Feed System Design of a Parabolic Reflector Antenna for Malaysia Shaped Beam Coverage

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***Abstract*—For Malaysia satellite communication services, MEASAT 3 is now in operation. Based on the satellite footprint, the contour beam shape for Malaysia coverage can be improved by employing multi-beam technology. In order to achieve precise multi-beam positions in a parabolic reflector antenna system, adequate feed horn positions are clarified through focal region ray tracings. In this paper, feed horn positions for practical Malaysia beams are determined based on the focal region data. Next, radiated beams of a parabolic reflector antenna are calculated by using the electromagnetic simulator. Through achievement of excellent beam shapes and positions for Malaysia region, the adequateness of feed horn position designing is ensured.**

***Index Terms*—Multi-beam; Satellite Communication; Parabolic Reflector Antenna; Feed Horn Position; Focal Region Ray-tracing.**

I. Introduction

For Malaysia satellite communication services, MEASAT 3 is now in operation[1]. MEASAT 3 has been designed for two main purposes which are additional capacity and satellite redundancy where it is able to operate both in C-Band and Ku-Band used for the Direct-to-home (DTH), video distribution and other Fixed Satellite Service (FSS) services. However, through observation on the satellite's footprint for Malaysia, further, improvement can be done to achieve a more precise coverage beam to maintain constant signal strength to the coverage area and in the meantime to avoid disruption from the unwanted region. For smaller beam size, the concentration of radiated power is higher and more consistent. By adopting this concept, the coverage beam for Malaysia can be improved by employing multi-beam technology.

In a broadcasting satellite system, several studies have been done by previous researchers to generate multi-beam with optimum feed position of a reflector. As a fundamental study, the theoretical concept of caustic at the surface of a reflector was derived in [2]. Caustic surface equations at focal region were derived with consideration of two planes which is elevation and vertical directions. This concept was applied in [3] through the development of a ray-tracing program in MATLAB to illustrate the ray traces and curves. To achieve precise beam shaping, precise feed horn design is important. The precise feed horn positions were calculated through focal region ray tracing for parabolic reflector antenna [4]. In designing precise Malaysia beam coverage, feed horn positions based on the focal region data will be useful.

In this paper, Malaysia coverage beams by multi-beams are composed as shown in Figure 1. For Peninsular Malaysia coverage area, 5 narrow beams labelled as B1, B2, B3, B4 and B5 are needed to produce a precise, contoured beam. Each beam size is 0.3°. By using feed horn data of the focal region ray tracing, feed position for individual beams are determined. In order to ensure beam positions shown in Figure 1, radiation beams are obtained by electromagnetic simulations for a parabolic reflector antenna. Through achievement of excellent radiation patterns in many beams, adequateness of feed designing and the possibility of precise multi-beams are ensured.

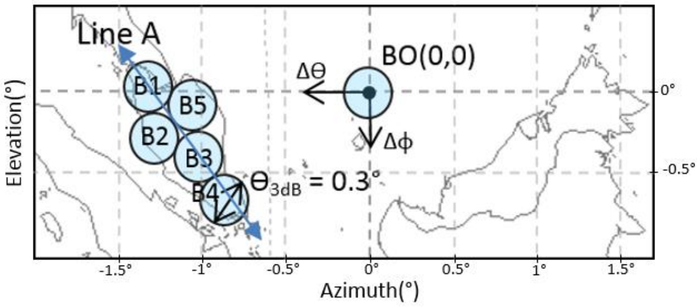

Figure 1: Beam Coverage of Malaysia Area

II. Antenna Design for Peninsular Malaysia

Geographically, Malaysia comprises of two part which is Peninsular Malaysia and Borneo Malaysia as shown in Figure 2. In this paper, multi-beam design of Peninsular Malaysia is observed.

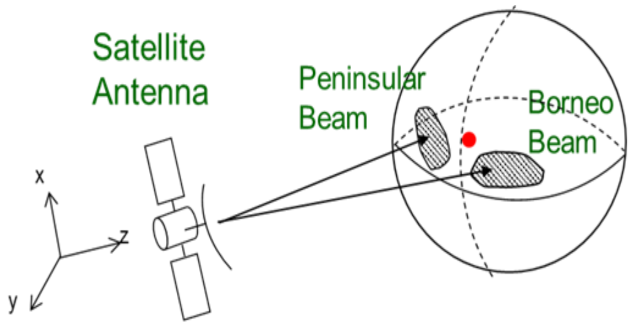

Figure 2: Malaysia beam from satellite point-of-view

A. Antenna configuration

The antenna structure and illustration between parabolic reflector and horn antenna are shown in Figure 3. To achieve contoured beam, distribution of multiple horns are required. The positions of the distributed feed horns must be arranged on the caustic locus to ensure that the radiated beam would not overlap with each other.

