# Reconfigurable Circularly Polarized Compact Short Backfire Antenna

M. Javid Asad, M. Zafrullah, and Mian Shahzad Iqbal

*Abstract*—In this research paper, a slotted coaxial line fed cross dipole excitation structure for short backfire antenna is proposed and developed to achieve reconfigurable circular polarization. The cross dipole, which is fed by the slotted coaxial line, consists of two orthogonal dipoles. The dipoles are mounted on the outer conductor of the coaxial line. A unique technique is developed to generate reconfigurable circular polarization using cross dipole configuration. The sub-reflector is supported by the feed line, thus requiring no extra support. The antenna is developed on elliptical ground plane with dielectric rim making antenna compact. It is demonstrated that cross dipole excited short backfire antenna can achieve voltage standing wave ratio (VSWR) bandwidth of 14.28% for 2:1 VSWR, axial ratio of 0.2 dB with axial ratio ($\leq$ 3dB) bandwidth of 2.14% and a gain of more than 12 dBi. The experimental results for the designed antenna structure are in close agreement with computer simulations.

*Keywords*—Circularly polarized, compact, short backfire antenna.

## I. INTRODUCTION

THE demand for directional antennas for different wireless applications has increased considerably [1-3]. WiMax (world interoperability for microwave access) used for point to multipoint communication has become hot area [4-5]. The subscriber directional antennas communicate with the base stations connected to internet in WiMax wireless systems. The short back fire antenna is very attractive because of its good radiation characteristics. This antenna is widely used in tracking, telemetry, mobile communication, maritime satellite communication, and other wireless applications [6 – 10]. Circularly polarized antenna is employed to avoid power loss caused by Faraday polarization rotation in satellite communications. Circular polarization can be achieved by using cross aperture technique commonly used in microstrip antennas. The cross aperture topology consists of two rectangular slots orthogonal to each other [11 – 14]. The circular polarization is achieved by making the rectangular slots of slightly different lengths. The radiations from the slots are 90º out of phase with each other due to difference in

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lengths of the slots. Therefore the fields radiated from these slots produce circular polarization at broadside in the far field zone. The microstrip line or single probe is generally used to feed the cross aperture [11 – 16]. The structure located approximately quarter wavelength above the primary reflector is used to excite short backfire antenna. Impedance matching becomes difficult if short backfire antenna is excited using single probe feed because parasitic inductance of quarter wavelength probe contributes significantly to the inductive component of the input impedance [17]. The cross dipole consisting of two orthogonal dipoles is another excitation structure for short backfire antenna. This excitation structure usually requires external polarizer like 90º hybrid coupler to produce circular polarization [18]. Moreover the frequency bandwidth for input impedance of cross dipole excited short backfire antenna is also narrow e.g. natural impedance bandwidth is 3-5% for 1.5:1 VSWR [19]. Rectangular and H-shaped slots on center-fed slotted patch antenna can be used to increase impedance band width considerably [20 – 22].

In this paper, the design and development of compact circularly polarized short backfire antenna is reported. The antenna is excited by cross dipole. Slotted coaxial line is used to feed the cross dipole giving good impedance matching. Circular polarization is achieved using cross dipole without employing external polarizer such as 90º hybrid coupler. The new technique is developed to make circular polarization reconfigurable. The antenna is developed with dielectric rim on elliptical ground plane instead of circular ground plane producing different radiation patterns in two planes, $\Phi = 0°$ and $\Phi = 90°$.

## II. ANTENNA STRUCTURE AND DESIGN

Fig. 1 shows the configuration of the proposed short backfire antenna (SBA). The SBA is designed in S-band using FEM (Finite Element Method) based full-wave electromagnetic software HFSS. It is excited by cross dipole, consisting of a primary elliptic reflector with major axis $D_{ar}$ and minor axis $D_{br}$, a circular sub-reflector of diameter $D_{sr}$ placed at height $H_{sr}$. The simulations were carried out to optimize all these parameters, using the following general design guideline:

1. Choose the diameters of major axis of primary reflector $D_{ar}$, the sub-reflector Dsr and height of sub-reflector $H_{sr}$ initially to be equal to those of conventional SBA [19], i.e. $D_{ar} = 2.0\lambda_0$, $D_{sr} = 0.46\lambda_0$ and $H_{sr} = 0.5\lambda_0$; where $\lambda_0$ is free space wavelength at the design frequency of 2.8 GHz.

