High Efficiency Mobile Ground Station Antenna using Displaced Ellipse Reflector

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ABSTRACT
This present article demonstrates the design of a mobile ground station terminal using a offset dual reflector antenna geometry called axially displaced ellipse (ADE). ADE configuration provides a compact geometry and superior efficiency particularly when size of the reflector is small. This ground station antenna has been designed for receiving data from IRS satellites in X-band . A directivity of 46.1 dBi with an efficiency of 75% has been achieved without any shaping to meet the desired G/T requirement for the ground station. It is shown that ADE configuration can be a very good candidate not only for space craft antennas but also for small mobile ground station terminals.

Keywords: G/T, link margin, axially displaced ellipse(ADE) antenna, small reflector antenna, high efficiency antenna.

1. INTRODUCTION
The design parameters of earth station antennas are mainly governed by link margin of the ground station required to receive data from orbiting satellites. Link margin of the ground station predominantly determined by the gain/noise temperature (G/T) of the antenna system. G/T requirement can be met by increasing the size and/or the efficiency of the antenna. Increasing the size of the reflector to achieve higher gain has a direct impact on the budget of the total system. Cost-effective ground station is an obvious demand in many countries for receiving data from remote sensing satellites as it reduces the cost of the final product. Small antenna with higher efficiency is an apparent requirement for this kind of application. Axially symmetric classical cassegrain are used from earlier days for reception of data from the satellites in ground station [1]. This antenna provides a good efficiency till the size of the reflector remains reasonably large. Classical cassegrain dual reflector configuration suffers from subreflector blockage resulting in a number of deleterious effects such as decrease in the antenna aperture efficiency. This can be minimized by different shaping techniques of the subreflector and making a pointed vertex to obtain uniform amplitude and phase illumination over the aperture of the main reflector [2]. Shaped cassegrain configuration is robust and provides high gain and high efficiency as long as long as the size of the reflector is reasonably large (100λ) compare to its operational wavelength. But design of an efficient cassegrain reflector having a size of smaller wavelength is always a difficult task as un avoidable diffraction effects degrades the performance of the reflector antenna. In this situation some improvement can be achieved with shaped reflector geometry, but control over the main reflector illumination is severely compromised and benefit of the pointed vertex becomes almost insignificant. Moreover feed horn size can not be scaled down as subreflector size reduces and some part of the feed radiation scattered by subreflector vertex region goes back to feed again instead of illuminating the main reflector. This degrades the feed return loss to a large extent. This problem can be compensated with a new type of configuration that uses cleaver geometry to achieve high efficiency and reducing blockage. This special configuration which uses an offset parabola and axially displaced tilted ellipse is referred as axially displaced ellipse reflector antenna (ADE). ADE configuration has been very efficiently demonstrated [3] and implemented for spacecraft communication [4],[5].Excellent features of ADE which includes high efficiency, compactness, minimum blockage and very good feed return loss makes it a very good candidate not only for onboard application but also for ground station terminals particularly when antenna dimensions are smaller in terms of operating wavelength. In this present work an ADE antenna having a diameter of 2.7m has been designed for the purpose of receiving data from various Indian Remote Sensing Satellites (IRS) in X-band (8 GHz-8.5 GHz). This small antenna system will be used as a mobile terminal and will have the capability to receive data efficiently from various IRS satellites with some compromise in the starting elevation angle from which it can receive data.

2. ANTENNA CONFIGURATION AND DESIGN
Configuration of ADE geometry consists of an offset parabola (main reflector) and a displaced ellipse (sub reflector).This has been demonstrated in the figure 1. The axis of the parabola sifted from the symmetry axis to generate an offset geometry. Main reflector is formed by rotating this offset parabola of focal length (FP) along the antenna axis of symmetry. The locus the parabola focus, when rotating 3600 about antenna symmetry axis will generate a circle that is called ring caustic. To appropriately illuminate this main reflector a subreflector with coinciding ring caustic and a focus (the system focus) is needed. This can be achieved with a displace section of an ellipse with tilted axis and inter focal distance 2c and spinning the ellipse about antenna axis of symmetry. One focus of the ellipse is a ring caustic which coincides with the focus of the parabola and another focus lies in the symmetry axis of the parabola. This is called system focus where feed is placed to illuminate the sub reflector. The final geometry produced by this process is ADE antenna. ADE geometry is determined by two conic section one offset parabola and other tilted ellipse. The parabola that defines the main reflector profile is determined by the blockage diameter (DB) by which parabola is offset from the antenna symmetry axis and the focal length (FP). Tilted ellipse is defined by the eccentricity (e), inter focal distance 2C and tilt angle (β). This conic section parameters are effectively determined by closed from equation clearly described in [3].Input to this closed from equation are main reflector diameter (DM), Sub reflector diameter (DS), blockage diameter (DB) which is taken such that (DS ≤DB≤ DM), half cone angle subtended by subreflector at the system focus (θE) and distance between main and dub reflector (lo/2). Here main reflector diameter is chosen 2.7m to satisfy mission objective and blockage diameter is kept equal to subreflector diameter. Rest input parameters are varied to generate optimize profile in order achieve maximum efficiency with low side lobe level. Physical Optics (PO) and Physical Theory of Diffraction

