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Compact antenna system for dual beam application in GSAT-1 satellite

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Abstract : The indigenously developed Geo-Stationary Launch Vehicle (GSLV) will launch GSAT-1 communication satellite. The antenna is catering uplink service for two different coverages : Indian region and South African countries. The antenna configuration is 0.4 m single offset reflector antenna with two feed horns system. The frequency band of operation is 5.850-6.370 GHz with gain requirement of 21 dBi over the very wide two separate coverages of the order of 8.0°. The paper deals with the design and analysis considering various factors such as EOC gain requirement over the dual wide coverages, with constraint of volume and feed inter-element spacing, focal length to reflector diameter ratio (*f/d*), offset angle, offset distance. The scope of this paper is limited to dual coverage antenna design and analysis, where a single offset parabolic is used as an aperture.

Keywords : Compact Antenna, dual beam application, GSAT-1 satellite

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1. Introduction

The basic purpose of realisation of more than one beam is to use same frequency number of time with specified polarisation for optimum utilisation of frequency spectrum. This is the current trend for the communication satellites [1,3]. A compact antenna system for dual beam has been realised for the GSAT-1 Comm. Satellite. The antenna beam centre directions are 90°E, 35°N and 25°E, 8°S for India and South Africa Coverage respectively considering antenna axis direction 55°E, 10.5°N and 55°E Geo slot for GSAT-1 Satellite parking.

The development of dual coverage beam with single offset reflector antenna is taken up first time at C-Band frequency. The avoidance of aperture blockage implies that offset reflector offer good potential for multi-element feed array and Multiple Beam Antenna (MBA) realisation. The feed element positions are determined from reflector geometry and the beam coverage requirements. The feeds are laterally displaced from the focus in the focal plane to scan the respective beam to meet the specified coverage requirement. An offset reflector with two displaced feeds is the final antenna configuration as shown in Figure 1. The small flare angle dominant TE11 mode conical horn was used as its aperture size is 11% (approx.) smaller than dual mode and corrugated horn for the same performance.

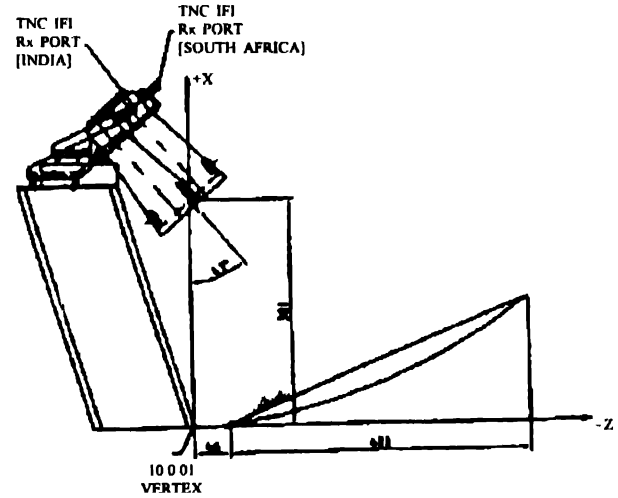

Figure 1. 0.4 M dual coverage fixed offset reflector antenna, GSAT-1

For the existing coverage requirements, the beam separation distance has imposed stringent limitation on feed element aperture size due to insufficient inter-element spacing.

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This leads compromise between element aperture diameter and achievable feed-element illumination taper. This further affects overall antenna performance [1, 3, 4].