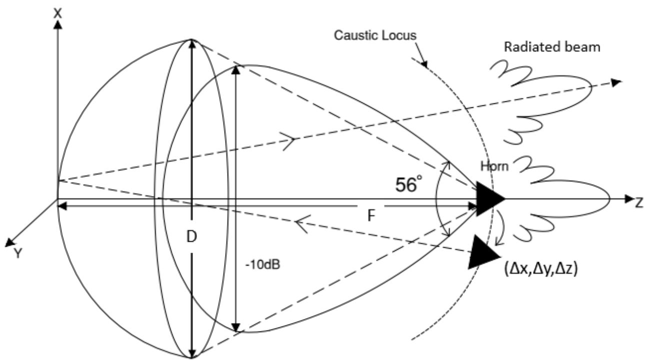

Figure 3: Parabolic reflector antenna with feed horns

B. *Antenna parameters*

Based on the configuration in Figure 1, an antenna for Fixed Satellite Services (FSS) [5] operated at 7.5GHz with 0.3° beam width was studied and demonstrated. Table 1 shows the antenna parameters used in designing the feed system that influence the performance of the parabolic antenna.

Table 1
Antenna Parameters

Item	Parameters	Value
Parabolic Reflector	Frequency	7.5GHz
	Wavelength (λ)	0.04m
	Diameter, D	10m
	Focal length, F	10m
	Edge Angle (Θ_E)	56°
Horn Antenna	Height of Horn aperture (*hh*)	0.065m (1.6λ)
	Width of horn aperture *(hw)*	0.1m (2.5λ)
	Length of Horn *(hl)*	0.08m (2λ)
	Height of waveguide segment *(wh)*	0.02m (λ/2)
	Width of waveguide segment (*ww*)	0.04m (λ)

Antenna diameter, D is chosen as 10m based on antenna beam width and side-lobe level (SLL) requirements. In a practical design of rectangular aperture antenna, it can be approximated as radially symmetric apertures with field amplitude distribution, which is tapered from the center toward the aperture edge [6]. Thus, by taking into account tapered value, D is estimated as follows:

$$D = 1.22 \frac{\lambda}{\theta_{3dB}} \quad \text{[rads]} \tag{1}$$

In designing parabolic reflector antenna, the focal-length-to-diameter ratio (F/D) is an important element which represents the size and curvature of a reflector. As the value of F/D increases, the cross polarization in the reflector aperture also decrease. In this paper, the value of F/D was set as 1.

The edge angle (Θ_E) measured from the feed axis to the reflector edge can be defined in terms of F/D [6] by using the following equation:

$$\tan\frac{\theta_E}{4} = \frac{1}{4\left(\frac{F}{D}\right)} \tag{2}$$

For proper illumination of a parabolic reflector, the feed pattern must be matched to the reflector. The reflector edge angle (Θ_E) is selected to be almost two times of the horn null angle (Θ_N) as shown below:

$$2\theta_N = \theta_E \tag{3}$$

III. FEED DETERMINATION BY RAY TRACING METHOD

In order to find the caustic locus of a parabolic reflector antenna, previously developed a focal region ray tracing program on MATLAB is employed. The calculation of the ray tracing results is shown in Figure 4. The ray concentration positions for incoming wave are at Θ_{in} = 0°, 10° and 20°. Larger Θ_{in} was chosen instead of small value for Malaysia beam because it is easier to analyze the behavior and trajectory of the caustic locus due to small changes of Θ_{in}.

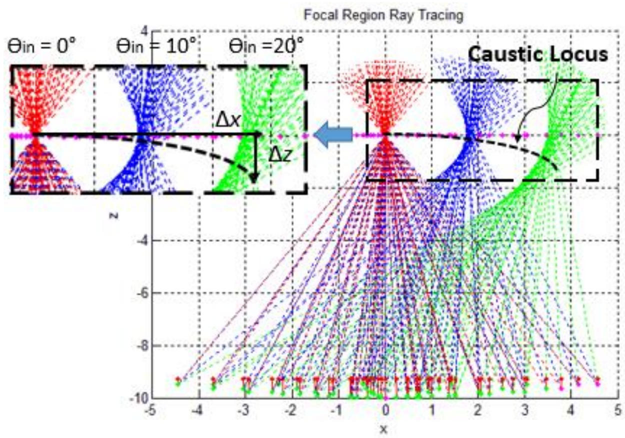

Figure 4: Focal region ray tracing method

The Beam Deviation Factor (BDF) concept has been widely used to demonstrate the dependency of feed position on F/D based on the aperture-phase aberration for antennas with arbitral F/D value [7]. BDF equation is given by:

