300 m, which enables the realization of both wide bandwidth and full polarization capability by using a conventional feed system (Peng Bo, Nan Rendong & Su Yan 2000). Considering the deviations between a sphere and a paraboloid, manufacturing error, and deformation by temperature variations, free space is inevitable between adjacent elements. These narrow gaps will have an effect on the electrical

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performance of FAST, i.e., lead to increased antenna noise temperature and gain loss, which should be considered during reflector design.

It is difficult to calculate the energy leakage caused by the gaps accurately due to their complex distribution on the surface. Therefore, it is necessary to simplify the model. As the diameter and curvature radius of the reflector are much larger than the observing wavelengths, the reflector can be considered as an infinitely large plate with three groups of parallel slit-like gaps in a good conductor, as illustrated in Fig. 1. The energy leakage of one group of infinitely long gaps is discussed, as an example, on which a uniform plane wave is incident.

According to the Babinet-Booker principle and the duality principle in electromagnetic theory, a scattering field of parallel currents on its complementary electrical screen will be derived instead of discussing the energy leakage directly (Lin, Chen & Wu, 1990).

2 CALCULATION AND METHOD

Fig. 2 shows the complementary electric screen, where d is the width of gaps on the reflector, W the space between adjacent gaps. And two coordinate systems (V_1, V_2, V_3) and (U_1, U_2, U_3) are selected, where the OV_1 -axis is in the direction of one line source, the OV_2 and OV_3 -axes are perpendicular to the line sources and the plate respectively, wave vector \mathbf{k} , angle φ between \mathbf{k} and the normal to the reflector, angle θ between \mathbf{k} and its projection on the reflector; the OU_3 -axis is in the direction of propagation of the plane wave, OU_1 and OU_2 -axes are the direction of the electric field \mathbf{E} and magnetic field \mathbf{H} respectively. β_{tp} is denoted as the angle between the OV_t -axis ($t = 1, 2, 3$) and the OU_p -axis ($p = 1, 2, 3$), so we have

$$V_t = \sum_{p=1}^3 U_p \cos \beta_{tp}. \quad (1)$$

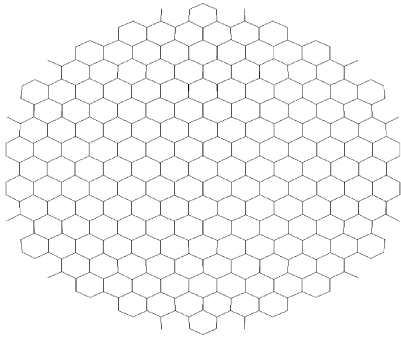


Fig. 1 The reflector composed of around two thousand hexagons

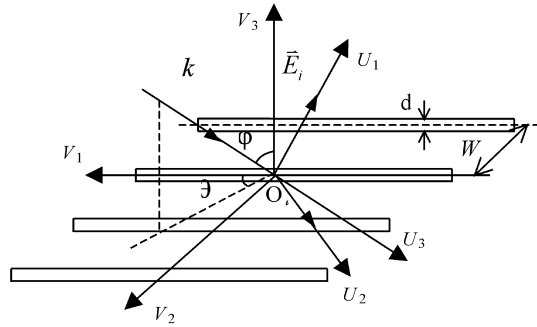


Fig. 2 The coordinate system of reflector

The incident field E_{it} associated with the plane wave on the m -th line source in the OV_1 -direction is

$$E_{it} = E_{i0} \cos \beta_{11} e^{-j\mathbf{k} \cdot \mathbf{r}} = E_{i0} \cos \beta_{11} e^{-jkV_1 \cos \beta_{13} - jkmW \cos \beta_{23}} (m = 0, \pm 1, \pm 2 \dots), \quad (2)$$

where E_{i0} stands for the electric field intensity at the origin O , k is a propagation constant. If the wire diameter d is much smaller than the wavelength λ and the space W , it can be considered as a uniform line source that has a current distribution with uniform amplitude and linear phase progression. Then we need only consider V_1 -directed currents in the calculation. The magnetic vector potential at (V_1, V_2, V_3) on the m -th line source is evaluated as