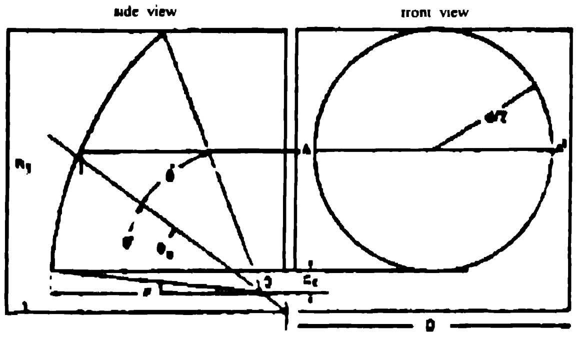

Figure 2. Offset Reflector Geometry

2. Theory

The offset reflector is unique for the larger feed size and easy reflector deployment to realise a compact antenna system. It also reduces the reaction of the reflector upon the primary-feed to a very low order. The excellent isolation between reflector and primary-feed implies that the primary-feed VSWR can be made to be essentially independent of the reflector. When multiple-element or dual polarised primary-feed elements are to be employed; the mutual coupling occuring between feed element via the reflector can be reduced to an insignificant level.

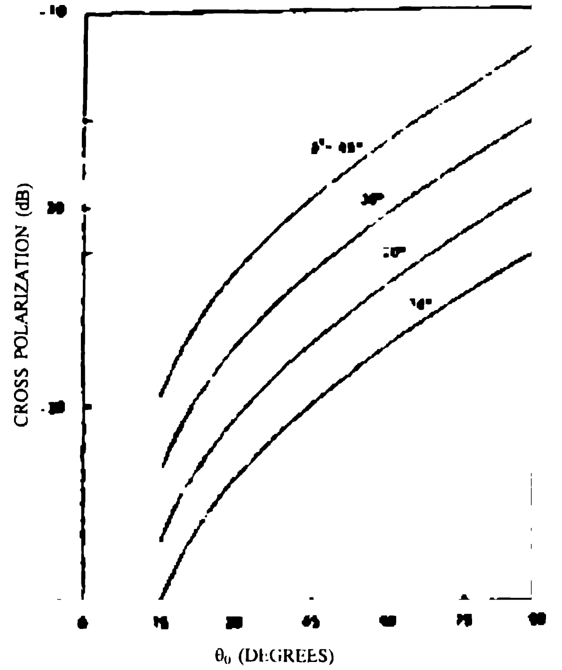

Figure 3. Peak cross-polar levels radiated in the plane of asymmetry (ϕ = ½) as a function of the offset reflector parameters θ_0 and θ'.

The cross polarisation performance of an offset reflector antenna mainly depends on offset angle (θ_0), f/d ratio and feed cross-polar performance as shown in Figure 3 and relatively insensitive to the feed-imposed illumination taper [1]. Lateral displacement of the feed of a parabolic antenna causes the beam to scan on the opposite side of the reflector axis [2].

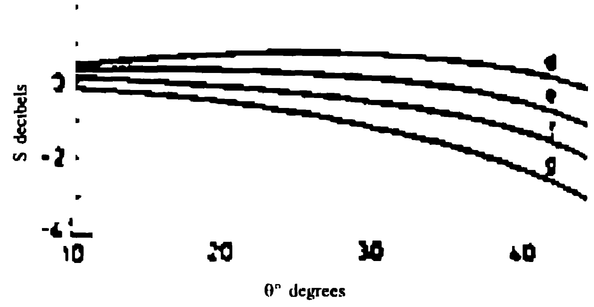

Figure 4. Space attenuation factor for offset reflection, including additional ½ (1 + cos θ') term from feed expression. For plane of symmetry use (d) θ_0 = 45°, (e) θ_0 = 40°, (f) θ_0 = 35° For plane of asymmetry use curve (g) for any offset angle