(PTD) based analysis with the help of commercially available reflector analysis program GRASP-9 for optimizing the design parameter and predicting radiation characteristics of ADE reflector antenna. For Maximum efficiency the sub reflector diameter (DS) is chosen 0.292 m and lo/ DS ratio is selected as 0.555. Sub reflector edge illumination angle (θE) and edge taper is chosen as 300 and -16.5 dB respectively in order to obtain peak gain and desired side lobe requirement (following ITR-465 recommendation). Once the optimized geometry is obtained, a corrugated horn has been design for generating required radiation pattern. PO analysis is used for main beam maxima and PTD is used for calculating the effects of the diffraction from the edges which contribute to the far out side lobe levels. PO and PTD methods are not very much accurate particularly when the size of the reflector is small. A Method of Moments (MOM) based analysis must be carried out for calculating subreflector current. Feed radiation characteristics have been obtained by Mode Matching Technique using commercially available computer program CHAMP. Feed radiation pattern (taken as spherical wave expansion) obtained by this process is used for calculating current of sub reflector using MOM for predicting accurate result. Circular struts are used to hold the subreflector assembly. Effects of the supporting structure and subreflector blockage also computed to predict accurate result.

3. SIMULATION RESULTS

Using the information presented above ADE design has been carried out for reception of data in X-band (8GHz-8.5GHz) from IRS satellite in ground station. Computer codes have been written to determine conic section parameters (FP, β, 2C, e) from the input parameters (DM, DB, DS, lo, θE). These input parameters are varied for optimization purpose i.e. for achieving maximum gain with desired side lobe level. A computer based analysis scheme that uses PO and PTD has been carried out and a peak gain of 46.52 dB corresponding efficiency of 83% has been achieved at the centre frequency 8.25 GHz. for optimized geometry. Side lobe level computed in this process is -16.1dB down from the peak gain. This analysis has been carried out on the basis of a Gaussian beam

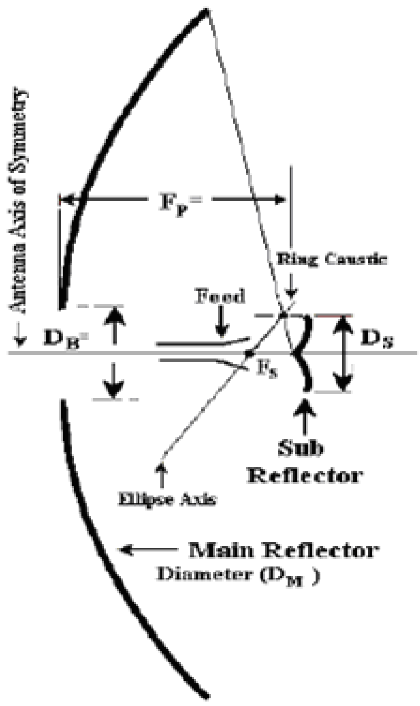

Fig. 1: A generalised 2D diagram of ADE reflector antenna

that is used to illuminate the for the optimized geometry is 300 for optimized geometry and corresponding edge taper is -16.5 dB. A corrugated horn has been designed with the help of computer based analysis that use mode matching techniques to a radiation pattern which resembles ideal Gaussian pattern. A smooth transition is used to for achieving good return loss at the throat of the horn. A mode converter with 8 slots is used efficiently excite Hybrid HE11 mode that produces excellent beam symmetry and low cross polarization. Computed return loss of the horn is bellow -40dB over the operating band. Gain of the horn is 17.2 dB at the centre frequency. Calculated maximum cross polarization is bellow -38 dB over the operating frequency band. PO based analysis is not so accurate particularly when reflector size is small. Therefore the induced subreflector current should be analysed using MOM method. The spherical wave expansion of horn radiation pattern is used for calculate subreflector current in MOM method. A simulated peak gain of 46.37 dB with relative first side lobe level bellow -16 dB has been achieved in this process. Subreflector blockage and supporting structure radiation are also responsible for many deleterious effects such as degradation of efficiency, increase in the side lobe level and deterioration in cross polarization. Cylindrical stainless steel struts with a diameter of 3cm has been used support subreflector assembly. In ADE configuration the feed horn remains very close to the subreflector. So subreflector can also be supported from the edge of the horn. These kinds of configurations are mainly used to achieve compactness and to meet light weight requirement in the spacecraft application. But this kind of configuration results in a greater loss compared to the conventional tripod struts. Tripod supporting

