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Design and Development of Rectangular Microstrip Array Antennas for X and Ku Band Operation

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Abstract: This paper presents the design and development of two element slot loaded rectangular microstrip array antenna for dual band operation. The dual bands are achieved at *X* and *Ku* band of frequencies. Effect of slots of different shapes embedded on the array elements is studied experimentally for enhancing the bandwidth. It is found that by using *L*-shape complementary slots on the array elements and *H*-shape slots in the ground plane, the bandwidth at *Ku*-band can be enhanced from 20.1 % to 40.4 % without much affecting the operating bandwidth at *X*-band. Further enhancement of bandwidth at the *Ku*-band does not affect the nature of broadside radiation characteristics. Details of antenna design are described and experimental results are discussed. The proposed antennas may find applications for the systems operating at *X* and *Ku*-bands.

Keywords: Microstrip array antenna, Dual band, Slots, Complementary.

1. INTRODUCTION

The microstrip antennas (MSAs) are the most widely used for the last few years due to their attractive features such as light weight, low volume, ease in fabrication and low cost [1]. However, the major disadvantage associated with MSAs is their narrow bandwidth [1-2] which restricts their many useful applications. Numbers of studies have been reported in the literature for enhancing the bandwidth [3 – 6]. Further, the dual frequency patch antennas have gained wide attention in radar communication particularly in synthetic aperture radar (SAR), as they avoid the use of two separate antennas for transmit and receive applications. Variety of methods have been proposed to obtain dual band operation, such as by loading slits [7], using slots in the patch [8], loading the patch with shorting pins [9], using stacked patches [10], etc. But the antenna operating at two different bands of frequencies and their enhancement are found rare in the literature. Hence a simple array and slot technique has been used in this study for constructing the proposed antennas intend to fill this void.

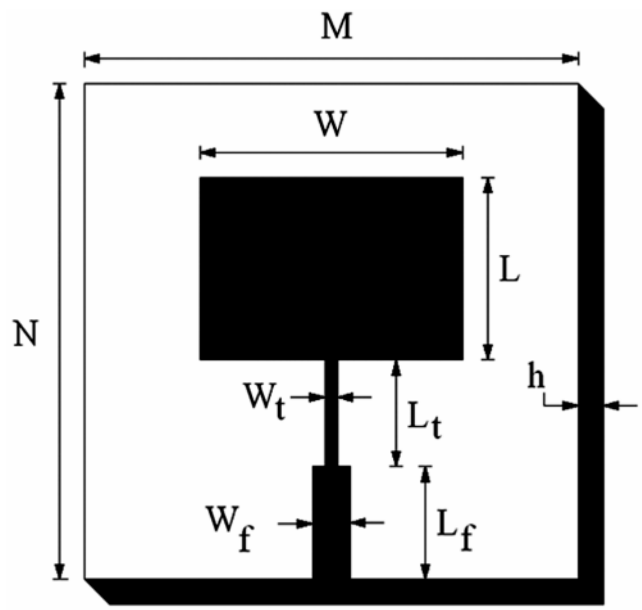

Fig. 1: Geometry of CRMA

2. DESCRIPTION OF ANTENNA GEOMETRY

The art work of the proposed antennas are developed using computer software AutoCAD-2006 and are fabricated on low cost glass epoxy substrate material of thickness h = 0.14 cm and permittivity € = 4.4. Figure 1 shows the geometry of conventional rectangular microstrip antenna (CRMA) which is designed for the resonant frequency of 9.4 GHz, using the equations available in the literature [1]. The substrate area of the CRMA is $A = M \times N$. The antenna is fed by using microstripline feeding. This feeding has been selected because of its simplicity and it can be simultaneously fabricated along with the antenna element. Figure 1 consists of a radiating patch of length L and width W, quarter wave transformer of length L_t and width W_t used between the patch and 50 Ω microstripline feed of length L_f and width W_f. At the tip of microstripline feed, a 50 Ω coaxial SMA connector is used for feeding the microwave power.

