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Cross Polarization Reduction in Offset Reflector Antenna using Multimode Horn Feed

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Abstract— In this paper, various dual mode conical horn antennas are designed, simulated and analysed.. The higher order mode is generated by introducing step change and various feeds are designed with different throat angles. The main goals of these designs were Co-polar Gain, Cross-polarization level reduction, Beam symmetry and Return loss. The cross-polarization and the return loss parameter are compared for all the feed designs and the effect of symmetrical aperture distribution by addition of these two modes is also analysed.

Keywords— Cross-polarization, phasing length, return loss, multimode horn

I. INTRODUCTION

The offset reflector antennas are most widely used antennas to recover the disadvantages such as field blockage, large side lobe levels etc. introduced by other reflector antenna types. Reflector antennas are useful for various applications such as satellite tracking, radar, remote sensing and direct to home communication services. However, this configuration introduces the drawback of high cross-polarization when it is illuminated by the primary feed. The overall performance is strongly affected by this limitation and sometimes it limits the use of this configuration for communication.[6]

It is observed that cross polarization introduced by offset feed is dependent on the offset angle and the F/D ratio.[1] By having large F/D ratio we can reduce the cross-polarization. But large F/D ratio leads us to heavy and bulky antenna structure which can not be practically usable. Hence we have to use efficient feed instead of changing the antenna geometry.

II. CONCEPT OF MULTIMODE FEED

The dominant single mode horn, whether conical (TE_{11}) or pyramidal (TE_{10}), radiates a pattern in which the E plane differs significantly from the H plane so that axial beam symmetry does not exist in general. This is called the lack of axial symmetry. The reason for this is that the electric field in the horn aperture is heavily tapered in the H plane but tapered very little or not at all in the E plane.

Thus by introducing the TM_{11} mode with the TE_{11} the lack of axial symmetry can be reduced and this will help us to reduce the cross-polarization of the horn antenna.[2][3] Essentially this mode doesn't effect on the H-plane aperture distribution of the horn and on the –plane radiation pattern. The addition of these two modes with proper phase and amplitude can exert a profound effect on the horn E-plane aperture distribution and the corresponding radiation pattern. This realization is shown in the figure below.

A. Mode Generation

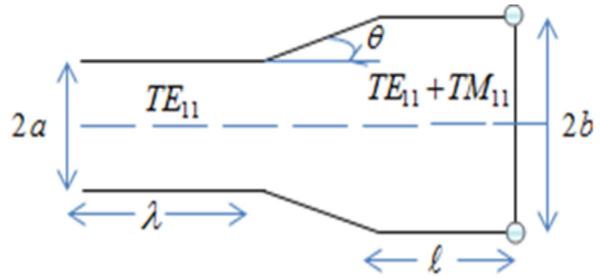

Fig.1 Mode Conversion in Multimode Cylindrical Horn

As shown in figure, step change is provided to get the TM_{11} mode generated. The diameters are chosen to satisfy the following conditions.

1. Only TE_{11} can propagate to the left of the step.
2. Only TE_{11}, TM_{01}, TE_{21}, TM_{11} can propagate to the right of the step.

3. TM_{11} is generated in the correct power ratio relative to TE_{11}
4. TE_{11} and TM_{11} have significantly different phase velocities.

B. Design Specifications

The dimensions for the design are considered from the following equations. The aperture radius is calculated by,[7]

$$b = \frac{c\, h_{mn}}{2\pi f_c} \tag{1}$$

Where,

f_c = Cutoff Frequency,

h_{mn} = Eigen values for TE_{mn} or TM_{mn} modes

$c = 3\times10^8\, m/s$

The phasing length is calculated from the equation ,

$$(\beta_{TE_{11}} - \beta_{TM_{11}})\ell = \frac{3\pi}{2} \tag{2}$$

Where,

$$\beta_{TM_{11}} = \frac{2\pi}{\lambda_{g_{TM_{11}}}} \quad \& \quad \beta_{TE_{11}} = \frac{2\pi}{\lambda_{g_{TE_{11}}}} \tag{3}$$

Where,

β=Phase-shift Constant

Guided Wavelength = $\lambda_g = \dfrac{\lambda}{\sqrt{1-\left(\dfrac{\lambda}{\lambda_c}\right)^2}}$ (4)

Where,

λ_c =Cutoff Wavelength

The throat length is calculated form[5],

$$\ell_1 = \frac{1}{2}(b-a)\cot\theta \tag{5}$$

The phasing length is required to ensure the proper phasing between the TE_{11} and TM_{11} modes. This is required because there is difference in the propagation velocity between these modes throughout the length of the horn. This length is chosen such that it can provide the additional differential phase shift to get the correct phase relation at the aperture. Due to this phasing length the modes TM_{01}, TE21, TE01 which are not required, not excited.

The effect of combining these two modes will give us symmetrical aperture distribution as shown in the figure.

