Hybrid Beamsteering of Ka-Band Array-Fed Reflector Antenna for Satellite Communication Links

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***Abstract* - In this paper we present the design and analysis of Ka band array fed reflector antenna for satellite communication links. The design consists of curved reflector geometry of 0.8 m which is fed with five element linear array antenna operating at 20.2 GHz (Ka band). As satellite applications demand beam-steering with higher gain and narrow beam, we use and analyze electro-mechanical beam-steering, i.e. electronic and mechanical steering (Hybrid beam-steering), through array fed reflectors. To ensure good scanning capabilities the feed array is configured in horizontal as well as in vertical directions. A 2-D scanning of ±6° is achieved when the feed element is placed horizontally in focal plane whereas ±3° when the feed element is placed vertically in focal plane with the proposed array fed reflector. The proposed antenna maintains a constant performance throughout the scanning range which helps vehicular tracking and many other satellite applications.**

Keywords* - *Array-fed reflector; Linear array antenna; Hybrid Beam Steering; Ka band satellite links.

I. INTRODUCTION

This Communication via satellites is a viable solution for internet access especially in remote areas, therefore to meet such current day satellite applications, hybrid antennas are of best choice [1]. In order to comply with the demanding GEO satellite gain requirements, phased arrays are usually combined with an imaging reflector configuration and are mostly used to enhance the feed arrays directivity [2]. In recent years significant amount of research was done on array fed reflector systems to achieve high performance over traditional horn fed reflectors [3] [4]. Horn fed reflectors structures are the most commonly used antenna types for satellite applications as they possess very high gain. Many researchers carried out work using horn antenna because of its high gain being a great advantage. Also, research was carried out replacing horn with a phased array antenna [5] [6], as a feed to the reflector geometry as it possess inherent advantages over horn feeds and hence the need for such type of reconfigurable systems has become an important aspect in recent satellite communication applications. Planar phased arrays, [7] are also preferred when the application requires some coverage re-configurability and are of good choice when the application requires good coverage and scanning capabilities. Array-fed reflectors exhibit the advantage of beam pointing over a certain specified range with allowable tolerance and can also create nulls at time of co-channel interference among users. In addition to implementation of digital processing techniques allows the maximization of the received signal strength. This paper is organized as follows. Section II gives an overview on the design of hybrid array fed reflector antenna. Section III, presents the result and analysis of proposed array fed reflector followed by conclusions in Section IV.

II. HYBRID ARRAY FED REFLECTOR ANTENNA DESIGN

A. Feed Antenna

The pictorial view of the proposed feed antenna is shown in figure 1. The antenna structure was designed at an operating frequency of 20.2 GHz. The line fed rectangular microstrip patch printed on an RT Duroid dielectric substrate with bottom ground whose relative permittivity is 2.2 with a loss tangent of 0.0009. The optimized parameters of the proposed antenna are listed in Table I.

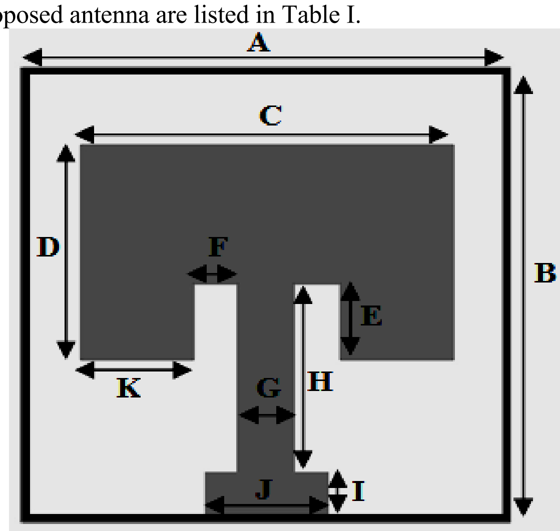


Figure 1. Single Element design.

