Study of the Scanning Characteristics of On-board Reflector Antenna with 7-feed Cluster

Jiadong Cao*, Wutu Wang, Wenchao Song and Bo Chen
China Academy of Space Technology (Xi’an), Xi’an, China

*Corresponding author: cjd1996@stu.xidian.edu.cn

Abstract. In this paper, the scanning characteristics of the feed clusters are investigated using Conjugate Field Match (CFM) for a single aperture on-board reflector antenna. By calculating the receiving fields in different incoming wave directions, the variation of the scanning characteristics of the 7-feed cluster at different longitudinal defocusing distances is analyzed. The simulation results show that longitudinal defocus can improve the scanning characteristics at larger scanning angles and provide a reference for the design of starborne antennas.

Keywords: Reflector antenna, feed cluster, scan characteristics, longitudinal defocus.

1. Introduction

The reflector multi-beam antenna is capable of generating multiple sub-beams simultaneously to cover the desired area on the ground. Due to its use of multiple narrow beams, a larger beam coverage can be obtained, frequency multiplexing can be achieved between different beams, effectively moderating the spectral resources, while providing higher radiation gain, and has the advantages of light weight, simple structure, mature design technology, and excellent performance, so it is widely used in satellite communications [1].

To achieve multi-beam coverage, the antenna needs to have a certain beam scanning capability. To address the need for multi-beam reflector antennas to achieve beam scanning, literature [2] optimized the scanning characteristics of 5m aperture antennas in the 10° range for large aperture reflector antennas by using ray tracing method to calculate the trajectory of the best position of the feed source during antenna scanning. In the literature [3], for a Cassegrain antenna, the radiation directional map of the antenna at different scanning angles is calculated and the sub-flap of the directional map and the variation of the antenna gain during beam scanning are analyzed.

In order to obtain better scanning capability and reduce scanning losses, feeds clusters are often used to form the beam instead of a single feed, and experiments have shown that feed clusters can significantly improve scanning capability as long as they are given suitable excitation [4, 5]. The literature [6] analyzed a single offset parabolic reflector antenna and simulated its focal field characteristics using conjugate field matching to calculate the excitation coefficient of each feed.

Longitudinal defocusing can also improve the scanning characteristics to some extent [7], however, the effect of the defocusing distance on the scanning characteristics remains to be investigated. Therefore, in this paper, the scan characteristics of the most basic 7-feed cluster in different defocus
states are studied using a large-diameter single-reflector antenna as a model, and the scan losses at different scan angles are analyzed.

2. Design of reflector antenna
A reflector multi-beam antenna is usually composed of a reflector surface, a feed (or feed array), and a beam forming network (BFN). The reflector is generally a parabolic, and the feed source is generally placed at the focal point of the parabolic surface. When the feeds are more, in order to prevent the feed cluster blocking, we usually offset the feed cluster. The geometric model of the reflector antenna is shown in Figure 1.

Among these, the main parameters of the antenna are.
- D: diameter of the reflector.
- F: Focal length.
- H+D/2: central offset distance of the reflecting surface.
- $\beta$: the angle at which the reflecting surface is offset.
- $\beta_1 - \beta_2$: radiation angle.

In order to facilitate the analysis, we established two coordinate systems, namely, the reflective surface coordinate system $x, y, z$, and the feed coordinate system $x_f, y_f, z_f$. The central origin of the reflective surface coordinate system is located at the center of the reflector surface, the x-axis is upward, and the y-axis is perpendicular to the paper face outward. Both $x, y, z$ and $x_f, y_f, z_f$ are all satisfy the right-hand spiral rule.

The parameters of the antenna are as follows ($\lambda$ is the operating wavelength).
- D: 84$\lambda$; F: 56$\lambda$; H: 17.5$\lambda$.

![Figure 1. The geometry of reflector antenna.](image1)

![Figure 2. 7-feed cluster.](image2)

3. Research methodology
The position and excitation of the feeds affect the beam when the antenna is scanning. Therefore, Conjugate Field Match (CFM) is used in this paper to determine the position of the feeder array and the initial excitation during the beam scanning process. The details of the method are as follows.
A plane wave is incident from an infinite distance in the same direction as the beam direction, and after irradiating the reflective surface a receptive field is formed in a finite region near the focal plane. The feed clusters are placed at the location where the energy of the receiving field is the highest, and the feed clusters receive the energy as completely as possible to find the best feeds’ location in this direction. The receiving field is sampled at the center of each feed, and the conjugate transpose of the main polarization component is the excitation coefficient of the corresponding feeds. In order to obtain the maximum gain, this excitation is then used as the initial value and the excitation coefficient is quadratically optimized using commercial software. Varying the plane wave incident direction, the gain and loss of the optimized beam are calculated at different scan angles.

