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Survey on Mitigating the Problems of Parabolic Reflectors for Efficient Communication

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Abstract: ***In this paper, various problems associated with parabolic reflectors, its causes and the approach to mitigate these problems are discussed. The problems include; side lobe radiations, edge diffraction, aperture blockage, cross polarisation, feed spill over, feed illumination taper, pointing error, surface error and phase error. These problems have adverse effect on the overall gain, efficiency and directivity of the antenna thereby inhibiting efficient communication process. The result of the survey reveals that, phase error tends to be the most difficult of the aforementioned problems due to the challenges associated with locating the phase centre at reflector's focus. The aperture blockage seems to have the least method of solution, because the problem can be solved by changing the centre feed to an offset feed. Detailed investigation of these problems and the relevant solutions are necessary, since parabolic reflectors are among the most common antennas with diverse application.***

Keywords: Parabolic Reflectors, Side Lobes, Feed Illumination Taper, Spill overs

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1. INTRODUCTION

Parabolic antennas are designed to receive or send microwave signal to communication satellite using both the reflector and antenna at the focus. The information may be data, video, audio or combination of all signals. In **[1],** detailed description on the analysis of parabolic antenna for microwave signal communication is discussed. Reception is achieved by parabolic reflectors using feed horn, (low noise block converter) LNB, reflector and coaxial cable connected to the receiver. The reflector directs the signal that it receives from the communication satellite, to the LNB and feed horn at the focus of parabolic antenna. The feed horn, which is a front end waveguide, collects the signal at the focal point and directs it torwards to LNB. The LNB in turn, converts the electromagnetic radiations into electrical signal and moves the signal from the downlinked C-band or Ku-band to L band range. The Direct Current (DC) for LNB is made available, by same coaxial cable conductor that carries the signal to the receiver. For transmission process, the signal to be sent is transmitted through the coaxial cable to the LNB. LNB converts the electrical signal to electromagnetic radiation and at same time up converts the microwave signal, through the feed horn to the communication satellite.

In **[2],** it can be seen that, the parabolic dish operates in same way as a concave lens since the dish reflects all signals parallel to it, and then to the focus. The satellite dish is designed to receive specific type of signals. Large sized dish are used for C-band signal reception while smaller ones are employed for Ku band signal. **[3]** Gave the advantages of parabolic antennas which include; high gain and high directivity while, the drawback is not limited to cost, size, desired reflector and driven element.

Other than the parabolic reflector, other shapes which include; hyperbolic, elliptic and circular reflectors also exist. Although, they are of different shapes, each can perform the function of the other, by defining a parameter known as eccentricity. This parameter allows the whole shapes of reflector antenna to be analysed in unified form. Parabolic reflector can be fed in different configuration which include; symmetric, asymmetric and off focus. The asymmetric and off focus fed are preferred to symmetric feeding. This is because, the latter causes aperture blocking effect due to feed and struts while the former prevents blockages **[4]**.

The aim of this work is therefore, to survey the different methods/approach for solving various problems related to parabolic antennas. The problems associated with parabolic antennas are side lobes, edge diffraction, aperture blockage, cross polarization, feed spill over, feed illumination taper, pointing error, shape error and phase error.

2. REVIEW OF RELATED WORKS.

[5] Improved the efficiency of an offset parabolic antenna beam with specific usage for radiometric purposes in space. The microwave radiometer been a highly sensitive receiver, is designed to measure noise, power/brightness temperature radiated by a target. It consist of three subsystems which are antenna & scan system, radiometer receiver and data control subsystem. For radiometric application, parabolic antenna with offset configuration, is seen as the best antenna system since it experienced reduced aperture blockage, high isolation (between the antenna & primary feed), suppressed side lobe level and opportunity for increased focal length to diameter ratio. But offset parabolic reflector has a shortfall of higher cross polarization when illuminated by a linearly polarized feed. This causes reduction in main beam efficiency, poor spatial resolution, measurement accuracy and radiometric sensitivity. Cross polarization in an offset reflector employed for radiometric application can be reduced using a Tri-mode conjugate matched feed. This is a special multi-mode feed used to illuminate the offset parabolic antenna. The method employs higher order mode TE_{21} mode and TM_{11} mode with a fundamental TE_{11} mode to compensate the cross polarisation introduced by offset geometry. The result obtained shows that when the two feeds (matched feed illuminated offset reflector and conventional dual-mode potter horn fed offset reflector) were compared, beam efficiency and cross polarization were improved due to matched feed illuminated offset reflection.