Figure 2 shows the geometry of inclined L-slot rectangular microstrip array antenna (ILRMSAA). The dimension of each rectangular array element in Fig. 2 remains same as that of rectangular element shown in Fig. 1. The array elements of Fig. 2 are excited through a corporate feed arrangement. This consist of a 50 Ω microstripline of length L'_{50} and width W'_{50}, connected at the centre point of the 100 Ω feed line of length L'_{100} and width W'_{100}, which forms a two way power divider. A quarter wave transformer of length L'_t and width W'_t is connected between 100 Ω feed line and centre point of radiating element to provide better impedance matching. The distance between the two radiating elements from their centre point is 'D' and should be $\lambda_0/2$ for minimum side lobes [14]. To fulfill this condition the 100 Ω microstripline in Fig. 2 is extended accordingly. The substrate area of Fig. 2 is $A' = M' \times N'$. The each inclined L-slots are of length L_1, L_2 and width W_1, which are placed at a distance of 1 mm from the radiating (W) and non-radiating (L) sides of the patch. The interior angle θ between L_1 and L_2 is 122°.

Figure 3 shows the geometry of L-slot rectangular microstrip array antenna (LRMSAA). In this antenna, the slots used in the array element of ILRMSAA are modified in the form of L as shown in Fig. 3. The horizontal and vertical lengths of each L-slot in the array element are L_3 and L_4 respectively. The width of L-slot is W_2. The L-slots are located at a distance of 1 mm from the radiating and non-radiating sides of the rectangular array element similar to ILRMSAA. The feed geometry of this antenna remains same as that of Fig. 2.

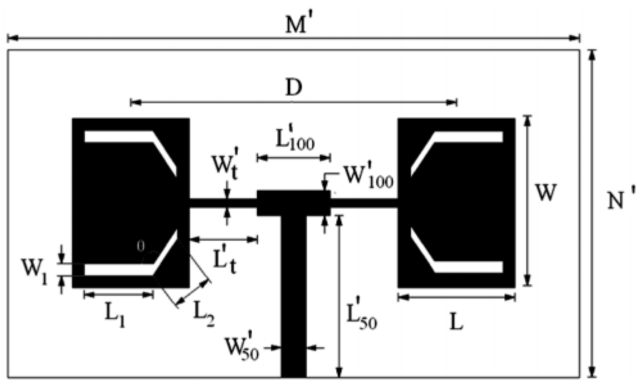

Fig. 2: Geometry of ILRMSAA

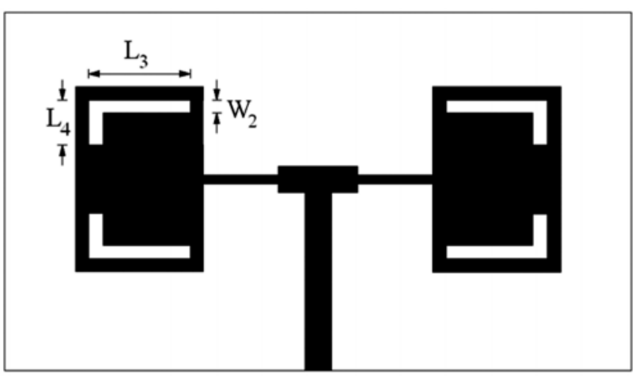

Fig. 3: Geometry of LRMSAA

Figure 4 shows the geometry of complementary L-slot rectangular microstrip array antenna (CLRMSAA), which is derived from Fig. 3. In this antenna the bifurcated portion of half slot loaded rectangular element is in mirror symmetry with each other. The feed arrangement of Fig. 4 remains same as that of Fig. 3. The tight ground plane of Fig. 4 is modified by loading H-type slot placed exactly at the centre of array element in the ground plane. This antenna is named as CLHRMSAA. The ground plane geometry of this antenna is as shown in Fig. 5 (a). The length of each horizontal arm in H-slot is L_5 and width W_3. The length and width of vertical arm of this slot are L_6 and W_4 respectively as shown in Fig. 5 (b). Table 1 shows the designed parameters of the proposed antennas.