TABLE I. DESIGN PARAMETERS OF THE PROPOSED ANTENNA

Parameter	Dimensions (mm)
A	13.9
B	12.1
C	6.4
D	4.7
E	1
F	0.3
G	0.5
H	3.9
I	0.8
J	1.2
K	2.6

B. Reflector Antenna

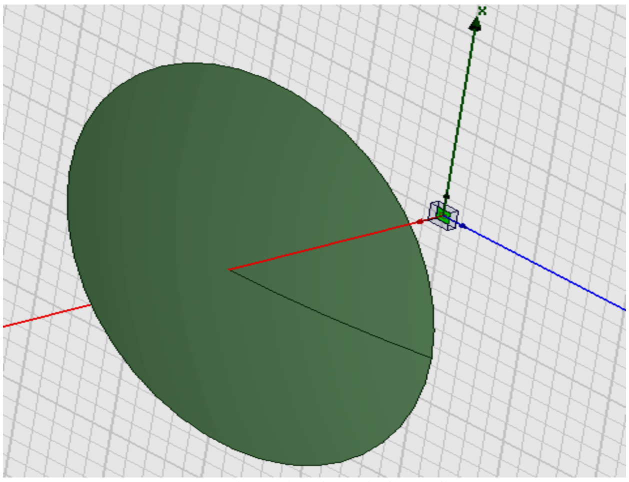
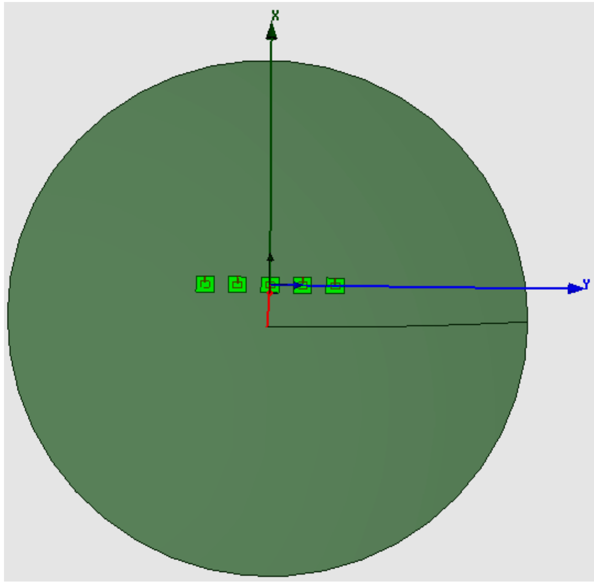


Figure 2. Schematic of Parabolic Reflector.

Parabolic reflectors are mainly preferred because of their high gain nature and figure 2 shows the Ka band reflector antenna which consists of a symmetric parabolic reflector of 0.8m in diameter (i.e. D = 0.8m) and a feed antenna which is placed at a focal distance of 0.5 m with an f/D ratio of 0.6. To realize a 3D parabolic reflector curve a 2D curve is swept along Z axis. The primary feed antenna and the secondary reflector are analyzed as perfect electric conductors. Figure 3a) and Figure 3b) show reflector antenna with an aperture of 0.8m diameter characterized with a five linear array antenna in two different configurations i.e. elements are displaced horizontally and vertically along the focal plane.



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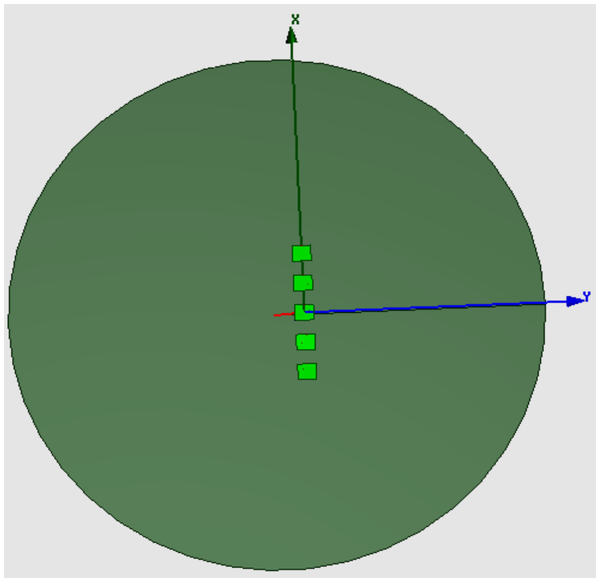

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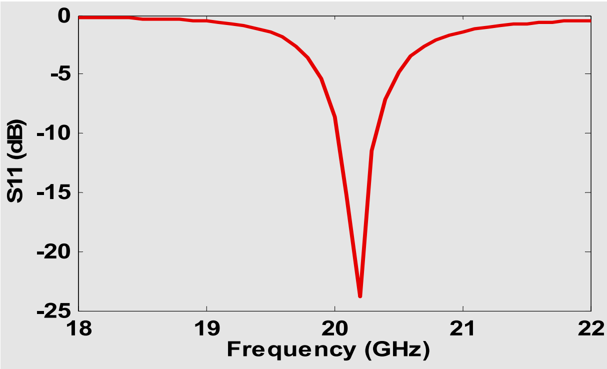
Figure 3. Schematic of Array fed Parabolic Reflector with a) horizontally and b) vertically displaced feeds.