$$BDF = \frac{\sin\theta_{in}}{\tan\theta_f} = \frac{1 + 0.36\left(\frac{D}{4F}\right)^2}{1 + \left(\frac{D}{4F}\right)^2} \tag{4}$$

Figure 5 shows the relation between feed position, beam direction and radiated beams. By considering BDF, the radiated beam F_1 shows shifted beam direction produced by the off-focus feed (F_1). The dependency of the feed position with F/D ratio was explained in Equation (4). As for small changes of feed displacement, the position from the *x*-axis direction can be estimated by equation (5) below:

$$\Delta x = \frac{F}{BDF}\sin\theta_{in} \tag{5}$$

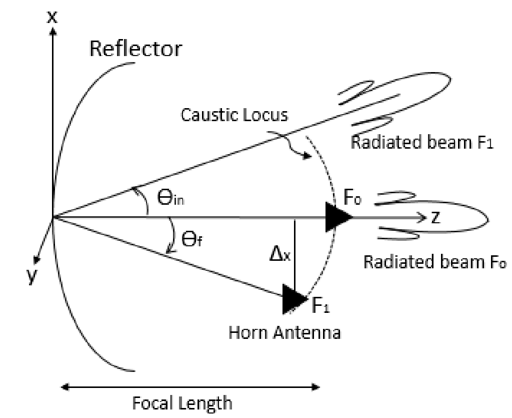

Figure 5: Relation of feed points and radiated beams

However, the feed displacement Δx only shows one-dimensional (1D) beam direction. Here, in order to obtain two-dimensional (2D) beam plot, the distances from the center of the reflector to the caustic point can be estimated by *S(x,z)* where:

$$S(x,z) = F\cos\theta_{in} \quad (6)$$

Thus,

$$\Delta z = \sqrt{F^2 + \Delta x^2 - S^2} \quad (7)$$

In accordance with the good agreement of all curves, it is shown that the best feed position can be determined by using equation (5). Caustic locus line, S(x,z) represent the position of the feeds distribution to achieve contoured beam .Thus, by using equation (4) - (7), the multi-beam antenna feed position can be determined by implementing ray tracing method.

IV. CALCULATION RESULTS OF MULTI-BEAMS

A. *Simulation parameters*

The simulation details are shown in Table 2 below. Geometrical Optics (GO) is chosen as simulation method to perform far-field simulation result by using FEKO Suite 6.2 Electromagnetic Simulator. GO method is a ray-based technique that modelled object based on optical propagation with reflection and refraction theory where the interference can be neglected [8]. This method is chosen due to its capabilities to handle very large structures or model. It can handle much larger structures compared with others method because the mesh only needs to resolve the surface geometry which is a smooth surface that applicable for the reflector. Thus, resulting in a large reduction in mesh storage requirements (Memory requirement) and very fast calculation. In order to ensure the accurateness of the feed position, the far-field simulation data was imported into third party software which is Origin Lab to perform two-dimensional (2D) contour plot.

Table 2
Simulation parameters

Item	Parameters	Details
Software	Simulator	FEKO Suite 6.2
	Data analysis	Origin Lab
Computer	Memory (RAM)	12 GB
	Clock time	2.2 GHz
	Simulator	FEKO
	Method	GO
Calculation process	Simulation Memory	3.8 GB
	Simulation Time	2m 32s

B. *Feed horn design*

As a feed horn, a rectangular horn antenna as shown in Figure 6 is employed. The beam-width, Θ_H of a horn is given by equation (7).

$$\theta_H = 1.2\frac{\lambda}{h_w} \quad (7)$$

Here, Θ_H becomes almost same as the null-angle (Θ_N). So, Θ_H = 28° is given for the Θ_E = 56° reflector by equation (3). The horn size of *hw* = 0.1m and *hh* = 0.065m is given. The radiation pattern of the horn is shown in Figure 6. At the reflector edge position, edge level of -11.6dB is achieved. This edge level is adequate to illuminate the reflector.