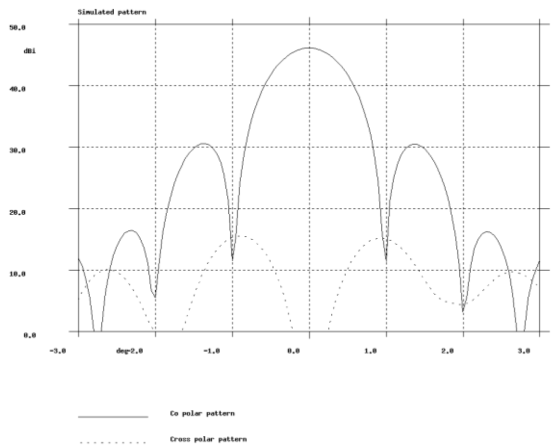

Fig.2: Simulated final pattern including blockage and other effects. Solid line-co-polar, dashed line- cross polar pattern

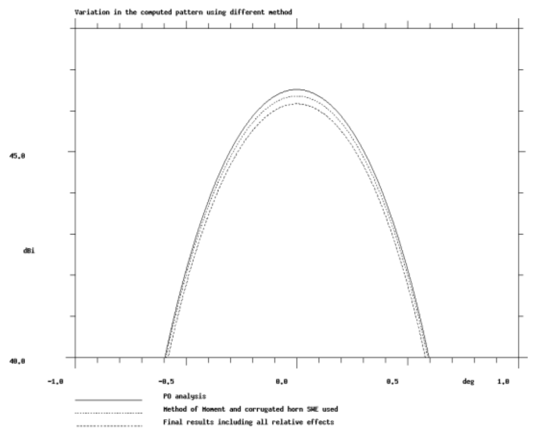

Fig.3: Variation in directivity using different method.

Upper line shows pattern obtained from simple PO analysis. Middle line shows pattern obtained by MOM analysis including corrugated horn radiation pattern. The last line is for Simulated final pattern including blockage and other effects.

structures have lesser impact on the radiation characteristics and easy to realize. So tripod support from the edge of the main reflector has been used as it is

suitable for ground station application. Effects of the radiation from support structure and sub reflector blockage has been calculated for predicting radiation characteristics of the antenna. Surface imperfection

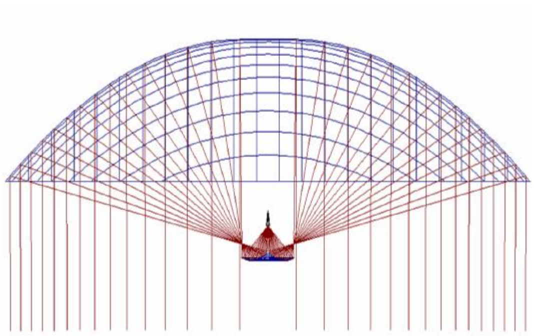

Fig.4: ADE ray tracing diagram shows its excellent features of minimum blockage and very good feed return loss.

also has an important bearing in realization of expected gain. Finally a simulated directivity of 46.1 dBi, which corresponds to an aperture efficiency of 75% has been obtained including all the relevant effects. Relative first side lobe level is -15.9dB bellow.

Fig-2 shows the final result with co and cross polar pattern. Cross polar pattern is well bellow -35dB at the required beam width. Fig-3 shows the variation in peak gain while using different method. A ray diagram of ADE is shown in fig in fig-4 which depicts that no rays goes back to feed again after reflection form subreflector. Feed return loss has been calculated placing the subreflector in front is - 20dB. This shows that shadow of the subreflector region remains unilluminated. So feed and other feed electronics like polarizer, LNA can be placed conveniently without any degradation in the efficiency of antenna system. The total system is under fabrication and expected to be assembled within few months. Measured results will be made available upon request.

4. CONCLUSIONS

In this present work design of an ADE reflector antenna having a size of 2.7m has been carried out for reception of data from the IRS satellites in X-band (8GHz-8.5GHz). Simulated pattern shows that ADE antenna can be very efficient candidate providing high efficiency, compactness, minimum blockage and excellent feed return loss not only for spacecraft but also for ground station application particularly when the size of the reflector is small. The final simulation results shows a directivity of 46.1 dBi with an efficiency of 75% considering all the effects of subreflector blockage, supporting structure radiation and surface imperfection.

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6. REFERENCES

[1] P.W.Hannan,"Microwave antennas derived from cassegrain tele-scope," IEEE Trans.Antennas and Propagat,vol.AP-9,pp 140-153,Mar 1961

[2] V.Galindo, "Design of dual reflector antennas with arbitrary phase and amplitude distribution," IEEE Trans.Antennas and Propagat,vol.AP-12,pp 403-408,Jul.1964

[3] F.J.S.Moreira and A.Prata, "Generalized classical axially symmetric dual reflector antennas," IEEE Trans.Antennas Propag,vol.49,no4,pp 547-554Apr2001

[4] A.Prata, F.J.S.Moreira and L.R.Amaro, "Displaced axis ellipse reflector antennas for spacecraft communication," in Proc.SBMO IEEE MTT-SIMOC.2003,pp 391-395

[5] Chandrakanta Kumar, V V Srinivasan,V K Laksmeesha, Surendra Pal, "Performance of an electrically small aperture, axially displaced ellipse reflector antenna," IEEE Antennas and propagation letters Vol-8,2009 Trans. Antennas Propag,vol.49,no4,pp 547-554Apr2001