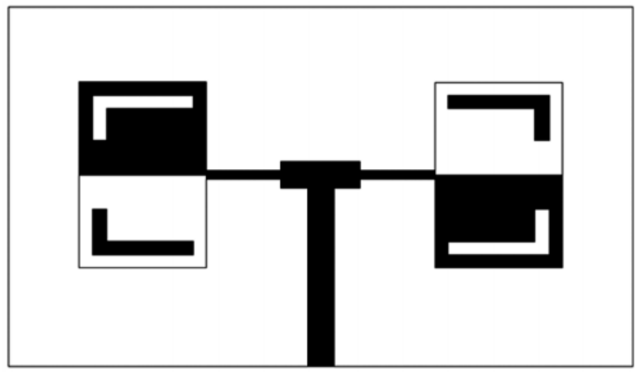

Fig. 4: Geometry of CLRMSAA

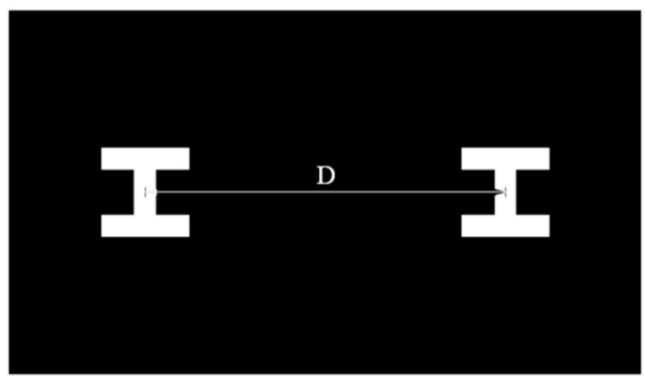

Fig. 5 (a): Geometry of Ground Plane of CLHRMSAA

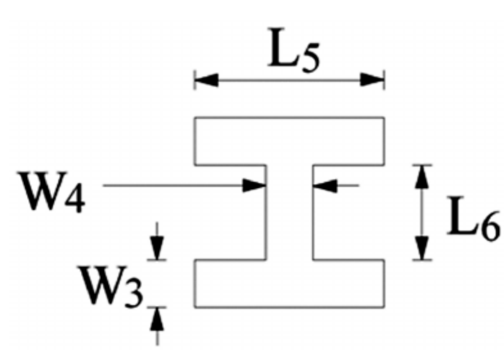

Fig. 5 (b): Geometry of H-slot of CLHRMSAA

Table 1
Design Parameters of Proposed Antennas

L = 7.10 mm	W = 9.80 mm
Lt = 4.18 mm	W_t = 0.48 mm
L_f = 4.10 mm	W_f = 3.16 mm
L_1 = 3.53 mm	W_1 = 1.00 mm
L_2 = 2.88 mm	W_2 = 1.00 mm
L_3 = 5.06 mm	L_4 = 3.44 mm
L'_{50} = 7.82 mm	W'_{50} = 3.16 mm
L'_t = 4.17 mm	W'_t = 0.13 mm
L'_{100} = 8.34 mm	W'_{100} = 0.74 mm
L_5 = 3.00 mm	W_3 = 0.50 mm
L_6 = 2.00 mm	W_4 = 0.50 mm
M = 25 mm	N = 25 mm
M' = 50 mm	N' = 20 mm

