Multi-beam Antenna Analysis

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Abstract

This paper describes the antenna analysis of the multi-beam for communication satellite. The design core parameters of the antenna system are optimal antenna diameter, feed horn type and horn size, F/D, and the coordinate of offset horns. The paper deals with the method to determine design core parameters of optimal antenna diameter, feed horn type and horn size, F/D, and the coordinate of offset horns, and the performances of design result

Key Word : satellite antenna multi-beam reflector antenna; parabolic antenna

Introduction

This paper describes the mutibeam antenna analysis of communication satellite to meet the requirement of gain, sidelobe, cross-polarization discrimination and cross- polarization isolation, so on at circular three 0.7 deg service coverages of S Korea, N Korea, and Dong Bei with pointing error of ± 0.1 degree. The antenna system is the deployable type comprising two single offset reflector antenna attached at east panel and west panel of spacecraft at Ka-band frequency. Other key requirement is that N Korea and Dong Bei beam re-use the frequency, which is same for frequency but is different for polarization.

The design core parameters of the antenna system are optimal antenna diameter, feed horn type and horn size, F/D, and the coordinate of offset horns. Because the antenna system transmit and receive simultaneously with one reflector, the initial reflector diameter is roughly determined by the graph of EOC angle, which give the directivity vs antenna diameter for EOC angle. The scan angle of Dong Bei beam is determined by the coordinates of Dong Bei beam center, S Korea beam center, and satellite. The horn's offset angle from the focal point of S Koreas horn is determined by the beam deviation factor(BDF) and scan angle of Dong bei beam. By offset angle of Dong Bei's horn, the horn size is determined, and BDF is mainly determined by the F/D of antenna geometry. Also F/D effect the cross-polarization discrimination.

The paper describes the method to determine design core parameters of optimal antenna diameter, feed horn type and horn size, F/D, and the coordinate of offset horns, and the performances of design result

Antenna System Overview

The antenna system is intended to provide the satellite coverage to the South Korea, North

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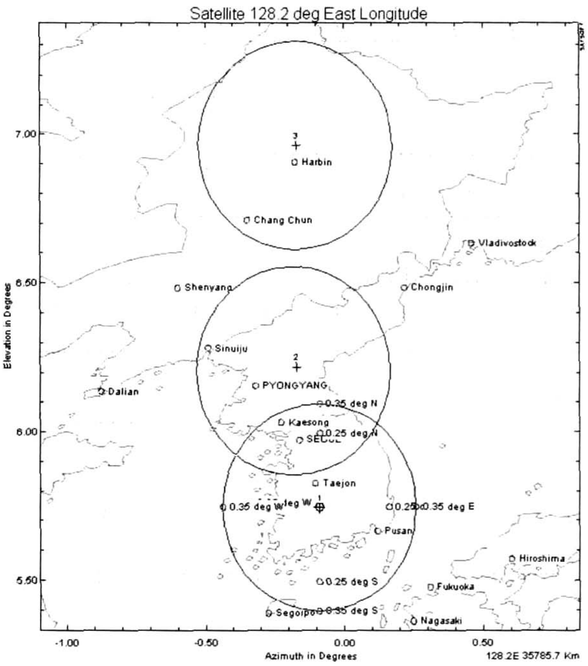

Fig. 1. Service Coverage

Korea, and Dong bei area (Northeast area of China) from a geostationary orbit location of 128.2 deg East longitude. The antenna system employs two(2) single offset reflector and three feed assembly. This geometry and the associated feed components support linear polarization for the communication services.

The antenna system comprise the two parts: East Panel and West panel of spacecraft. The antenna system for East panel of spacecraft comprise one(1) single Offset reflector assembly, and two(2) feed assembly. The antenna system also for west panel of spacecraft shall comprise one(1) single offset reflector assembly, and single(1) feed assembly. The antenna system supporting structure support the main, the horn and diplexer, and waveguide assemblies.