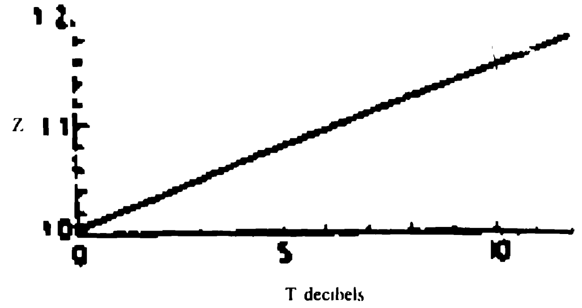

Figure 5. Beamwidth factor N as a function of reflector illuminator taper

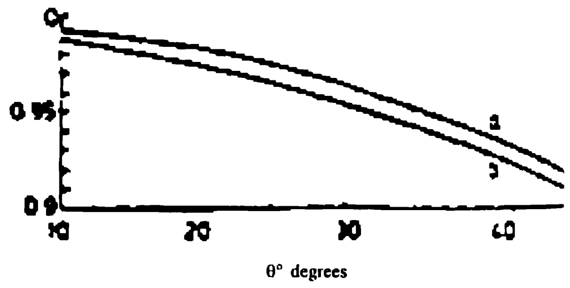

Figure 6. Beam deviation factor with mean reflector illuminations of (a) −10 dB and (b) −6 dB

The ratio of beam scan angle to feed scan angle is defined as the beam deviation factor (BDF), generally of the order of 0.85 to 0.98 as shown in Figure 6. The reduction in gain, beam broadening, increase in sidelobe on axis side and decrease in sidelobe on other side, increase in peak cross polarisation level and shifting of its null in the same direction that of co-polar beam are the common phenomena with beam scanning and on number of Half-Power Beamwidth (HPBW), factor (δ), scanned (1).

The mutual coupling depends on operational frequency and polarisation of each element, type of element and separation between the feed element. Further, the mutual coupling affects both co-polar and cross-polar radiation performance of an antenna [4].

3. Design theory

To design a dual beam or multiple beam antenna system, stringent limits are imposed by the element pattern, number of element and their inter-element spacing, total size and weight of feed array. The feed elements used are circular-aperture conical horn with non-optimum aperture diameter (dm = 68 mm) due to constraint of inter-element spacing.

In the electric design of a dual beam offset reflector antenna, a large number of parameters, see Figure 2, must be taken into account [1,3]. To illustrate the design process a step-in-step procedure is essential as shown in Table 1.

Table 1. Design Procedure Steps.

Step	Operation	Output
1	Specify projected aperture diameter	d
2	Specify reflector parameters	F, θ_0, θ^*
3	Specify primary-feed parameters	type, bn
4	Determine primary-feed locations	δn, $\varnothing n$
5	Outline performance estimate	HPBW, gain, sidelobe, cross polarisation, & check feed inter-element spacing

The secondary pattern half power full beam width ($\psi_{\rm on}$) for an on-axis beam is given by eq. (1), where d is the projected diameter of offset reflector and T is the feed-illumination taper which can be estimated using eq. (4) [see Figure 4]. This equation is valid for feeds located close to the focal point of the reflector and is modified to include the beam-broadening effect with scan, θ(scan), as given by eq. (2) and shown in Figure 5.

$$\psi_{\rm on} = (0.762T + 58.44)\ \lambda/d, \text{ in degree,} \tag{1}$$

$$\theta(\text{scan})\ \theta s = \psi_{\rm on} * 10^{0.05GL}, \text{ in degree.} \tag{2}$$

Gain Loss (GL) due to scan is given by

$$GL(dB) = \frac{0.0015\delta^2}{[(F/Dp)^2+0.02]^2} + \frac{0.0011\delta^2}{[(F/Dp)^2+0.02]} \tag{3}$$

where δ is the number of beamwidths ($\psi_{\rm on}$) scanned from boresight and Dp is the diameter of the parent parabolic reflector. For offset reflector antenna geometry, half power beamwidth ($\psi_{\rm on}$), half subtended angle (θ^*), feed clearance distance (dc) and effective focal length (Fe) are estimated using eqs. (1), (5), (6) and (7) respectively.

$$T = -20\ \log_{10}[\exp\{-0.3467\ [\theta^*(dm/\lambda)/31]^2\}], \tag{4}$$

$$2\theta^* = 2\tan^{-1}[(2Fd)/(4F^2 + h(d+h)], \tag{5}$$

$$dc = 2F\tan[(\theta_0 - \theta^*)/2], \tag{6}$$

$$Fe = F[(1+\cos\theta^*)/(\cos\theta_0) + \cos\theta^*)], \tag{7}$$

where dm = feed aperture diameter.