$$A^{(m)} = A_{V_1}^{(m)} \hat{V}_1 + A_{V_2}^{(m)} \hat{V}_2 + A_{V_3}^{(m)} \hat{V}_3. \quad (3)$$

and

$$A_{V_2}^{(m)} = A_{V_3}^{(m)} = 0, \quad (4)$$

$$\begin{aligned} A_{V_1}^{(m)} &= \frac{\mu_0}{2\pi} \int_{-\infty}^{+\infty} \frac{I_m e^{-jkr}}{r} dV_1 \\ &= \frac{\mu_0 I_0}{2j} e^{-jkmW \cos \beta_{23}} e^{-jkV_1 \cos \beta_{13}} H_0^{(2)} \left[k \sin \beta_{13} \sqrt{(V_2 - mW)^2 + V_3^2} \right] \end{aligned} \quad (5)$$

where I_0 is the value of the current at origin O . Substituting the Hankel function by an approximating function (Milton Abramowitz & Irene A. Stegun, 1964), the total vector potential in the far-zone region can be obtained by summing over the individual $2N + 1$ element currents as

$$A_{V_1} = \sum_{m=-N}^{m=N} A_{V_1}^{(m)} = \frac{\mu_0 I_0 \lambda}{2jW \pi \cos \beta_{33}} e^{-jkU_3}. \quad (6)$$

The far-zone electric field can be further deduced from equation (6) as.

$$E_{U_1} = -\frac{\mu_0 I_0 \omega \lambda \cos \beta_{11}}{2\pi W \cos \beta_{33}} e^{-jkU_3}, \quad (7)$$

$$E_{U_2} = -\frac{\mu_0 I_0 \omega \lambda \cos \beta_{12}}{2\pi W \cos \beta_{33}} e^{-jkU_3}, \quad (8)$$

$$E_{U_3} = 0. \quad (9)$$

From Eqs. (7), (8) and (9), the scattered field has components E_{U_1} and E_{U_2} which are parallel and perpendicular to \mathbf{E}_i respectively. Therefore, the scattered field is elliptically polarized. Its magnitude is

$$E_s = \sqrt{E_{U_1}^2 + E_{U_2}^2} = \frac{\mu_0 I_0 \omega \lambda \sin \beta_{13}}{2\pi W \cos \beta_{33}} e^{-jkU_3}. \quad (10)$$

I_0 can be derived from boundary conditions, that the sum of the tangential component of the electric field intensity on the 0-th line conductor is zero (Warren, Stutzman & Gray 1981). Thus, the scattered field of parallel electric currents on the complementary electric screen is

$$E_{\text{sm}}^{(e)} = \frac{-\lambda E_{i0}}{W \pi \cos \beta_{33}} \frac{\cos \beta_{11} e^{-jkU_3}}{\sin \beta_{13} \left[H_0^{(2)} \left(\frac{kd \sin \beta_{13}}{2} \right) + 2 \sum_{m=1}^{+\infty} e^{-jkmW \cos \beta_{23}} H_0^{(2)} (k|m|W \sin \beta_{13}) \right]}. \quad (11)$$

The energy leakage factor is given by $\delta = |\mathbf{P}_2/\mathbf{P}_1|$, where \mathbf{P}_1 and \mathbf{P}_2 are the Poynting vectors before and behind the screen respectively. For a large screen with three groups of slit-like gaps, the total energy leakage factor is approximately

$$\delta = \frac{2\lambda^2 \cos^2 \beta_{11}}{W^2 \pi^2 \cos^2 \beta_{33} \sin^2 \beta_{13} \left[H_0^{(2)} \left(\frac{kd \sin \beta_{13}}{2} \right) + 2 \sum_{m=1}^{+\infty} e^{-jkmW \cos \beta_{23}} H_0^{(2)} (k|m|W \sin \beta_{13}) \right]}. \quad (12)$$

Assuming the ground temperature is 300 K (Ulaby, Moore & Fung, 1988), the noise temperature caused by the gaps is

$$T_N = 300\delta = \frac{600\lambda^2 \cos^2 \beta_{11}}{W^2 \pi^2 \cos^2 \beta_{33} \sin^2 \beta_{13} \left[H_0^{(2)}\left(\frac{k d \sin \beta_{13}}{2}\right) + 2 \sum_{m=1}^{+\infty} e^{-j k m W \cos \beta_{23}} H_0^{(2)}(k|m|W \sin \beta_{13}) \right]} \quad (13)$$

The three-dimensional plot in Fig. 3 illustrates the relation among the system noise temperature T_N , the relative width of the gaps d/λ and angle $E - V_1$, where $E - V_1$ is an angle between the projection of \mathbf{E}_i on the reflector and the V_1 -axis. Fig. 4 demonstrates the system noise temperature T_N as a function of d/λ with different W/λ .