The service coverage area are circular, 0.7deg for transmit and for receive, centered about the beam axis. Typical beam coverages are shown in Figure 1 for both transmit and receive. This coverage includes 0.1deg pointing uncertainty. The frequency range 19.8 20.2 GHz for transmit and 29.60-30.00 GHz for receive.

A receive and transmit antenna provide the vertical polarization for South Korea area, horizontal polarization for North Korea area, and vertical polarization for Dong bei area. The gain slope at EOC without pointing error is less than 11 dB/deg in receive frequency band, and less than 22 dB/deg in transmit frequency band. Other requirements are that sidelobe level is more than 20 dB, and EOC directivity at 0.7 deg are 43.46 dBi for transmit, and 44.99 dBi for receive. The cross-polarization isolation is more than 30 dB.

Ka-band Multibeam Antenna

Ka-band Antenna Properties

Because the antenna system transmit and receive simultaneously with one reflector, the initial reflector diameter is roughly determined by the graph of EOC angle, which give the directivity vs the antenna diameter for EOC angle. The on-axis directivity Go for a uniformly illuminated circular aperture of the diameter D is

$$G_o(\text{dB}) = 10\log(110\ \eta D_m^2\ f_{GHz}^2) \qquad (1)$$

Where the coefficient factor of antenna is $0 \le \eta \le 1$. For a uniformly illuminated aperture, the half-power (3dB) beamwidth is:

$$\theta_3 = \frac{\lambda}{D}\ \text{rad} \quad \text{or} \quad \theta_3 = \frac{k\lambda}{D}\ \text{deg} \qquad (2)$$

Where k is beamwith constant. In this case, k is 57.297. But the edge taper of a practical antenna is 5dB to 20 dB, and the average is about 15 dB. In this case, k is around 70. Therefore,

$$\theta_3 = 70\frac{3}{10.\, f_{GHz} D_m} \text{ deg} \tag{3}$$

$$\theta_3 = \frac{21}{f_{GHz} D_m} \tag{4}$$

The gain of the antenna near axis can be approximated by a number of functions, including a squared trigonometrical function.

$$G_{\text{off}} = G_o \cos^2\left(90\frac{\theta_{off}}{\theta_3}\right) \tag{5}$$

Because the directivity Do at the off-axis angle is the same as the directivity at EOC angle of satellite. Therefore, using the equation(5), one can find the directivity vs antenna diameters for several EOC angle. Requirement of EOC directivity at 0.7 deg are 43.46 dBi for transmit, and 44.99 dBi for receive at Ka-band frequency. In the case, the optimal diameter is about 1.1 m as shown in Figure 2.