TE_{11} TM_{11}

Fig. 2 Field Cancellation due to vector Addition of Field

III. RESULT OF SIMULATION

The simulation is done using the HFSS software which is high frequency structure simulator. HFSS uses FEM (Finite Element Method) in which the complex structure is divided in small element and each element is then solved independently. The final solution is summation all the solutions. Here return loss and cross polarization are considered as the calculative parameter. The aperture distribution shown in Fig.2 is verified in the HFSS simulation results.

The results of cross-polarization and return loss for various feed designs are listed in the following table. This table also contains the dimensions for aperture radius, phasing length, throat angle in degree for all different designs. These designs are designed by considering 3.5GHz as the operating frequency.

Here in case-1 four designed are mentioned which differs by different throat angles and only one step is provided as shown in fig.1 and case -2 contains the design having two steps. The comparative analysis is presented in the table.1

TABLE I
Comparative Analysis of Designs

	Type	**a (cm)**	**b (cm)**	**ℓ (cm)**	**S_{11} (dB)**	**X-pol (dB)**
Case-1 (Single Step)	Feed with ϴ=10 degree	4.09	6.01	22.57	-25	22
	Feed with ϴ=20 degree	4.09	6.01	22.57	-15	14
Case-2 (2λ Tapering)	Feed with ϴ=6.45 degree	4.09	6.01	22.57	-32	25
	Feed with ϴ=10 degree	4.09	7.06	22.57	-32	20
Case-3 (Double Step)	Feed with ϴ=10 degree	4.09	6.01	22.57	-22	14

Here,
a = small/input aperture radius, ϴ = throat angle,
b= larger/output aperture radius, ℓ = phasing length,

From Table I we can conclude that the return loss and cross-polarization is achieved in favorable manner in the case-2 feed designs compared to other cases. We are getting low cross-polarization in the double step design. The radiation patterns are shown below from which we can measure the cross-polarization for all the types of feed designs mentioned in the Table I. These patterns include the gain for the cross-polar and co-polar components in terms of dB. Fig.3 is the graph for the return loss by simulation through which we can compare the results for all the multi-mode horn feed designs.

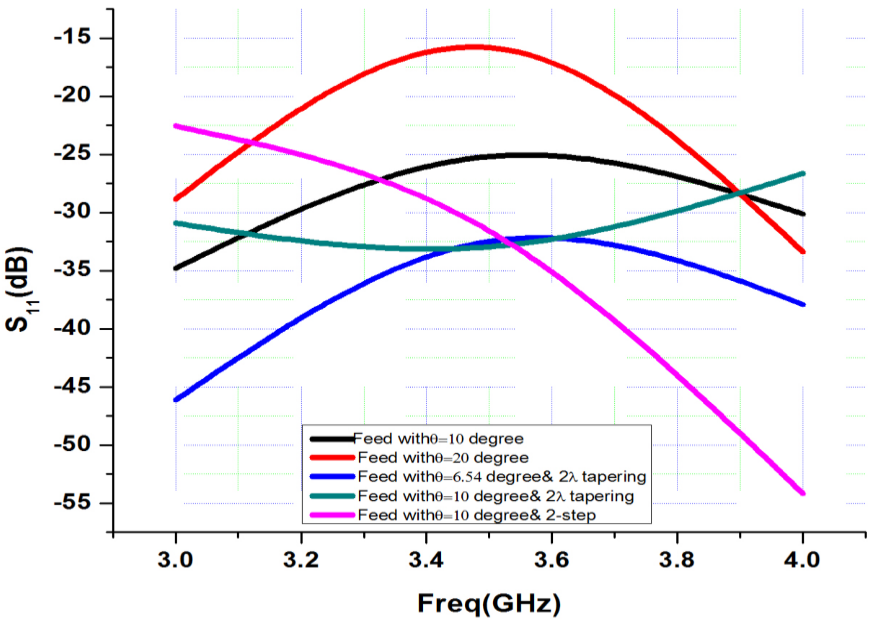

Fig. 3 Comparison Of Simulated Return Loss For Various Feeds

From fig.3 we can say that the highest return loss is achieved in the feeds included in the case-2 category in which the tapering length is fixed as double of the operating wavelength (2λ). In this case, we have increased the throat angle from 6.54 degree to 10 degree in the second design which leads to the increment in the output radius which is 7.06 cm for this feed design. We are also getting higher cross –polarization reduction in the case-2 designs compared to the other feed designs and it can be realized from the fig .6 and fig.7.