3. EXPERIMENTAL RESULTS

The impedance bandwidth over return loss less than –10 dB for the proposed antennas is measured at *X* and *Ku* band of frequencies. The measurements are taken on Vector Network Analyzer (Agilent Technologies E8362B, PNA series). The variation of return loss versus frequency of CRMA is as shown in Fig. 6. From this figure it is seen that the antenna resonates very close to its designed frequency of 9.4 GHz. This validates the design concept of CRMA. From Fig. 6, the bandwidth is calculated by using the equation,

$$BW = \left[\frac{f_H - f_L}{f_C}\right] \times 100\% \quad \text{... (1)}$$

where, f_H and f_L are the upper and lower cut-off frequency of the band respectively when its return loss becomes –10 dB and f_c is the center frequency between f_H and f_L. Hence by using Eq. (1) the bandwidth BW_1 of CRMA is found to be 4.40%. The theoretical bandwidth of this antenna is calculated using [12],

$$\text{Bandwidth (\%)} = \left[\frac{A \times h}{\lambda_0 \sqrt{\varepsilon_r}}\right] \times \sqrt{\frac{W}{L}} \quad \text{... (2)}$$

where, *A* is the correction factor, which is found to be 180 as per [12]. The theoretical bandwidth of CRMA is found to be 4.42 %, which is in good agreement with the experimental value.

Figure 7 shows the variation of return loss versus frequency of ILRMSAA. The antenna resonates for two band of frequencies BW_2 and BW_3. The respective bandwidths are 2.9% and 20.10%. It is clear that the BW_2 lies in the *X*-band (8 – 12 GHz), where as BW_3 lies in the *Ku* band (12 – 18 GHz). Hence the construction of ILRMSAA does

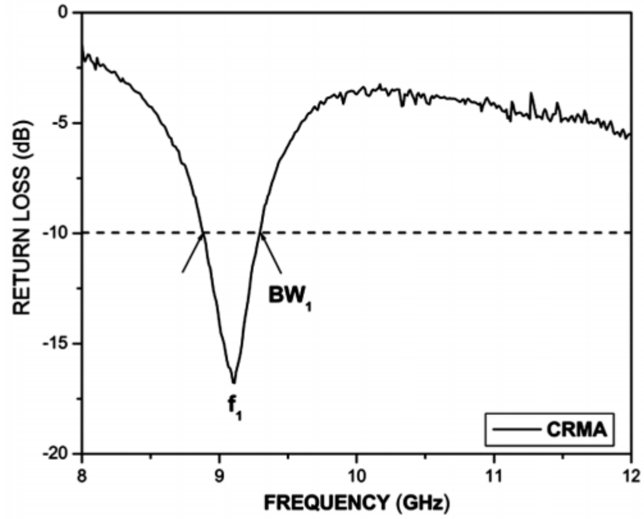

Fig. 6: Variation of Return Loss Versus Frequency of CRMA

not affect the basic resonant property of antenna that is the primary band BW_2 which lies at *X*-band but gives secondary band BW_3 at *Ku*-band. However, it is seen that the resonant frequency f_2 of ILRMSAA in the primary band shifts to 8.35 GHz, when compared to resonant frequency f_1 of CRMA, i.e. 9.11 GHz in BW_1. The shift of resonant frequency is mainly due to corporate feed used in ILRMSAA. The dual bands are due to independent resonance of array elements and slots in ILRMSAA [13].

