Design and Simulation of Subsize BWG Feed System for Shipborne TT&C Antenna

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Abstract. Compared with traditional Cassegrain antenna, the BWG (Beam Waveguide) feed system has many advantages. This paper designs subsize BWG, according to shipborne environment. Geometrical optics is used to determine the relative location and size of each mirror. Finally, performance for the feed system is simulated and optimized based on GRASP 9.0.

Introduction

A multi-band shipborne TT&C antenna is designed combined with the need of follow-up tasks based on BWG feed system. Compared with traditional Cassegrain antenna, the BWG feed system has many advantages, such as: no revolving joint, low wastage feeder, comfortable work environment for LNA, high multi-band aperture illumination efficiency, low sidelobe level, etc[1]. It is the most important part of 12m antenna equipped on TT&C ship,which will be designed in this paper.

Design Goals

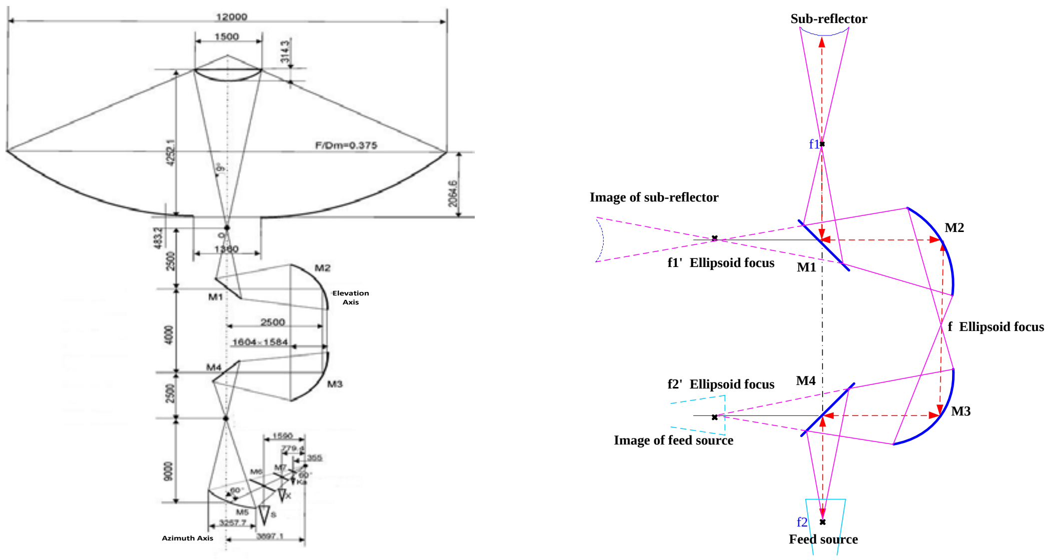
Indexes used to appraise BWG feed system’s performance include: transmission efficiency, ohmic loss and equivalent irradiation level on sub-reflector edge. According to the need of shipborne TT&C antenna, key parameters of BWG feed system are set as follows:

1) Work frequency: 2~33GHz;
2) Transmission efficiency: ⩾80%;
3) Reflection efficiency: ⩾98%;
4) Equivalent irradiation level on sub-reflector edge: ⩽-23dB.

Design of Subsize BWG Feed System

Scheme for Subsize BWG Feed System. Fig. 1(a) shows the designed scheme for subsize BWG feed system, which is composed of eight mirrors: M1, M4, M6, M7 and M8 are plane; M2 and M3 are paraboloidal; M5 is ellipsoidal. To ensure S/X/Ka band working at the same time, M6 reflects S band signal and transmits X &Ka band signals, M7 reflects X band signal and transmits Ka band signal.

Parameter choice principle for BWG feed system is that high transmission efficiency, low cross-polarization level and little change on Equivalent scatter direction from sub-reflector[2]. So projected diameter of the curved mirror is set as 20λ~30λ, parameters for M2 and M3 must be equal and locations placed are face to face, distance between curved mirrors satisfies $L0 \leqslant 0.2D2/\lambda$, plane mirror projection on transmission direction plane needs ＞30λ and equivalent irradiation level on sub-reflector edge of M4 should be lower than -23dB.



(a) BWG feed system (b) Relationship based on geometrical optics

Fig. 1 Equivalence relationship for four-mirror BWG feed system

Mirror Design for BWG. Traditional equivalence relationship for four-mirror BWG feed system is shown as Fig. 1(b)[3].

