Research of the Defocus Characteristics of On-board Reflector Antenna with Feed Cluster

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Abstract: In this paper, the scanning characteristics of a 19-feed cluster are investigated using Conjugate Field Match (CFM) for a single aperture on-board reflector antenna on the basis of a 7-feed cluster. The simulation results show that the 19-feed cluster has higher gain and lower loss than the 7-feed cluster at a larger degree of lateral defocus, and a certain degree of longitudinal defocus can improve the scanning characteristics. This article provides a reference for the design of on-board reflector antennas.

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].

In order to achieve multi-beam coverage, the antenna needs to have a certain beam scanning capability. In order to obtain a better scanning capability and reduce scanning losses, feed clusters are often used to form the beam. The literature [2] investigates the scanning characteristics of 7-feed cluster in different defocusing states for large-aperture reflector antenna. The results show that the 7-feed clusters have some improvement on the scanning ability of the beam.

However, the effect of different number of feeds in cluster on the beam scanning characteristics remains to be investigated, and we would like to obtain lower scan loss and higher gain. Therefore, in this paper, based on the 7 feeder clusters, the scan characteristics of 19-feed cluster in different defocusing states are investigated, and the scan losses in different scan angles are analyzed.

2. Feed cluster defocus

In order to solve the problem of beam gain reduction and multi-beam coverage of a single feed at large scan angles, multiple feeds need to be arranged into a feed cluster. Joint optimization of the secondary pattern is performed, and beams are synthesized by changing the amplitude and phase of the feeds to improve the scanning characteristics. The number of feeds in the feed cluster is determined according to the requirements of the beam, and the arrangement generally includes isosceles triangle, rectangular and honeycomb arrangements.

Longitudinal defocus can also improve scanning characteristics to a certain extent. Feed cluster defocusing is divided into longitudinal defocusing and lateral defocusing. In order to facilitate the analysis, we established two coordinate systems, namely, the feed coordinate system x_f, y_f, z_f. The center origin of the feed coordinate system is at the focal point of the reflector surface, z_f points to the center of the reflector surface, and y_f is perpendicular to the paper surface inward. x_f, y_f, z_f are all satisfy the right-hand spiral rule.

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The longitudinal defocusing is a positive offset of the feed cluster by a certain distance along the z_f axis, and the lateral defocusing is a horizontal offset of the feed cluster along the x_f and y_f directions.

When the feed cluster is located on the focal plane, the feed power at the center of the feed cluster will be the largest, while the feed power at the edge will be small, so the power fluctuations between the feeds will be large, which is not conducive to the design of the power amplifiers in beam forming network. Longitudinal defocusing is beneficial to reduce the power fluctuations between the feeds participating in beamforming, and make the power distribution between the feeds tend to be even, as shown in Figure 1. Although longitudinal defocusing will cause a decrease in gain, it can allow more feeds to participate in beam forming, and can reduce scanning loss to a certain extent when scanning at a large angle.

To realize multi-beam scanning at different positions, lateral defocusing is often used. When the feed is defocused laterally, linear phase deviation and cubic phase deviation will be formed on the reflecting surface. The linear phase deviation will deflect the main beam of the pattern to the opposite direction of the feed defocus, and the stereo phase deviation will cause the main beam of the pattern Shift a certain angle in a certain direction, and finally realize the shift of the beam position.

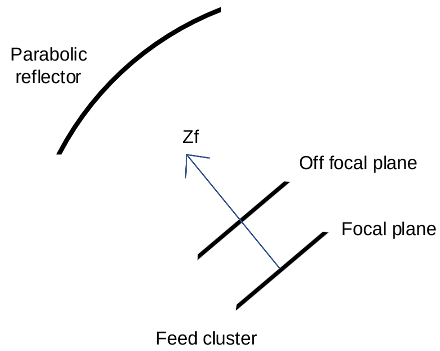


Fig. 1 Longitudinal defocus of the feed cluster

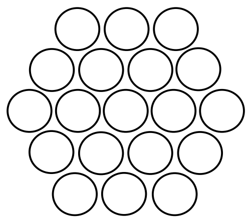


Fig. 2 Feed cluster

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.

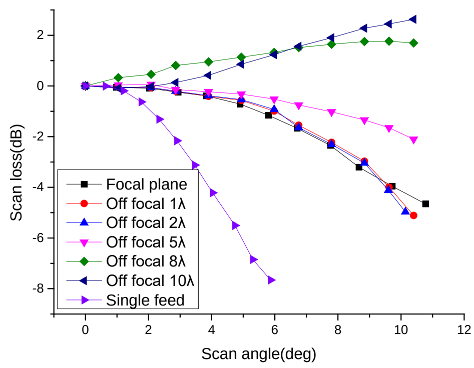
A plane wave is incident from an infinite distance in the same direction as the beam direction, and after irradiating the reflective surface a receptive field is formed in a finite region near the focal plane. The feed clusters are placed at the location where the energy of the receiving field is the 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 [3-5]. 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.