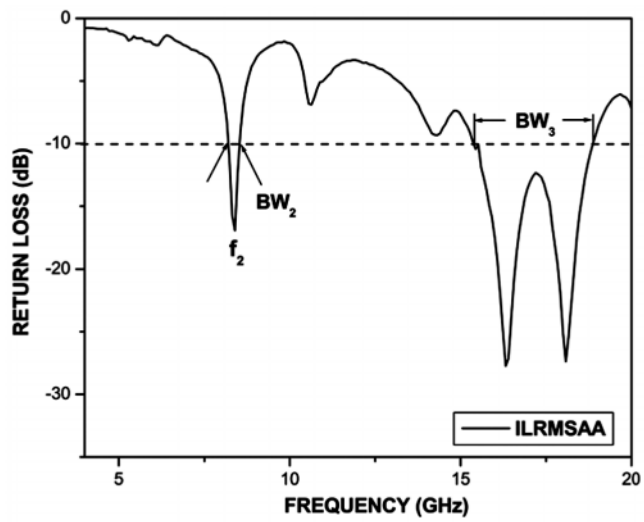

Fig. 7: Variation of Return Loss Versus Frequency of ILRMSAA

Figure 8 shows the variation of return loss versus frequency of LRMSAA. It is seen that the antenna again resonates for dual band of frequencies BW_4 and BW_5. The magnitude of each operating bandwidth BW_4 and BW_5 is found to be 3.88% and 28.16% respectively. Hence by inserting *L*-slots in the array elements of LRMSAA, the operating bandwidth BW_5 at the *Ku*-band increases from 20.10% to 28.16% when compared to the operating bandwidth of BW3 of ILRMSAA as shown in Fig. 7.

The BW_5 of LRMSAA has been enhanced further from 28.16% to 33% by modifying the array elements of LRMSAA in the form of *L*-complementary slot, i.e. CLRMSAA. This enhancement is shown in Fig. 9, which is the return loss versus frequency variation graph of CLRMSAA. Again it is evident from this figure that the enhancement of bandwidth at the Ku-band does not affect the primary resonant property of CLRMSAA at *X*-band. The magnitude of operating bandwidth BW_6 and BW_7 of CLRMSAA are found to be 4% and 33% respectively.

The maximum enhancement of 40.4% of bandwidth BW_9 at the *Ku*-band is possible by using *H*-type slot used below the array element in the ground plane of CLRMSAA, i.e. CLHRMSAA. This enhancement is shown in Fig. 10, which is the return loss versus frequency graph of CLHRMSAA. Hence it is clear that, CLHRMSAA is quite effective in enhancing the bandwidth of antenna at *Ku*-band retaining the resonant property of antenna at *X*-band.

Figures 11 – 15 show the *x-y* plane co-polar and cross-polar radiation patterns of CRMA, ILRMSAA, LRMSAA, CLRMSAA and CLHRMSAA, which are measured at their primary bands. From these figures, it is clear that the patterns are broadsided and linearly polarized. The dual band operation and enhancement of bandwidth does not affect the nature of broadside radiation characteristics.