(1) M1 and M4

Profiles of M1 and M4 are formed by plane $y = 2500 - x$ intersected with cone $y^2 + z^2 = x^2 tg^2\theta_m$, which can be written as:

$$(x - \frac{a+F}{1-tg^2\theta_m})^2 + \frac{z^2}{1-tg^2\theta_m} = (\frac{a+F}{1-tg^2\theta_m})^2 - \frac{(a+F)^2}{1-tg^2\theta_m} \quad (1)$$

Ellipse center: $(x_0 = (a+F)/(1-tg^2\theta_m), z_0 = 0)$; long axis: $(a+F)tg\theta_m/(1-tg^2\theta_m)$; minor axis: $(a+F)tg\theta_m/\sqrt{1-tg^2\theta_m}$.

We set illuminating angle $\theta_m = 9^\circ$ and focal distance $f = 2500mm$, Fig. 2 represents the geometric dimensioning of M1 and M4.

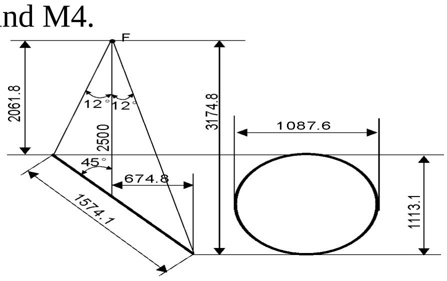


Fig. 2 Geometric dimensioning of M1 and M4

(2) M2 and M3

To enhance the capture efficiency, profiles of M1 and M4 can be obtained as

$$\begin{cases} x^2 + z^2 = 4Fy \\ (y-F)^2 + z^2 = x^2 tg^2\theta_m \end{cases} \quad (2)$$

Projection on plane xoz is circular, its equation is: $(x - 2F\sqrt{1+tg^2\theta_m})^2 + z^2 = (2Ftg\theta_m)^2$; center: ($x_0 = 2F\sqrt{1+tg^2\theta_m}, z_0 = 0$), radius: $R = 2Ftg\theta_m$. In the same way, projection equation on plane yoz is: $[y - F(1+2tg\theta_m)]^2/(2Ftg\theta_m\sqrt{1+tg^2\theta_m})^2 + z^2/(2Ftg\theta_m)^2 = 1$, minor semi-axis: $b = 2Ftg\theta_m$, long semi-axis: $a = 2Ftg\theta_m\sqrt{1+tg^2\theta_m}$, ellipse center: $(y_0 = F(1+2tg^2\theta_m), z_0 = 0)$.

We set illuminating angle $\theta_m = 9^\circ$ and focal distance $f = 2500mm$, Fig. 3 represents the geometric dimensioning of M2 and M3.

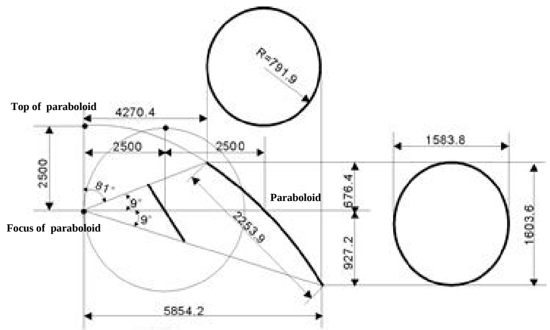


Fig. 3 Geometric dimensioning of M2 and M3

(3) M5

M5, M6, M7 and M8 are used to realize S/X/Ka band working. As Fig. 4, $f2$ and $f'3$ is the two focuses of M5, $f2$ and the focus image of M3 are coincident. 22dBi gain horn goes up to 29dBi by M5. We know the smaller angle θ between incidence and reflex waves, the better wave symmetry. But when $\theta < 50^\circ$, M6 and S band horn will shade M5, so overall arrangement of M5, M6, M7 and M8 should be designed prudentially.

The relationship of curvature radius R_1, R_2 and focus f is: $1/f = 1/R_1 + 1/R_2$.

M5 can be described as:

$$\frac{z^2}{a^2} + \frac{x^2 + y^2}{b^2} = 1 \tag{3}$$

In(3), $e = 1 - 2f_0 / |R_1 + R_2|$, $f_0 = \left(|R_1 + R_2| - \sqrt{R_1{}^2 + R_2{}^2 - 2R_1R_2\cos 2\theta_i}\right)/2$, $b = f_0\sqrt{(1+e)/(1-e)}$, $a = f_0/(1-e)$.