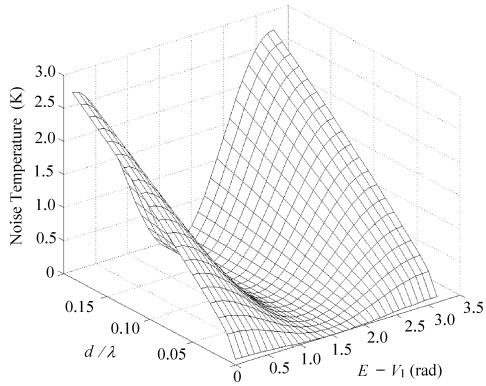


Fig. 3 T_N as a function of d/λ and $E - V_1$ angle ($W/\lambda = 10.5$, $\theta = \pi/2$, $\varphi = \pi/3$)

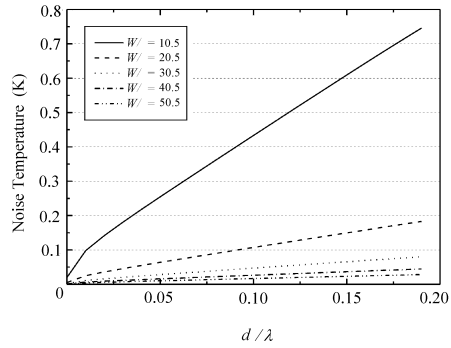


Fig. 4 T_N as a function of d/λ with different W/λ ($\theta = 0$, $\varphi = 0$)

In Table 1, the system noise temperature results are shown for $\varphi = 60^\circ$, $\theta = 90^\circ$, and $E - V_1 = 90^\circ$.

Table 1 System Noise Temperatures at Frequencies of 0.3 and 1 GHz

d/λ	$f = 0.3 \text{ GHz}$					$f = 1 \text{ GHz}$				
	$d \text{ (cm)}$	δ	$T_N \text{ (K)}$	δ	$T_N \text{ (K)}$	$d \text{ (cm)}$	δ	$T_N \text{ (K)}$	δ	$T_N \text{ (K)}$
0.01	1	0.0017	0.52	9.7E-4	0.29	0.3	2.4E-4	0.07	8.6E-5	0.03
0.05	5	0.0038	1.14	0.0025	0.76	1.5	6.0E-4	0.18	2.2E-4	0.06
0.10	10	0.0061	1.84	0.0044	1.31	3.0	9.5E-4	0.29	3.5E-4	0.11
0.15	15	0.0088	2.65	0.0063	1.88	4.5	0.0013	0.38	4.8E-4	0.15
0.20	20	0.0122	3.67	0.0082	2.46	6.0	0.0015	0.46	6.1E-4	0.18

3 CONCLUSION

From Figs. 3, 4, and Table 1, the system noise temperature due to the gaps in the reflector is, when other parameters are fixed, mainly influenced by the following,

(1) The relative width of the gaps d/λ . The system noise temperature T_N increases with increasing d/λ .

(2) The relative distance between the adjacent line sources W/λ . T_N decreases as W/λ increases.

(3) The angle φ . T_N varies with φ non-linearly.

(4) The angle $E - V_1$. When the projection of the electric field on the reflector is perpendicular to the line sources, T_N reaches its maximum.

(5) The angle θ . T_N increases with increasing θ . As $\theta = 90^\circ$, T_N reaches its maximum.

(6) If the diagonal dimensions of the elements are taken as 10 m or 15 m, and d/λ is less than 0.2, T_N is less than 4 K and then can be ignored.

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