[6] Examined trade-off between the aperture taper and spill over efficiencies of reflector antenna. Spill over loss occurs when feed radiation misses the reflector while feed blockage happens when feed energy is reflected back into the feed and doesn't become part of the main beam. Aperture field method was used to determine efficiencies and edge diffraction for parabolic reflector antennas with feed at the focus. The result obtained shows that beam width depends on edge illumination. In other words as edge attenuation increases, the beam width widens and side lobe decreases. It showed that the principal cause of gain degradation of parabolic reflector were illumination and spill over loss.

[7] Reduced side lobe in offset dish parabolic antennas using metallic scatters. The drawback of side lobes for a transmitting antenna is that unintended receiver may pick up classified information. While in the case of receiving antenna, it makes the antenna much more prone to noise from signals of any source. Side lobe when in excess causes power wastage and interference. In this work, strip positioning method was used with offset reflector. The method proved to be simple, efficient and cost effective. It used placing of metallic strips or scatters on the main reflector at a specific location with specific dimension and shape. The result obtained shows that in order to reduce side lobe level significantly, the strip should be made of perfect conductor, so that incident wave from primary source could be scattered or diffracted accordingly.

[8] Designed and analysed parabolic reflector by varying its feed type in order to achieve a high gain, pencil like beam with well reduced minor lobes. The paper used two methods (general and aperture radiation approximation) to analyse the parabolic reflector. F/D, gain and radiation pattern were the parabolic reflector characteristics analysed. The two methods were used to calculate main radiation pattern with horn feed, dipole feed and square corner feed. The result obtained shows that the comparism between these feeds were based on intensity and directivity. It indicated that the horn feed among the others had more directivity and intensity. More intensity and directivity were achieved because of aperture approximation.

[9] Made use of MTPO to reduce the effect of diffraction at the edge of parabolic antenna for satellite communication. The methodology used was to formulate the MTPO model for scattered fields of parabolic reflectors. Then Edge point technique and Stationery point method were used to evaluate the scattered integral. The non-uniform solution of scattered field was converted to uniform solution using Detour parameter. Finally, for parabolic reflector, the total scattered field was obtained. The result showed that, edge diffraction appeared as side lobe radiations, with rectangular and polar plot. For same antenna parameter, the side lobe level using PO were more than that of MTPO. This is due to the introduction of the second surface which considers the distance (d) (the one between the focus antenna and reflector).

[10] Investigated the influence of amplitude tapering and feed blockage on the radiation characteristics of Ku band parabolic reflector antennas. It considered the effect of amplitude tapering and feed aperture blocking on gain and first side lobes level of Ku band parabolic reflector antenna. The method employed was to design four different parabolic reflector and feed them with two different horns (Conic and Pyramidal). The result obtained shows that increase in the first side lobe level in parabolic reflector antenna are highly dependent on nature of aperture distribution function. First side lobe level increased with a larger aperture blocking. Feed blocking on antenna gain decreases with feed antenna aperture enlargement dramatically, in order to obtain a high gain, lower side lobe level and avoid degrading effect of feed blockage. Employing electrically larger reflector antenna was used in order to maintain greater uniformity of radiation field distribution.

3. METHODOLOGY

Every antenna design is aimed at producing a structure with reduced back & side lobes, improved gain, efficiency and directivity. To obtain peak gain in parabolic reflectors, the radiation pattern of antenna feed should match the dish shape & the dish should be uniformly illuminated with the edge provided with steady field strength. But in practice, the radiation pattern of antennas drop slowly at the edge, so the feed antenna is a trade-off between spill over and adequate illumination. Aperture efficiency accounts for all the losses that minimizes antenna gain **[11].** The problems associated with parabolic reflector antennas are Feed spill over, Feed illumination taper, Aperture blockage, Phase error, Surface error, Cross polarization, Edge diffraction, Side lobe and pointing error.