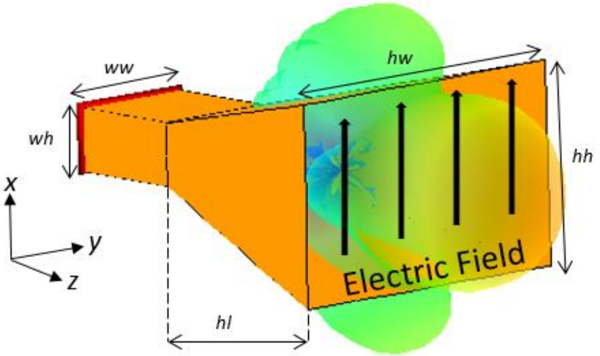

Figure 6: Feed horn structure

Figure 7 shows the obtained radiation pattern of the pyramidal horn antenna as shown in Figure 6. In order to achieve high aperture efficiency design of a parabolic reflector antenna, the feed radiation pattern must be rotationally symmetric [9]. As observed from the figure, the gain variation is almost symmetrical in both E-plane and H-plane. In the E-plane radiation pattern, the half power beam width (-3dB) become 28° while in the H-plane radiation pattern the half power beam width (-3dB) become 28.2° which is almost equivalent from the theoretical Θ_H predicted from the equation (7). From equation (2), the calculated value for the reflector edge level is 56°. This value agrees well with the measured edge level angle, Θ_E at -11dB down from the maximum gain value. This condition satisfies the concept shown in equation (3),where Θ_E is double from Θ_N for the designed pyramidal horn antenna [6].

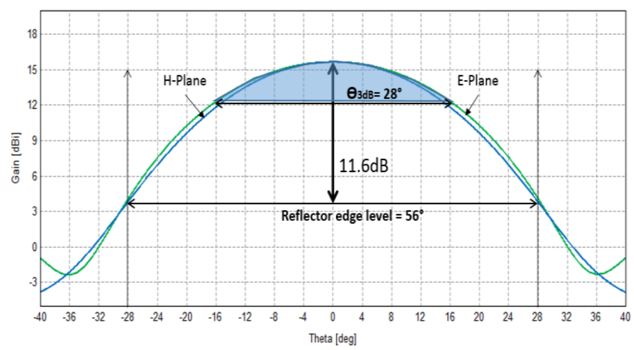

Figure 7: Pyramidal horn radiation pattern

C. *Feed arrangement*

The relation of the beam allocation and the feed displacement is summarized in Table 3. Δx and Δy are calculated by using equation (5) for Θ_{EL} and Θ_{AZ} values, respectively. Δz is calculated by equation (7). Based on Table 3, practical feed horn allocation is shown in Figure 8. Feed positions become a mirror positions of beam position around the coordinate origin.

Table 3
Feed horn position in FEKO

Item	Beam Allocation		Feed Displacement		
	Θ_{AZ}(°)	Θ_{EL}(°)	Δx	Δy	Δz
B1	-1.32	0.03	-0.01	-0.24	-0.005
B2	-1.3	-0.29	0.05	-0.23	-0.005
B3	-1.03	-0.42	0.08	-0.18	-0.003
B4	-0.88	-0.68	0.12	-0.16	-0.002
B5	-1.05	-0.1	0.02	-0.19	-0.004

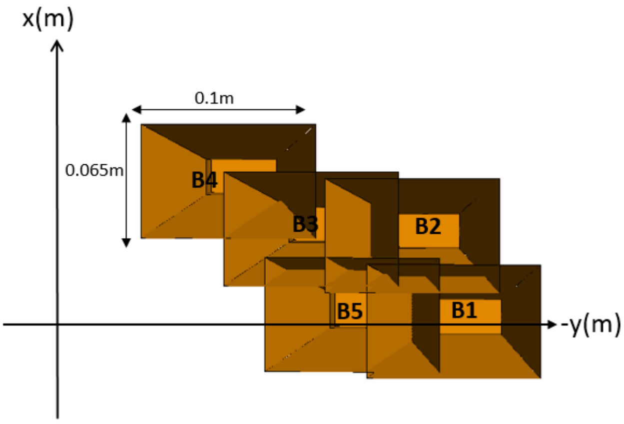

Figure 8: Feed horn arrangement

D. Radiation pattern

Simulation results of radiation patterns from a parabolic reflector by a FEKO simulator are shown in Figure 9. As a reference, on focus beam B0 is shown. B1, B3 and B4 beam are cross-sectional beams on Line A as shown in Figure 1. At B1, the shape of the main beam and side lobes are maintained very well compared to B0 shape. Due to shifted position of feed from the center of the reflector, the antenna gain of B1 beam was decreased, yet in very small value such as 0.2dB. Based on the reference beam B0 at (0, 0), no deformation occurs in term of the beam shape. Table 4 below shows the gain obtained for all incident beam in Peninsular Malaysia. By achieving good radiation pattern at the B1, B3, and B4 beam, it is concluded that the feed position designing is very accurate.