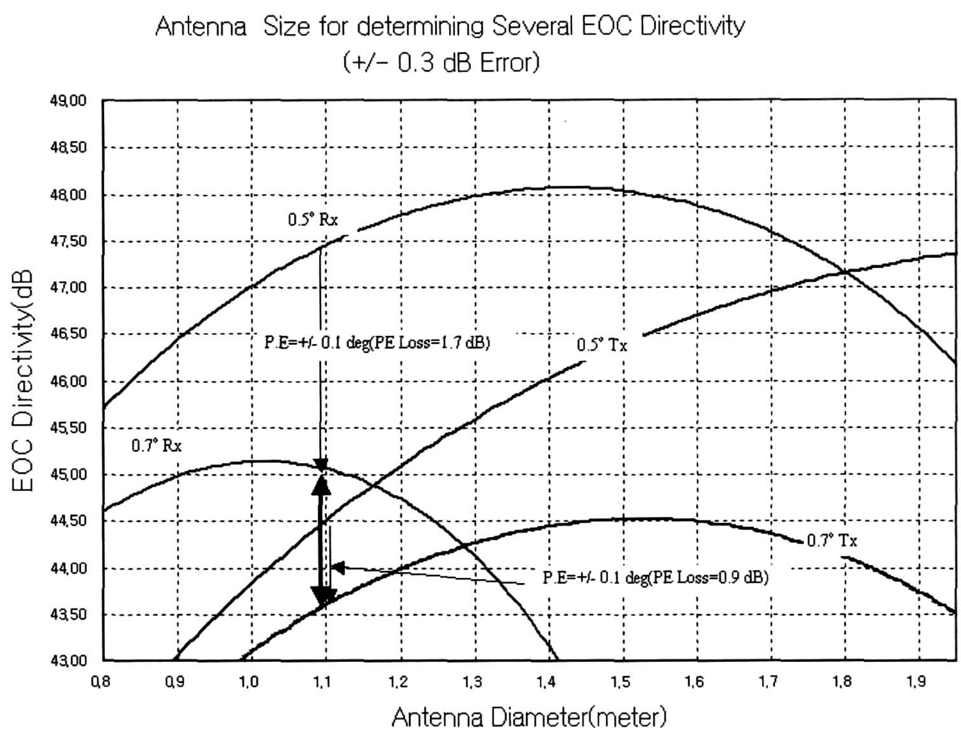

Fig. 2. EOC Directivity vs antenna diameter at 20/30 GHz

Antenna Configuration

The scan angle of Dong Bei beam is determined by the coordinates of Dong Bei beam center, S Korea beam center, and satellite, which is 1.219 deg from S Korea Beam center. The horn's offset angle from the focal point of S Koreas horn is determined by the beam deviation factor(BDF) and the scan angle of Dong bei beam. As the results, the beam deviation factor(BDF) is 0.989 for F/D of 1.6 considering the cross-polarization isolation of 30 dB, and the horn's offset

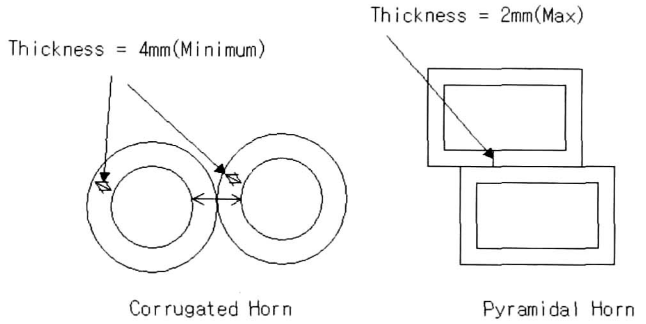

Fig. 3. Corrugated Horn and Pyramidal Horn Comparison

angle is 1.2325 deg . This result of the offset angle result in 3.99cm, and 2.8cm for y-axis, and x-axis, respectively at antenna coordinate.

Because the distance between the center of S Korea horn and the center of Dong Bei horn is 3.99cm. The maximum diameter of horn including horn's thickness and spacing between two horns is less than 3.99 cm. There could be the choice for pyramidal horn and corrugated horn. It is known that the corrugated horn has better performances than pyramidal horn. But for getting identical edge tapers which are 7 dB for Tx frequency, and 14 dB for Rx frequency, the aperture size of corrugated horn must be larger than that of pyramidal horn.

The corrugated horn's thickness also is larger than pyramidal horn as shown Figure 3. Therefore, the pyramidal horn is used as the horn of reflector antenna as shown in Figure 8. The final antenna design results and configuration are as shown in Figure 4 and Figure 9. The focal length(F1) for S Korea beam and F2 for Dong Bei beam are 1760 mm and 1758.618 mm, respectively. The half edge tape angle is 16.818 degree.