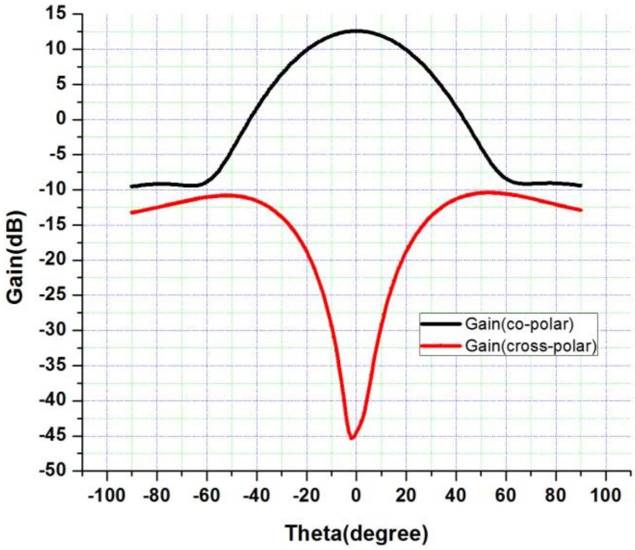

Fig. 4 Radiation Pattern of Feed with ϴ=10 degree

Fig.4 to Fig.8 shows the radiation pattern of feeds mention in Table I which are simulated at the center frequency (3.5GHz). The feeds are designed for the gain of 10 dB. All the feeds show good copular gain characteristics an both E and H patterns are symmetrical so only pattern is shown. Fig also shows that the cross–polarization is also in good agreement with the theory. We are achieving cross-polarization better than 20 dB in most of the designs.

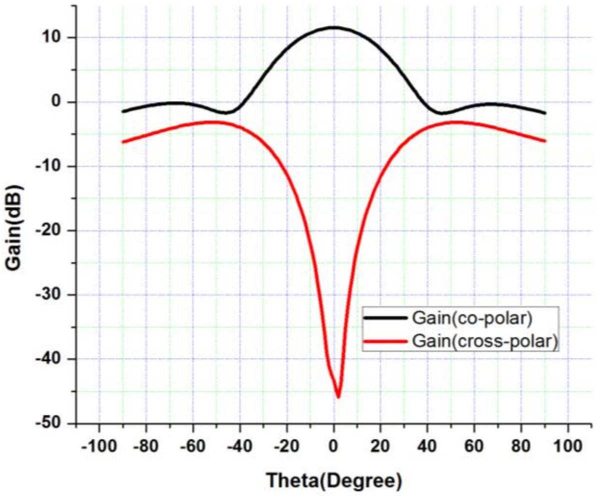

Fig. 5 Radiation Pattern of Feed with ϴ= 20 degree

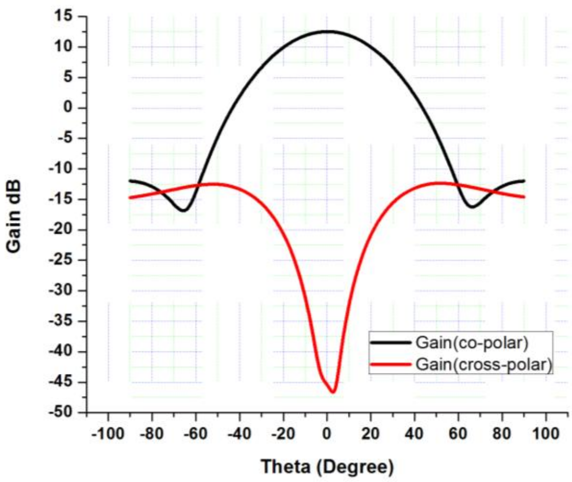

Fig. 6 Radiation Pattern of Feed with ϴ=6.45 degree

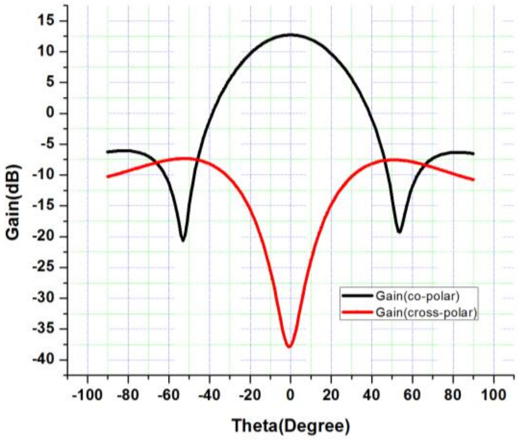

Fig. 7 Radiation Pattern of Feed with ϴ=10 degree & 2 lemda tapering

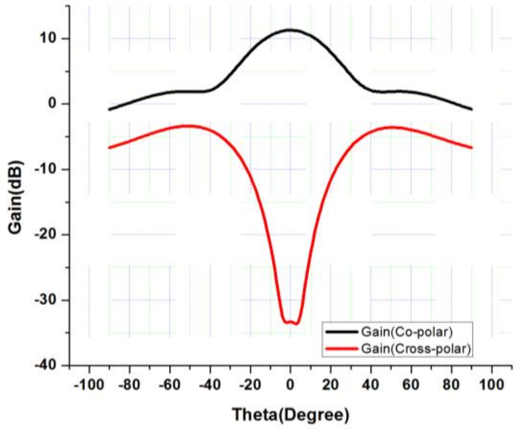

Fig. 8 Radiation Pattern of Double Step Feed with ϴ=10 degree

IV. CONCLUSION

Here the dual mode horn antenna performance is measured in terms of the return loss and cross-polarization reduction. By using the combination of TE11 and TM11 we can have high return loss, sufficient reduction in cross –polarization and the field distribution on the aperture can be achieved symmetric in the satisfied manner which leads to beam symmetry.

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