Side lobes: is one of the problems of antennas especially parabolic reflector. It reduces gain, directivity and makes the antenna vulnerable to interferences. In **[12]** it was seen that the higher the side lobe level, the more likely the antenna interferes or is interfered with by a receiver in same direction. Increase in side lobes also leads to losses of power, since the signal is wasted in undesired direction. Strip positioning is a simple, efficient and cost effective approach employed for the purpose of minimizing side lobe radiations. It constructively scatter the incoming wave radiated by the main source, in the reflector's main direction, thereby reducing the side lobe level significantly. To efficiently minimize the side lobe, the position of the strip on the main reflector is critical. The optimum position of strips depends on the focal direction, the shape of strips and the effect of the number of scatters on the directional characteristics of such antennas. **[13]** Used three disc-shaped elements on the surface of parabolic antenna for side lobe suppression. By adjusting the position and height of these elements, the side lobe surface was changed. The result indicated that the level of first side lobe is relatively lower than the other side lobe and the observation was made from the radiation pattern designed in X-band.

Edge Diffraction: is a problem that occurs at reflector's edge. **[9]** Reported that edge diffraction causes scattering, amplitude ripple, phase ripple, plane wave phase deviation and far field pattern modification**. [14]** Used serrated edge treatment to mitigate the effect of edge diffraction associated with compact range reflectors. **[15]** Pointed that, there are several ways to reduce ripples of both phase and magnitude within a quiet zone when taking measurement in CATR (Compact Antenna Test Range). To reduce edge diffracted fields at the reflector's edge, folding of edge and serration of edge were considered. **[9]** Minimized edge diffraction by using MTPO, with the introduction of a second surface (aperture). The second surface gave account of diffracted field which enabled diffracted field at the edge to be modelled. The distance (d) was proportional to the side lobes, when MTPO and PO were compared using the polar and rectangular plots. Where d is the distance between the focus and the reflector.

Aperture Blockage: This is a common problem with parabolic reflectors, especially with centre or front fed antenna at the focus. The feed horn casts a shadow that interferes with the beam, from the reflector of parabolic antenna. The feed horn causes an obstruction for rays coming from the reflector. **[16]** Solved this problem by employing an offset feed. In offset feed, the feed is located outside the wave path to prevent pattern deterioration.

Cross Polarization: is an electromagnetic energy radiated or lost in an unintended direction. Geometry of the reflector, F/D of the antenna system, imperfection of reflector surface and struts are parameters that cross polarization depends on. High cross polarization results in reduction of beam efficiency and poor spatial resolution. In microwave radiometers, cross polarization produces undesired interference between two adjacent channels in a communication link. It creates boresight jitter in monopulse tracking radar, which affects the tracking accuracies and results in unsatisfactory radar operation **[17].**

[18]Employed digital beam forming technique and combination of elements to minimize cross-polarization on a single offset parabolic reflector. Azimuth elements in feed systems were used, to cancel the cross polar component of the antenna produced by the offset configuration. However, digital beam forming techniques combine a set of element in elevation, to minimize the cross polar level and at same time keep the co polar component performance. **[19]** Employed dual mode micro strip primary feeds to reduce cross polarization in offset reflector, the modes of interest are TM_{11} and TM_{21}. The matched feeds are comparable to waveguide type, because of its ability to reduce cross polarization of offset reflector antenna to well below -32dB at both asymmetry and diagonal plane. **[20]** Used polarization filter to correct cross polarization monopulse response of reflector antenna. The function of the filter was to pass a specified polarization as defined by the direction of the electric field vector while rejecting the orthogonal polarization. Wide bandwidth filter can be designed for linear polarization, by placing an appropriately spaced set of linear conductors parallel to the electric field vector to be rejected.