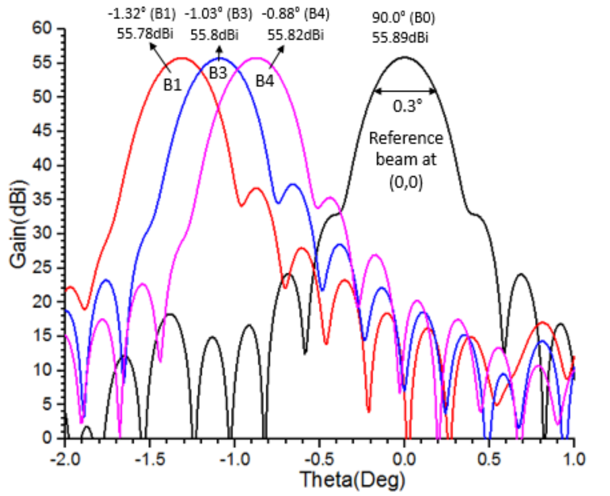

Figure 9: One-dimensional radiation pattern of beam on Line A with reference beam at (0,0)

Table 4
Beam position and gain achieved

Beam Points	Gain (dBi)
B1	55.78
B2	55.68
B3	55.8
B4	55.82
B5	55.75

The calculated two-dimensional radiation pattern is shown in Figure 10. -3dB contours are shown by black circles at all beams. Beam allocation agrees very well with the designed target of Figure 1. In order to check the beam allocation accuracy, beam center angles agree very well with the target angels as shown in Table 5. By this good agreement, adequateness of feed position designing is ensured.

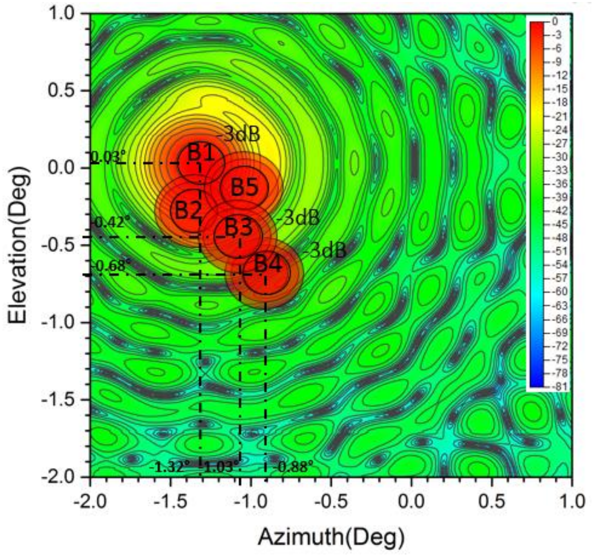

Figure 10: Two-dimensional radiation pattern view for Peninsular Malaysia

Table 5
Designed beam position

Item	Target		Achieved	
	Θ_{AZ}	Θ_{EL}	Θ_{AZ}	Θ_{EL}
B1	-1.32°	0.03°	-1.32°	0.03°
B2	-1.3°	-0.29°	-1.3°	-0.29°
B3	-1.03°	-0.42°	-1.03°	-0.42°
B4	-0.88°	-0.68°	-0.88°	-0.68°
B5	-1.05°	-0.1°	-1.05°	-0.1°

V. Conclusion

For the precise Peninsular Malaysia coverage, multi-beam forming of a parabolic reflector antenna is applied by using horn antenna as the feeding elements. In order to determine accurate feed position, focal region ray tracing results are used. In the feed design, a pyramidal horn antenna was designed and arranged accordingly based on the Peninsular Malaysia beam area on earth. The adequateness of the feed position in this paper is verified through detailed simulation via FEKO Electromagnetic Simulator. Through the calculated radiation patterns, the result of the beam shift obtained shows good agreement with no difference between the targeted area and measured area for these 5 beams as shown in Table 5. The accurate beam positions achieved with no deformation and very small gain deduction which is 0.2dB. As a result, the accuracy of the ray tracing method to obtain the best feed position designing and the possibility of precise Malaysia coverage are ensured.

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