III. RESULTS AND ANALYSIS

Figure 4a) and Figure 4b) depict the reflection coefficient of the proposed single element and reflector design respectively. The reflection coefficient observed at the resonating frequency 20.2 GHz by single element is -23.80 dB and similarly it is -15.33 dB for the proposed reflector by maintaining the impedance bandwidth of 400 MHz.



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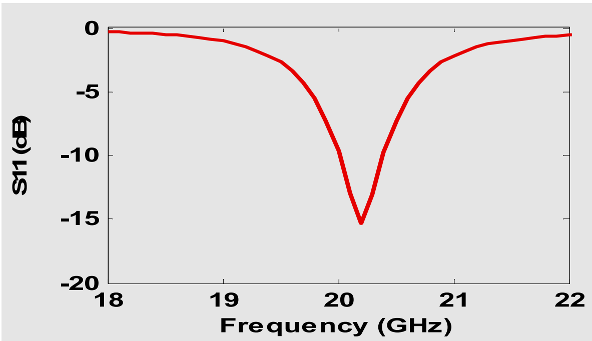

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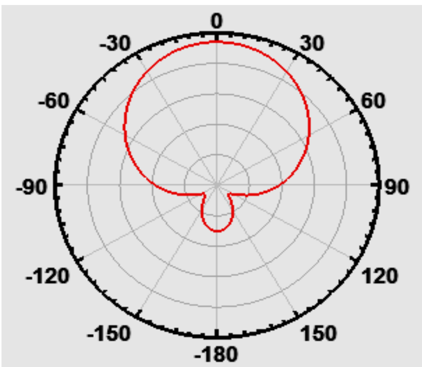
Figure 4. Return Loss Vs Frequency of a) Single element, b) Parabolic Reflector.



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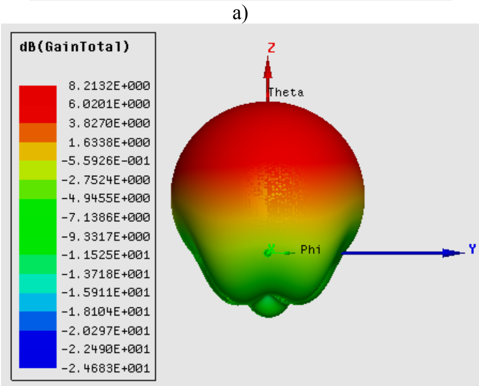

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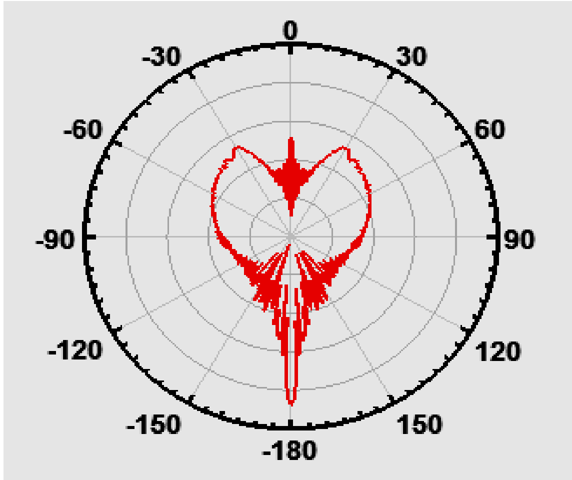
Figure 5. a) 2D radiation pattern, b)3D radiation pattern of Feed element.



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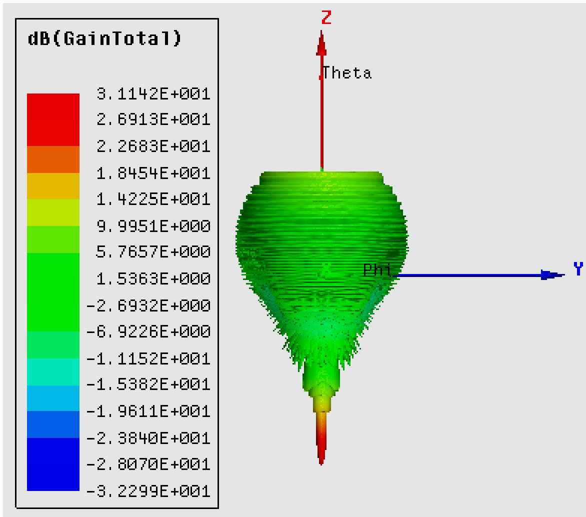