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

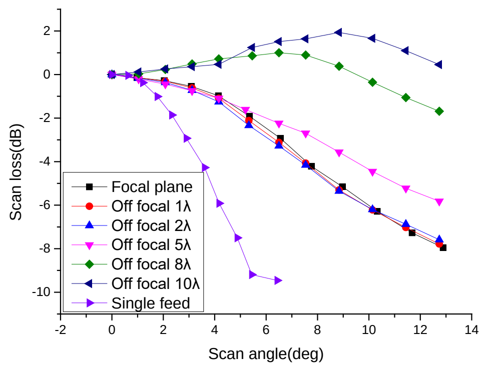
4. Research result

Taking the antenna as a model for simulation which equipped aperture of 84λ, focal length of 56λ, and center offset of 59.5λ, and the 19 feeds are arranged in a regular hexagonal honeycomb with aperture of 0.7λ and space of 0.77λ into a cluster, as shown in Figure 2.

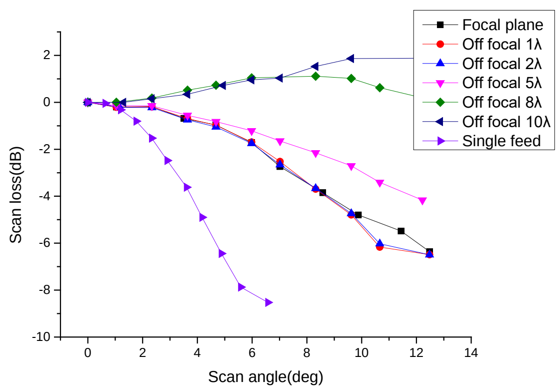
The feed clusters are scanned in the focal plane, defocused 1λ, 2λ, 5λ, 8λ and 10λ planes along the negative and positive directions of θ at $\varphi = 0^{o}$ and $\varphi = 90^{o}$, respectively, while the feed clusters are defocused horizontally along the positive, negative directions of x_f and positive directions of y_f, respectively. Its scanning loss curve in different directions is shown in Figure 3. 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.



(a) Positive direction of x_f



(b) Negative direction of x_f



(c) Positive direction of y_f

Fig. 3 Scan loss curves

Through the analysis of Figure 3, we draw the following conclusions:

(1) A feed cluster with a larger number of feeds can obtain better scanning characteristics. Compared with the 7-feed cluster, the 19-feed cluster can receive more energy of the radiation field,

especially at larger scanning angles. If the acceptable scanning loss is -4dB, the 19-feed cluster can scan up to 9.8° (Positive direction of x_f), and the 7-feed cluster can scan up to 6.1° (Positive direction of x_f), while the single feed can only scan 3.9° (Positive direction of x_f).

(2) The more number of feeds in cluster, the greater the beam gain will be achieved under the larger defocus distance. The peak gain at 0° scan angle at different longitudinal defocus distances is shown in Figure 4. After the defocus distance is greater than 2λ, the beam gain peak value is significantly reduced. Compared with 2λ, the gain of 7-feed cluster decreases by 4.8dB, and the gain of 19-feed cluster decreases 2.1dB.

(3) When the longitudinal defocusing distance is greater than 5λ, there will be no scanning loss, and the gain will increase with the increase of the scan angle. However, since the initial gain of the 0° scan angle is low, the gain is mainly affected by the loss caused by the longitudinal defocus. When the longitudinal defocus of the feed cluster reaches 10λ, severe defocusing occurs because the distance is too large. At this time, the receiving field pattern is seriously deformed. Because of the irregular deformation, a higher gain appears in a certain area, which improves the scanning loss to a certain extent.

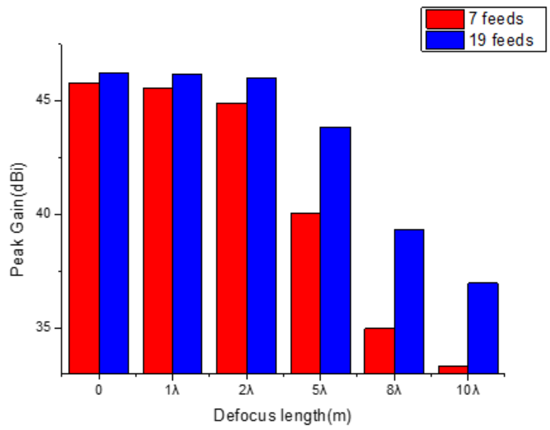


Fig. 4 Peak gain at 0° scan angle

We have noticed that when the beam is scanned to a large angle, the beam pattern will be severely deformed. At this time, the beam can no longer cover the required area, so discussing the beam gain and loss will lose reference value. In order to solve the problem of distortion of the beam pattern and keep the number of feeds in the feed cluster within a certain range, this can be achieved by changing the arrangement of the feeds. According to the energy distribution of the receiving field, the low-power feeds are discarded, and the feeds are arranged in the energy collection area, so that the feed clusters can receive as much energy as possible while maintaining a certain scanning loss.

5. Summary

In this paper, using the conjugate field matching method, based on the study of the scanning characteristics of the 7-feed clusters, the scanning characteristics of the 19-feed clusters in the scanning process are studied, and the influence of different number of feed clusters on the peak gain is analyzed. The simulation results show that compared with the 7- feed cluster, the 19- feed cluster can maintain a higher gain when the scanning angle is larger, and it can improve the scanning loss to a certain extent. The research in this paper has certain reference significance for the design of satellite reflector antennas in the future.

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