Feed Spill over: describes feed radiation that appears outside the dish's edge or feed radiation that was not present at the reflector. It causes reduction in gain, increase in back lobes, interference and increases susceptibility to ground noise **[11]**. **[21]** Used lens shaped to control reflector antennas spill over. The two shaped lenses were located at multi band feed aperture. The first lens surface converted the pattern of radiation into a wave that was plain in nature, while the second surface realigned the radiation to the reflector parabolic surface. This enabled better control of primary and illumination patterns making antenna system design to be optimized. **[22]** Used tapered illuminator to reduce edge illumination thereby reducing side lobes and spill over. **[23]** Mentioned that the efficiency of spill over can be increased by reducing the distance between the feed and reflecting surface or by reflector size increase.

Surface Error: is deviation from ideal surface experienced by the reflector surface of the antenna. This deviation makes it hard, to keep the required field's amplitude and phase on the aperture. This discrepancy can lead to the overall deterioration of antenna performance. Maximum gain, beam width, maximum level of side lobe and cross polarization interference are important parameters that affects reflector antennas performance. Wind loads, force of gravity, strains due to heat, tolerances of manufacturing and panel misalignment are distortion that causes surface error. This surface error are categorized into deterministic and random errors. Deterministic errors are caused by force of gravitation, wind speeds, expansion due to temperature and design of structure. While random error is associated with tolerance present in panel's precision manufacturing. By adjusting antenna profile manually or using reflector surface with adaptive feature, deterministic surface error can be compensated for manually. During construction and coupling stages, precision instruments like theodolite, prism and inclinometer are needed, while during installation, measuring instruments are required like tape, rod, wheel, linear transducer for distance measurement **[24**].

Feed Illumination Taper: According to **[25]**, tapered illumination happens in antenna with reflector naturally, because of radiation pattern due to feed and distance variation between feed and reflector's various parts. Reduction in gain, reduced side lobes in most cases, increased antenna beam width and beam factor are effects illumination taper has on antenna performance. Because of the way parabolic antennas were designed, with antenna at the focus farther from the reflector's edge than from the centre, less radiation arrives at reflector's edge than that at the centre. This phenomenon is called space or taper attenuation. **[26]** Minimized the problem, by adjusting the feed pattern (antenna at the focus), in order to have constant illumination over the surface of the reflector. Thereby, providing more illumination at the edge of the dish than at the centre of the dish. The illumination was near the dish's edge, for energy to drop off very quickly beyond the edge.

Pointing Error: is the major cause of link failure, interference with the neighbouring satellite and reduction of gain in the desired direction. Pointing error arises from inability of an antenna to aim properly in the right direction and misalignment with target location. The antenna beam width which depends on antenna diameter and operating frequency are factors that determine the required pointing accuracy **[27].** Pointing error can be categorized into static and dynamic. Static error occurs during the time of installation because of improper aiming while dynamic error changes over time. Static errors include; (circular polarization) CP squint, effect of tolerance on mount mechanism such as lock downshift, backlash and mechanical to optical axis misalignment. Dynamic errors include; wind deflection, station keeping, foundation setting and uneven solar heating of the reflector. Simple peak method, beam bracketing and cross pol method are used to reduce the pointing error. Beam bracketing is more preferable, because the rest of its repeatable and accurate pointing **[28]**.

Phase Error: occurs when the phase of the radiated field is not uniform over all the area of the reflector, causing different part of reflector to reflect out of phase radiations into the main beam. These anomalies, therefore reduce the gain, total energy in the main beam and efficiency. Reduced gain and pattern distortion are experienced, when the antenna feeds don't have same phase centre in the E-plane and H-plane. This effect is same as not having the phase centre at the focal point **[29]**. A feed whose radiation have different phase will have multiple sources which produces an interference pattern, when illuminating dish, thereby reducing the dish's effective radiation illuminating it. For parabolic reflector to have same phase when illuminated, the whole illumination must originate from a single focus point of the reflector. But this is not possible with real antennas, because of their physical size. This error due to phase is solved by locating phase centre at parabola focus, so that all dish main beam radiated are in phase so that efficiency is maximized. The wave front should be spherical over full angle of illumination which is a feature of a good antenna feed making it possible for entire reflector to be illuminated using a single phase centre. The phase centre should be located accurately, if not it leads to introduction of additional phase error.

4. RESULT AND DISCUSSION

The table below show the problems, causes, results and solutions to problem associated with parabolic reflector antenna.