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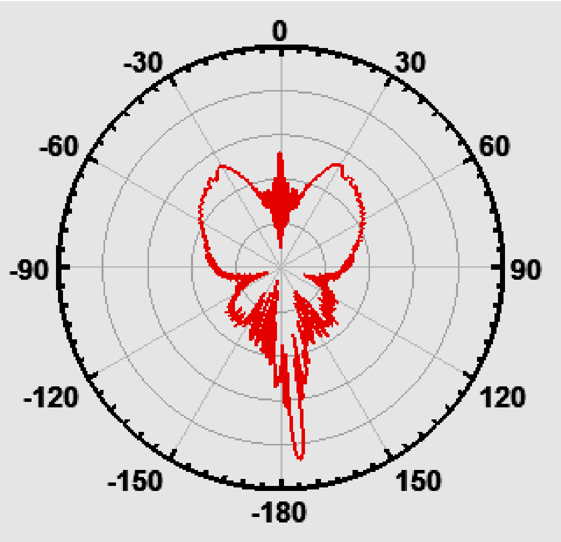
Figure 6. a) 2D radiation pattern, b) 3D radiation pattern of reflector antenna.

Figure 5 and Figure 6 show primary and secondary radiation patterns of the proposed antenna geometry. The patterns demonstrate a magnification effect in terms of directivity. It is observed that the primary antenna gain pattern which is of 8.2 dB is transformed into 31.2 dB with a side lobe level of 13.3dB because of proper illumination of feed onto the reflector. Figure 7 shows the steering in the radiation pattern of the of about ±6^{o} with 0.8dB gain reduction in case of horizontal switching of the feed element and ±3^{o} with 0.3dB gain reduction in case of vertical switching of the feed element along the focal plane. An increase in side lobe level of 1.2 dB is observed in case of horizontal switching and 0.5dB in case of vertical switching of the feed elements.



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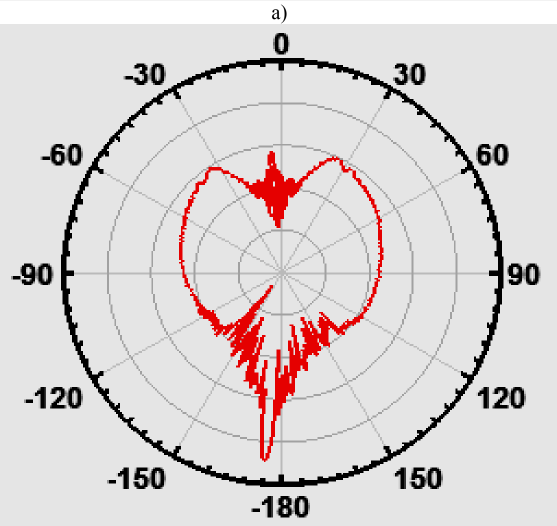
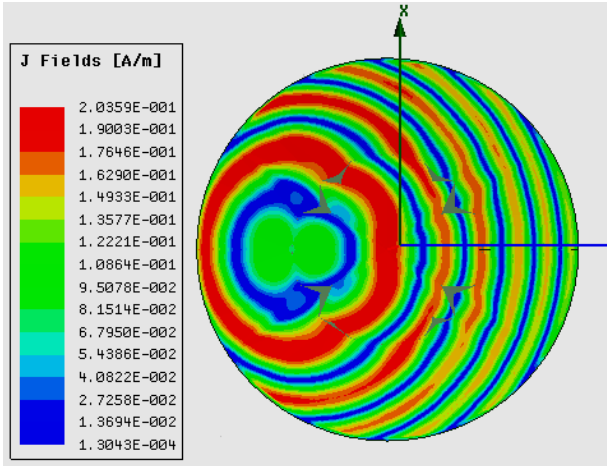


b)

Figure 7. Beamsteering due to a) Horizontally switched feed, b) Vertically switched feed.

Figure 8 shows the current densities on the reflector surface. As the reflectors directivity mainly depends on illumination of the feed onto the reflector, feed radiations must be produced properly and are induced onto the reflector. In case of narrow feed radiations poor directivity is resulted due to insufficient illumination onto the reflector. Whereas in case of too broad patterns, spillover losses occur and thereby reduce the efficiency.