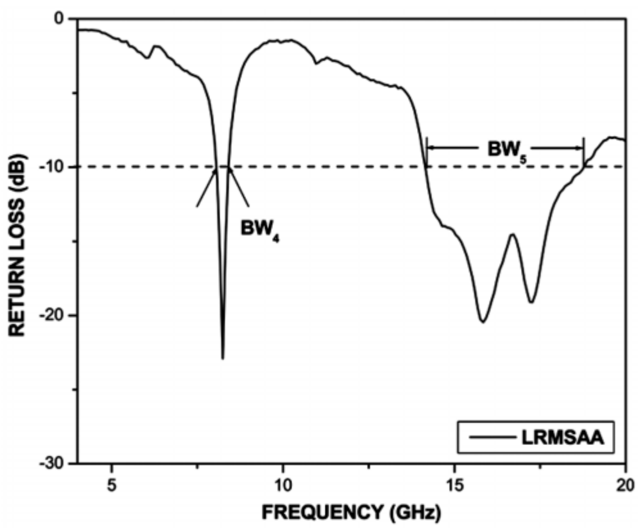

Fig. 8: Variation of Return Loss Versus Frequency of LRMSAA

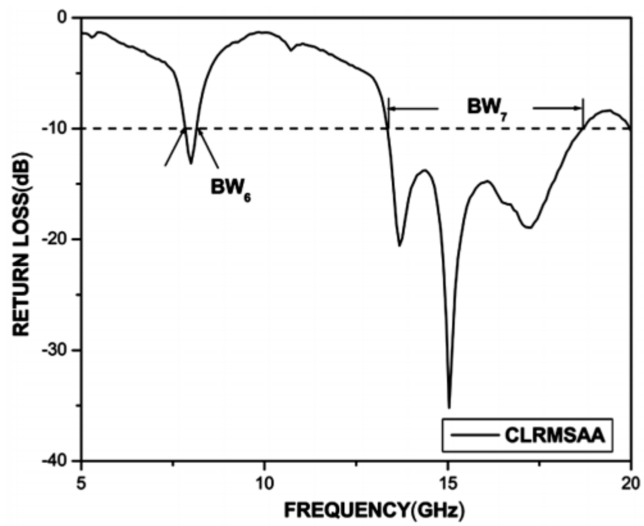

Fig. 9: Variation of Return Loss Versus Frequency of CLRMSAA

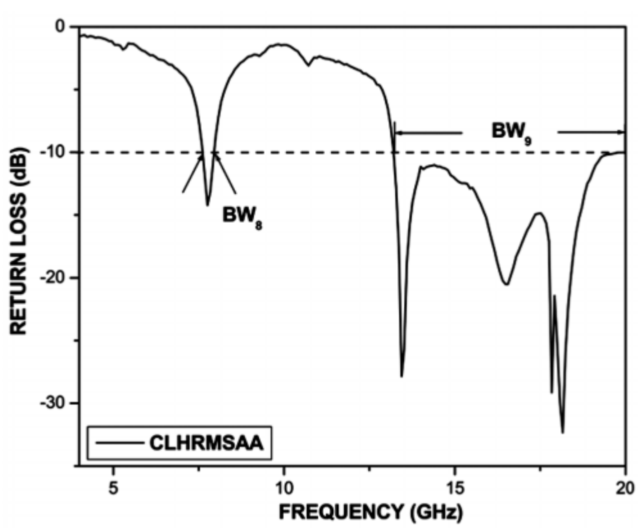

Fig. 10: Variation of Return Loss Versus Frequency of CLHRMSAA

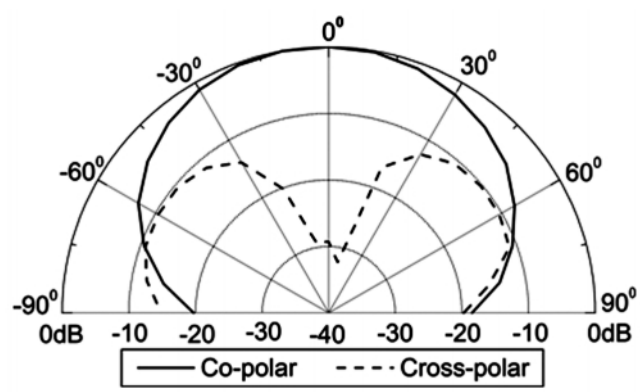

Fig. 11: Co-polar and Cross Polar Radiation Pattern of CRMA Measured at 9.11 GHz

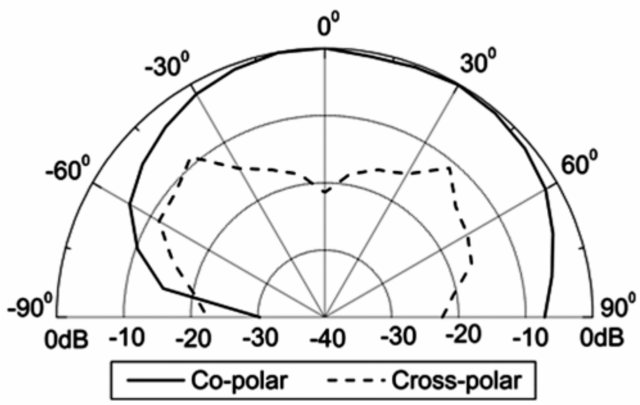

Fig. 12: Co-polar and Cross Polar Radiation Pattern of ILRMSA Measured at 8.4 GHz