If move origin coordinate rotated ψ to the center of ellipsoid and rotate, whose normal is z', (3) can be rewritten to:

$$\frac{(z'\cos\psi + x'\sin\psi - \sqrt{a^2 + b^2} - R_1\cos\theta_p)^2}{a^2} + \frac{(x'\cos\psi - z'\sin\psi + R_1\sin\theta_p)^2 + y'^2}{b^2} = 1 \tag{4}$$

In (4), θ_p is the angle between incidence wave and link-line of the two focuses. $\psi = \theta_p - \theta_i$, $A_0 = \sqrt{R_1{}^2 + R_2{}^2 - 2R_1R_2\cos 2\theta_i}$, $\theta_p = \pi - \cos^{-1}\left[\left(R_1{}^2 + A_0{}^2 - R_2{}^2\right)/2R_1A_0\right]$.

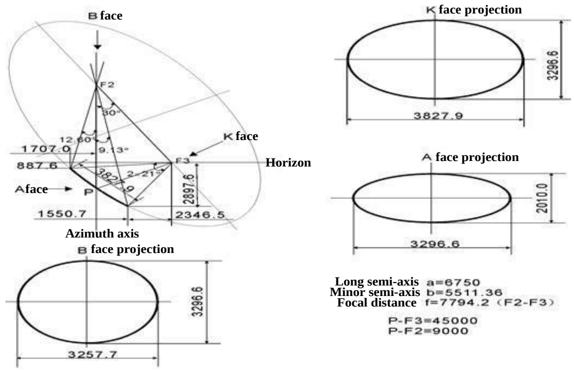
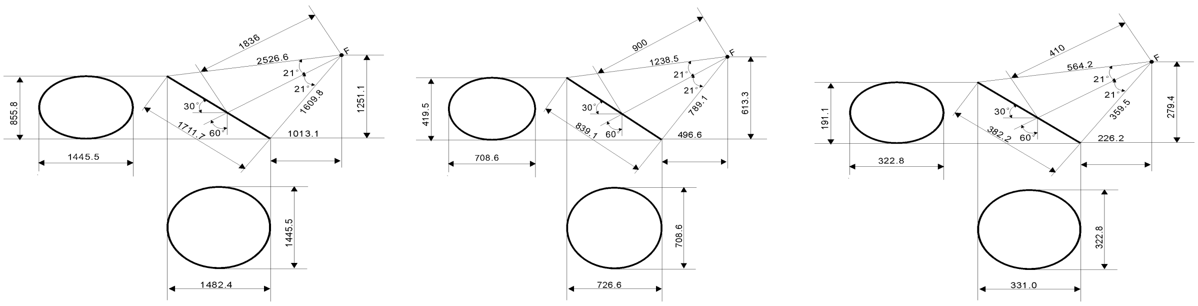


Fig. 4 Geometric dimensioning of M5

(4) M6, M7 and M8

M6, M7 are used to choose frequency band and M8 reflexes waves. During design them, we know large electrical size and short distance between reflecting surface and the focus of M5 can get low radiation leakage.

The same computing method are adopted to calculate the geometric dimensioning of M6, M7 and M8, as shown in Fig. 5.

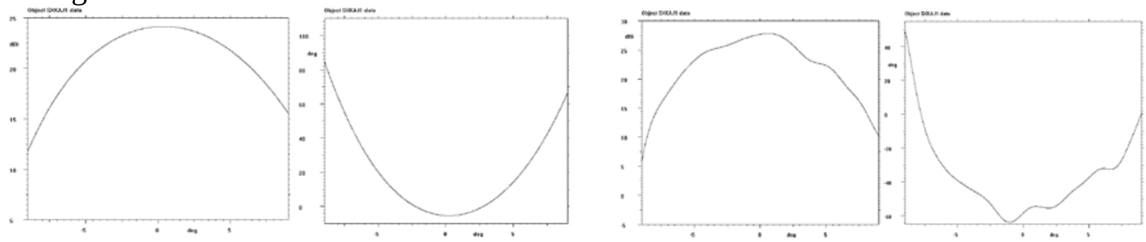


(a) M6 (b) M7 (c) M8

Fig. 5 Geometric dimensioning of M6, M7 and M8

Performance Simulation for BWG Feed System

In this paper, we use GRASP 9.0 to calculate and optimize the performance of BWG feed system. The S band Scatter radiation pattern form the phase center of feed source based on GRASP 9.0 is given in Fig. 6.



(a) Transmitting in S band (b) Receiving in S band

Fig. 6 Amplitude-phase diagram for S band

From Fig. 6, we can find the amplitude-phase diagram is not circle symmetrical because output angles of M5 is not equal, which can be solved by rotate M5 in antenna adjustment stage.

Conclusions

To satisfy the need of shipborne deep space TT&C, this paper designs subsize feed system and utilize geometrical optics to calculate initial values for each mirror. Finally, the performance of BWG feed system is simulated and optimized by GRASP 9.0. The result is useful for engineering.

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