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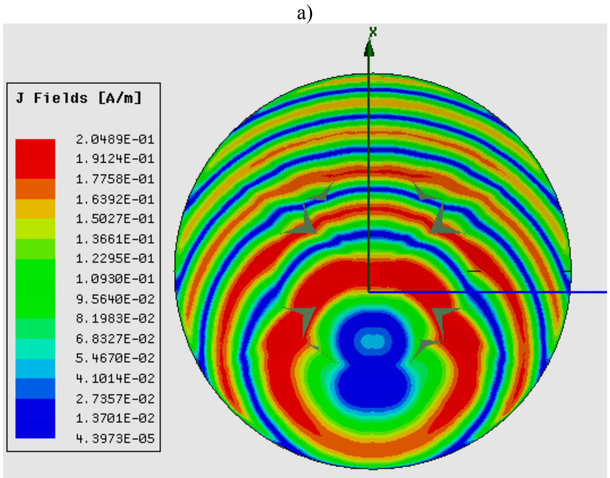

b)

Figure 8. Current Density distributions of a) Horizontally switched feed, b) Vertically displaced feed.

Further the numerical analysis is performed for different switching element configurations are summarized in Table 2. From Table II one can observe that there is degradation of directivity due to displacement of feed illumination on the reflector surface in both the configurations. One way to overcome this effect and increase the directivity is to increase the size of the secondary reflector surface.

TABLE II. PERFORMANCE OF THE ANTENNA FOR DIFFERENT SWITCHING CONFIGURATIONS

Element	Beam-steering	Gain (dB)	SLL (dB)
Centre	NA	31.2	13.3
Horizontal Switching	±6^o	30.4	14.5
Vertical Switching	±3^o	30.9	13.8

Variation of reflector size alters the antenna parameters, increases the system cost and as well as weight. Therefore, to provide maximum directivity for a desired scan angle the concept of electro mechanical beam steering is implemented

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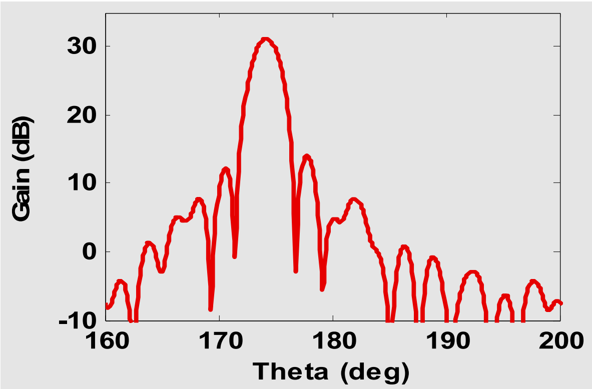
which involves electronic steering and mechanical steering. Mechanical rotation of the reflector can be implemented by using actuators. Figure 9 a) and Figure b) show the maximum gain achieved in each case of horizontal and vertical switching of feed element for 3o rotation of the reflector. The secondary radiation patterns maintain an acceptable performance in terms of directivity and side lobe level within the specified range of operation. This type of electro-mechanical beam steering technique enhances the feeds directivity in entire desired scanning range and thereby provides good coverage reconfigurability.



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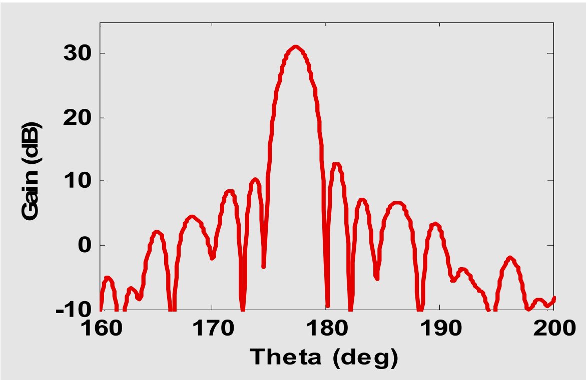

b)

Figure 9. Current Density distributions of a) Horizontally switched feed, b) Vertically displaced feed.

IV. CONCLUSIONS

In this work, the proposed curved reflector geometry of 0.8m is characterized with a five-element linear array antenna. Analysis in terms of gain, return loss, beam-steering, surface current approximation is investigated. A maximum 2-D scanning of ±6° and ±3° are achieved by switching the equi-spaced 5 element linear array in horizontal and vertical configurations respectively at 20.2 GHz by implementing hybrid beam-steering. Such type of hybrid array fed reflector antennas can be described as a cost-effective solution and can maintain constant performance in the entire scanning range at Ka-band satellite frequencies. Hence hybrid structures of such kind are highly advantageous at high frequencies.

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