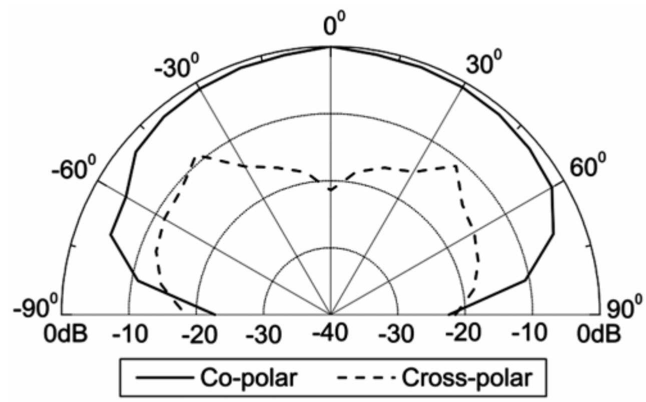

Fig. 13: Co-polar and Cross Polar Radiation Pattern of LRMSAA Measured at 8.24 GHz

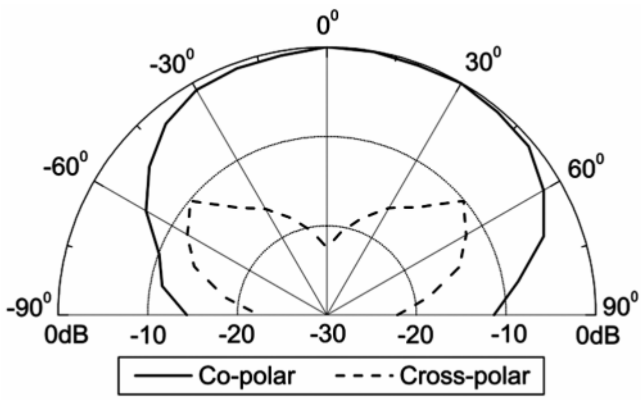

Fig. 14: Co-polar and Cross Polar Radiation Pattern of CLRMSAA Measured at 8.04 GHz

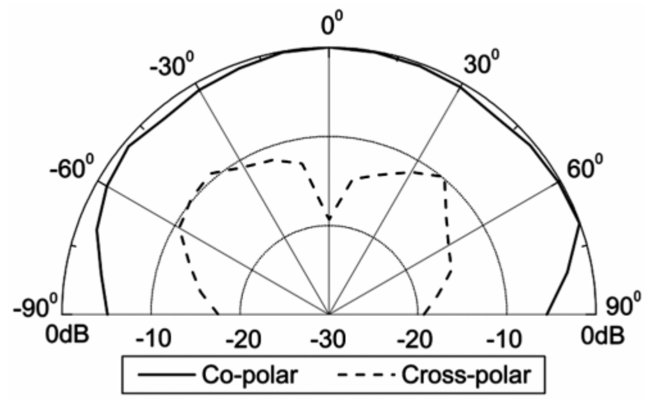

Fig. 15: Co-polar and Cross Polar Radiation Pattern of CLHRMSAA Measured at 7.76 GHz

4. CONCLUSION

From the detailed experimental study, it is concluded that the dual band operation of antenna at two different bands of frequencies is possible by constructing two element slot loaded rectangular microstrip array antenna. Effect of slots of different shapes has been studied experimentally for enhancing the bandwidth. It is found that by using *L*-complementary slots on the array elements and *H*-shape slots in the ground plane, the bandwidth at the *Ku*-band can be enhanced to 40.4% without much affecting the primary band. The enhancement of bandwidth at *Ku*-band does not affect the nature of broadside radiation characteristics. The proposed antennas are simple in their design and construction and they use low cost substrate material. These antennas may find applications for the systems operating at *X* and *Ku*-band of frequencies.

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