Table 4.1 Summary of Problems and Solution of Parabolic Reflectors

S. N.	PROBLEMS	CAUSES	RESULTS	SOLUTIONS
1	Side Lobes	➢ Spillover ➢ Edge Diffraction	➢ Causes interference. ➢ Reduces gain and directivity. ➢ Wastes power	➢ Metallic scatters or strips (Strip positioning). ➢ Three disc shaped element.
2	Edge Diffraction	Occurs at reflector's edge (rim or dish)	➢ Scattering. ➢ Amplitude ripple. ➢ Plane wave phase deviation. ➢ Far field pattern modification	➢ Serrated edge treatment of the reflector. ➢ Rolling of reflector's edge. ➢ Using MTPO to model and reduce edge diffraction
3	Aperture Blockage	Shadow cast by feed, struts and supports interferes with the beam from the reflector.	Reduction in gain and efficiency.	Offset feed which prevents pattern deterioration.
4	Cross Polarization	Different polarization exhibited by both the receive and transmit antennas.	➢ Reduction in beam efficiency. ➢ Poor spatial resolution. (Microwave Radiometric). ➢ Interference ➢ Boresight jitter (monopulse tracking Radar)	➢ Digital beam forming. ➢ Dual mode micro strip primary feed. ➢ Polarization filter.

5	Feed Spillover	Radiation from the feed misaligns with the reflector.	➢ Reduction in gain ➢ Increased back lobe ➢ Interference ➢ Ground noise increase.	➢ Shaped lens. ➢ Tapered illuminator. ➢ Reducing the distance separating the feed and reflector. ➢ Increasing the reflector size.
6	Surface Error	Caused by random and deterministic errors. Deterministic errors include; forces of gravitational, wind speeds, expansion due to heat and design of structure. Random errors include tolerance introduced into the manufacturing precision of the panel.	It affects the following ➢ Maximum gain ➢ Beam width ➢ Maximum level of ➢ side lobe Cross polarization ➢ Causes interference	By manually adjusting antenna profile or using adaptive reflector, deterministic error can be taken care of mechanically. Theodolite, prism and inclinometer are used during fabrication and assembly stage. Tape, rod, wheel and linear transducers are needed for distance measurement during installation.
7	Feed illumination taper	More illumination at reflector's centre than at reflector's edge. Because of the separation between the feed and the reflector.	➢ Reduction in gain. ➢ Reduced side lobes in most cases ➢ Increased antenna beam width and beam factor.	Feed adjustment so that it produces constant illumination over the surface of the reflector. So that more illuminations are provided at the edge than at the centre of the reflector. Also illumination should be near the edge of the dish so that the energy drops off quickly beyond the edge.
8	Pointing Error	Wrong or improper aiming of the antenna. The causes are categorized into static and dynamic. CP squint and tolerance because of mount mechanism are examples of static while wind deflections, station keeping, foundation setting and uneven heating of reflector by solar are examples of dynamic errors.	➢ Link failure ➢ Interference ➢ Reduction in gain ➢ Wrong knowledge of target location	➢ Simple peak method. ➢ Beam bracketing. ➢ Cross polarization method.
9	Phase Error	Non uniformity of radiated field phase over all the areas of the reflector which leads to out phase problem.	➢ Reduction in gain ➢ Reduced total main beam energy. ➢ Reduction in efficiency	Locating the phase centre at parabola focus. So that all energy the dish main beam radiated is in phase making it possible for efficiency to be maximized.

5. CONCLUSION

In this work, detailed survey on different approach to solving the problems associated with parabolic reflector have been reviewed. Each problem is unique based on its specific cause, solution and application. In this paper, it was observed that aperture blockage was one of the simplest and commonest problem of reflector antennas. However, phase error appears to be one of the most challenging problems encountered in reflector antennas. The former appears to have much difficulty in locating the phase centre at reflector's focus. It can therefore be concluded that, all the problems limiting the performance of parabolic reflectors affects directly the overall gain, directivity and efficiency of the antenna. One of its commonest application is for microwave and satellite communication due to its pencil beam radiation and improved efficiency.

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