Then feed location coordinates, feed aperture radius (bn), phase centre location radial distance from focus (δn), and phase centre polar angle ($\varnothing n$) is given by eqs. (8) and (9).

$$\delta n = (Fe/BDF)$$

$$\sqrt{(\sin^2\psi_n + \sin^2\psi_s \pm 2\sin(\psi_n)\sin(\psi_s)\sin(\Phi_n))} \tag{8}$$

$$\varnothing n = \text{arc}\ \tan\left[(\sin(\psi_n)\sin(\Phi_n) \pm \sin(\psi_s))/ (\sin(\psi_n)\cos(\Phi_n))\right] \tag{9}$$

$$df = \sqrt{(x_1 - x_2) + (y_1 - y_2)} \tag{10}$$

where ψ_n is the boresight pointing angle of n-th beam, Φ_n is the azumuthal pointing angle of n-th beam and ψ_s is the beam squint angle. Using δn and Φn, one can calculate the x and y component of each feed element location as $y_n = \delta n\ \sin(\Phi n)$ and $x_n = \delta n \cos(\Phi n)$ for respective beam. Then the inter-element distance (df) can be given by equation (10).

4. Results

The measurements were carried out on the far field range with automated test set-up with raster scanning technique defining grid size of −10 to +10 degree in azimuth and elevation with 0.1 degree step in both directions. This was required to acquire sufficient co-polar and cross-polar radiation patterns data for the generation of coverage contours-footprints. The measured VSWR is of the order of 1.22 while mutual coupling between beamport is −40 dB. The measured sidelobe levels are within 19–21 dB with 2–3 dB imbalance in levels. The predicted and measured gain and cross polarisation isolation contours are shown in Figures 7, 8, 9

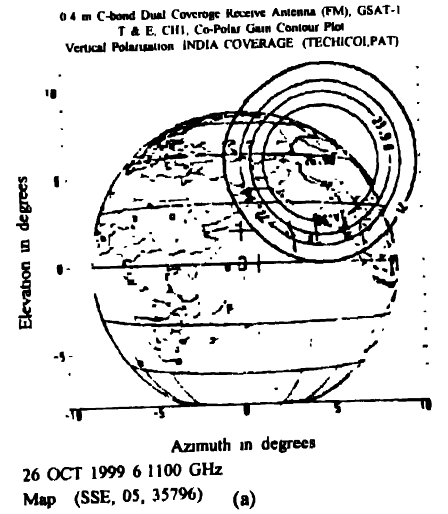

Figure 7. Measured contour plot for India coverage (a) Gain.