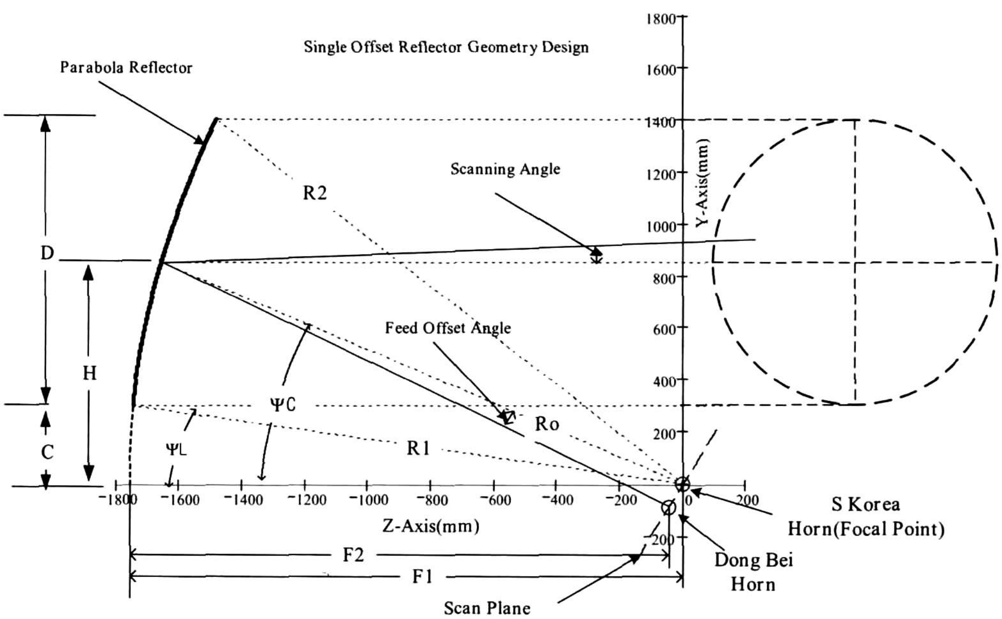

Fig. 4. Antenna Configuration of S Korea and Dong Bei Beam

Antenna Performances

The cross-polarization discrimination of horn to meet cross-polarization isolation of 30 dB in antenna system should be more than 30dB at the edge taper angle of 16.818 degree. The simulation results of horn's x-pol discrimination are 40 dB, and 45 dB for Tx and Rx, respectively as shown in Figure 5.

All performance results such as EOC gain, gain slope, sidelobe level, cross-polarization discrimination and isolation meet the antenna requirement as shown in Figure 6 and Figure 7.

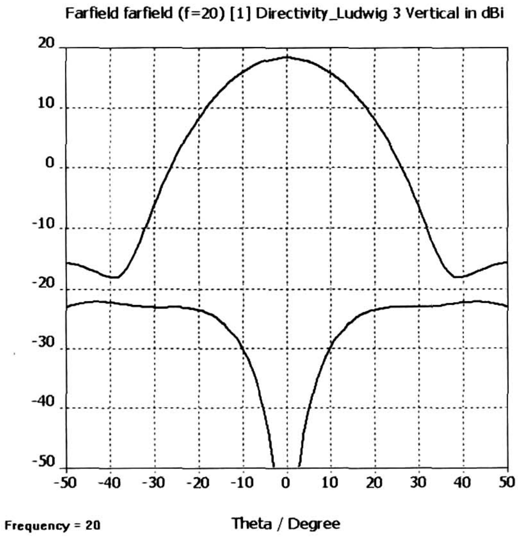

Fig. 5. Simulation results of horn's

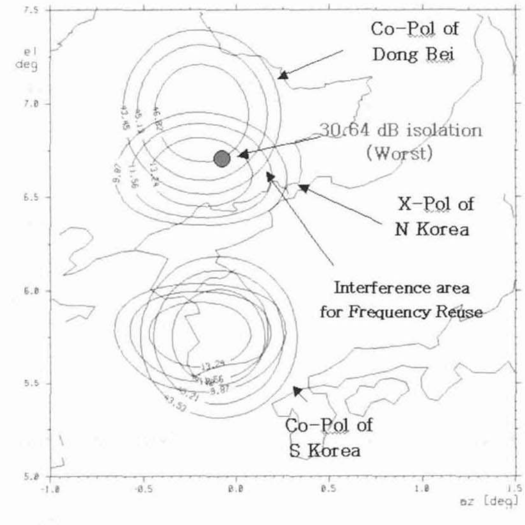

Fig. 6. Directivity Contour pattern (30 GHz) X-pol discrimination(20 GHz)