In order to study the effect of longitudinal defocus on the scan loss, the feed cluster is therefore pushed forward 1λ, 2λ, 5λ, 8λ, and 10λ along the \( z \) axis, respectively, and the beam is scanned on the defocused plane in the same way to calculate the scan loss.

This paper was calculated using commercial software GRASP 19.0 and POS 6.4.

4. Beam-scan characteristics

The 7-feed cluster is arranged according to a hexagonal honeycomb with an aperture of 0.7λ and spacing of 0.77λ, as shown in Figure 2.

The feed clusters are scanned in the focal plane, defocused 1λ, 2λ, 5λ, 8λ and 10λ planes along the negative and positive directions of \( \theta \) at \( \varphi = 0^\circ \) and \( \varphi = 90^\circ \), respectively, while the feed clusters are defocused horizontally along the positive, negative directions of \( x_f \) and positive directions of \( y_f \), respectively. Figure 4(a) shows the scan-loss curves of the feeder cluster when \( \varphi = 0^\circ \) and \( \theta < 0^\circ \), Figure 4(b) shows the scan-loss curves of the feed clusters when \( \varphi = 0^\circ \) and scan along \( \theta > 0^\circ \), and Figure 4(c) shows the scan-loss curves of the feed clusters when \( \varphi = 90^\circ \) and scan along \( \theta < 0^\circ \). By the symmetry of the reflector, the scanning characteristics of the \( \theta > 0^\circ \) direction are the same as those of the \( \theta < 0^\circ \) direction when \( \varphi = 90^\circ \). The scan loss in the figure is zeroed at the peak gain of the 0° scan angle, and the horizontal scan angle is the absolute size.

The analysis of Figure 3 leads us to the following conclusions.

1. Feed clusters with a larger number of feeds can achieve better scanning characteristics, especially at larger scanning angles. If the acceptable scan loss is -4 dB, the 7-feed cluster can scan up to 6.1° (\( \varphi = 0^\circ \), \( \theta < 0^\circ \)), while the single feed can scan only 3.9° (\( \varphi = 0^\circ \), \( \theta < 0^\circ \)).

2. The smaller the longitudinal defocusing distance, the larger the beam gain is achieved. The peak gain of the beam is significantly reduced after the defocus distance greater than 2λ, and the gain is reduced by 4.8 dB with a defocus of 5λ compared to 2λ.

3. In the process of scanning along \( \theta > 0^\circ \) direction, when \( \varphi = 0^\circ \) and along \( \theta < 0^\circ \) direction, \( \varphi = 90^\circ \), when the longitudinal defocusing distance is greater than 5λ, there is a peak in the scan loss curve, which appears at about 8° (for defocusing 8λ, 9° for defocusing 10λ) in the \( \varphi = 0^\circ \), \( \theta > 0^\circ \)
direction, and at about 10° (for defocusing 8λ, 11° for defocusing 10λ) in the \( \varphi = 90°, \theta < 0° \) direction.

(4) Although a larger defocus distance will produce a lower scan loss, it also leads to a lower gain. Therefore the longitudinal defocus distance should be weighed against the practical needs in the design of the antenna.

5. Summary
In this paper, the optimal feed position and beam pointing of the reflector antenna with feed clusters during scanning are calculated using the conjugate field matching method, and analyzing the scan loss of the 7-feed clusters during scanning and the effect of the longitudinal defocus of the feed clusters on the scan loss. The simulation results show that the longitudinal defocus has an improvement on the scan loss in the case of a large scan angle. This study is of some reference significance for the design of future on-board reflective surface antennas.

References
[1] Zhou L, Li D, Guo W, Review of Multiple-Beam Antennas for Satellite Communications, ACTA ELECTRONICA SINICA, 29 (2001) No. 6, pp. 824-828. (in Chinese)
[2] Wang L, Huang W, Zhang Y, “Research on the feed trajectory of the wide-angle scanning of the offset-fed reflector antenna,” in National Antenna Annual Meeting, Xi’an, 2017, p. 3. (in Chinese)
[3] Yu X, Li J, Zhang X, Beam scanning characteristics of side-feed offset Cassegrain antenna, Chinese journal of radio science, 34 (2019) No. 5, pp. 638-632. (in Chinese)
[4] LAM P, SHUNG-WU L, CHANG D, et al, Directivity optimization of a reflector antenna with cluster feeds: A closed-form solution, IEEE Transactions on Antennas and Propagation, 33 (1985) No. 11, pp. 63-74.
[5] C. C. Chen and C. F. Franklin, Ku-band multiple beam antenna. NASA Contract Report 154364, Langley Res. Center, Hampton, VA, Dec. 1980.
[6] Wang Pu, Simulation and Calculation of Single Offset Multi-focal Reflector Antenna (Master, Xidian University, China, 2014), pp. 15. (in Chinese)
[7] FUJINO Y, HAMAMOTO N, Design of Antenna System, Journal of the National Institute of Information and Communications Technology, 62 (2015) No. 1, pp. 99-109.