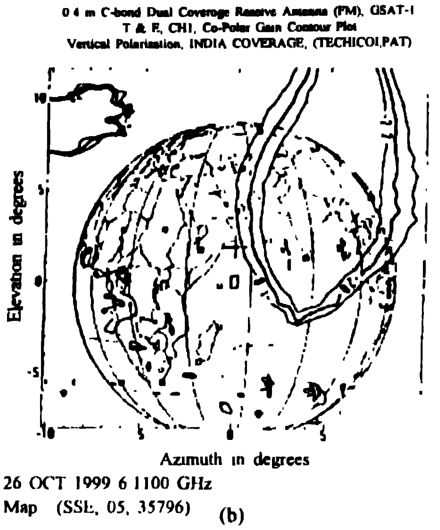

Figure 7. Measured contour plot for India coverage (b) Cross polar isolation

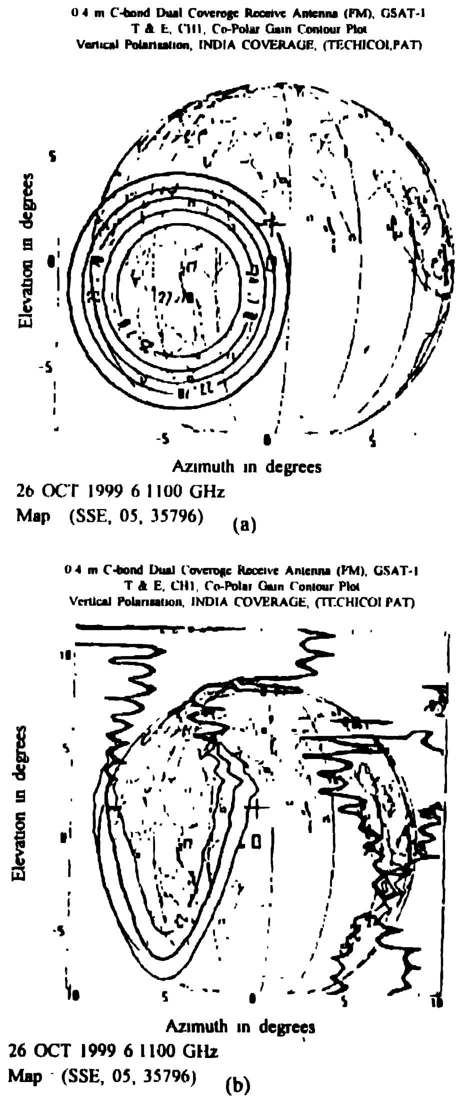

Figure 8. Measured contour plot for South Africa coverage (a) Gain and (b) Cross polar isolation.

which shows good agreement. The estimated reduction in gain is 0.051 dB and it is within the measurement error budget.

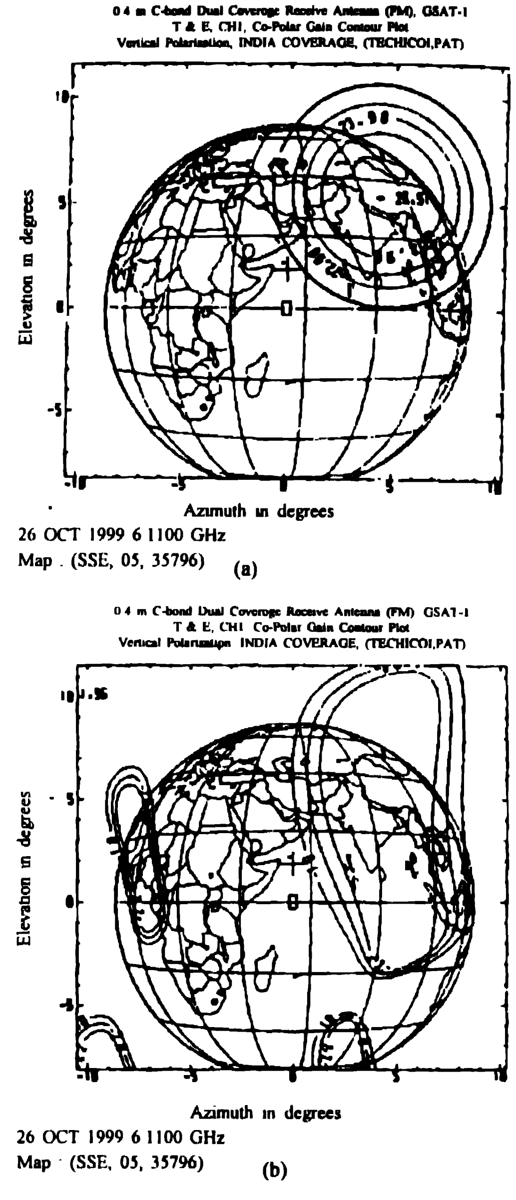

Figure 9. Predicted contour plot for Indian region coverage (a) Gain and (b) Cross polar isolation

5. Conclusion

The dual beam coverage antenna system is designed and realised first time for Indian Communication Satellite. The comparison of predicted and measured results are presented The optimal solution is obtained for both the beam coverage in order to have minimal effect of beam scanning on gain, sidelobes and beamwidth. Simple design procedure is given in brief with necessary mathematical equations. This is beginning for the future development of multiple beam antenna system.

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