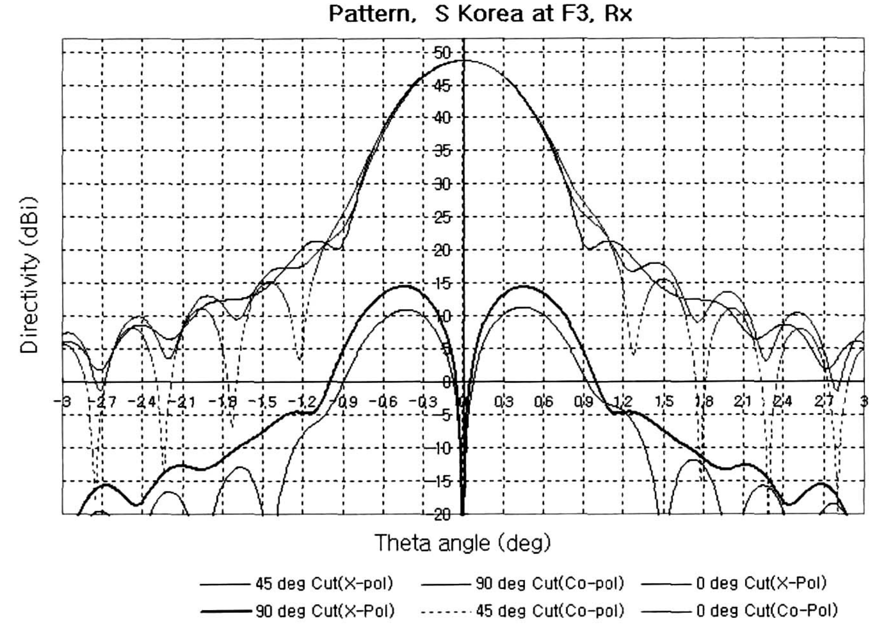

Fig. 7. Tx Co-POL Directivity / X-POL Cut at 30.0 GHz, S Korea

Conclusions

All performances of the antenna meet the antenna requirement. But there are performance degradation EOC gain sidelobe level for Dong Bei beam due to horn offset. The scan loss of Dong Bei beam is 0.05 dB. The sidelobe isolation of Dong Bei beam is more high than S Korea beam.

The calculation of pyramidal horn pattern was performed by CST tool, and the pattern simulation of the antenna system was Grasp8 S/W from TICRA company.

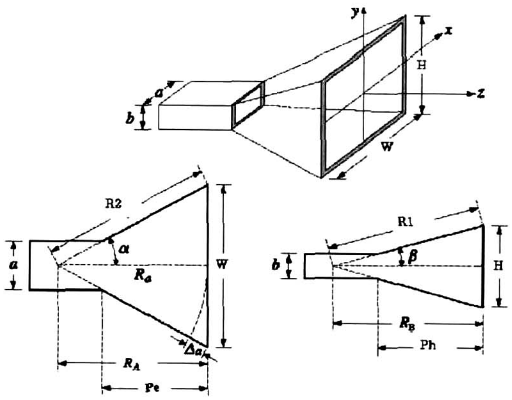

Fig. 8. Design Geometry of Pyramidal Horn

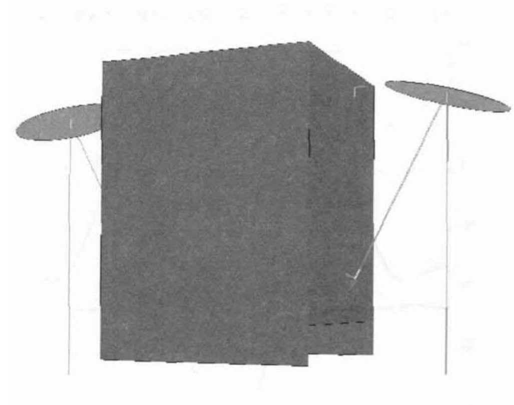

Fig. 9. Designed Two antenna Configuration

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