2. Set the height of cross dipole $H_d$ and location of the

feeding screw to $0.25\lambda_0$.

3. Design slotted coaxial line and the two orthogonal dipoles having same length equal to $0.5\lambda_0$.

4. Increase the length of one dipole and reduce the length of other to achieve circular polarization.

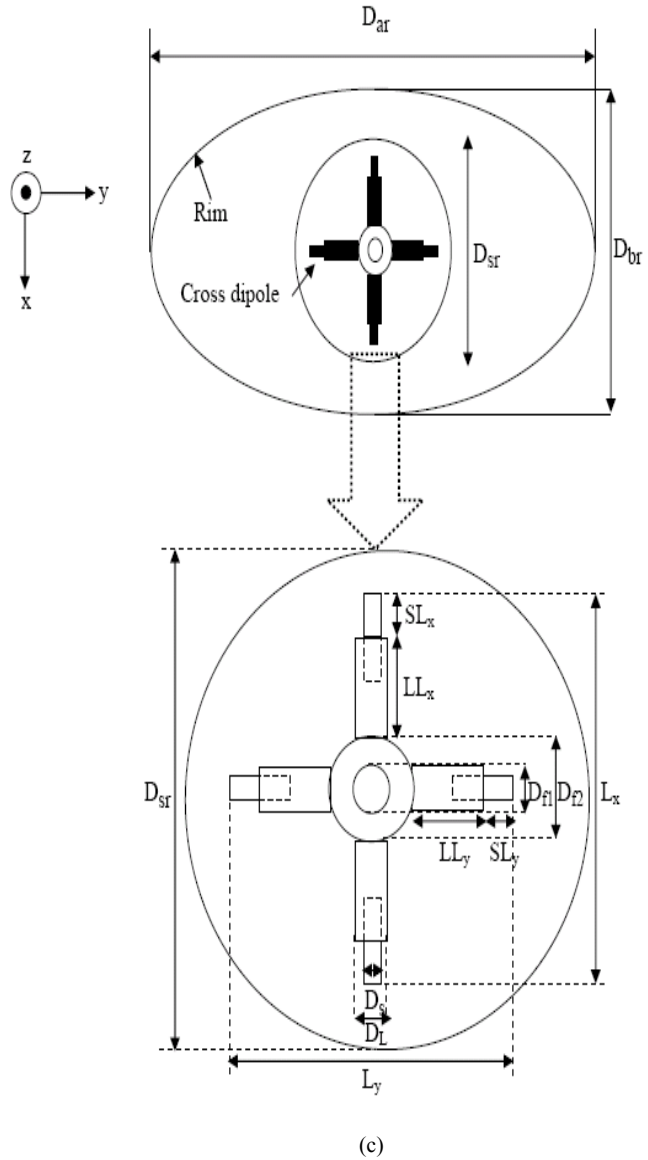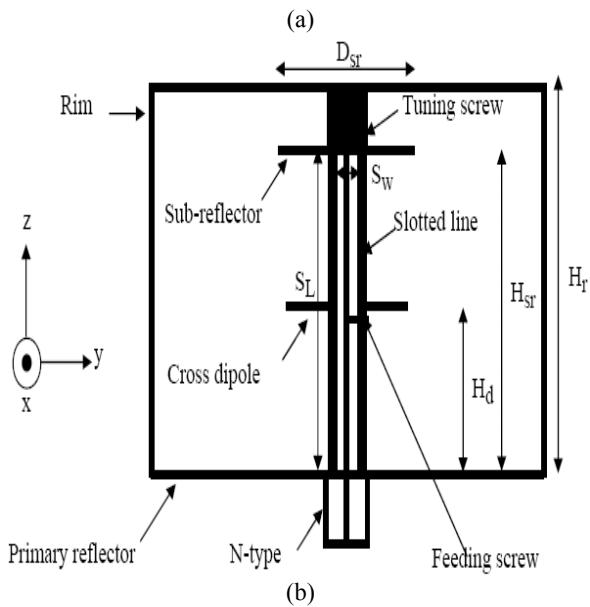5. Adjust the position of tuning screw for impedance matching and broad bandwidth.
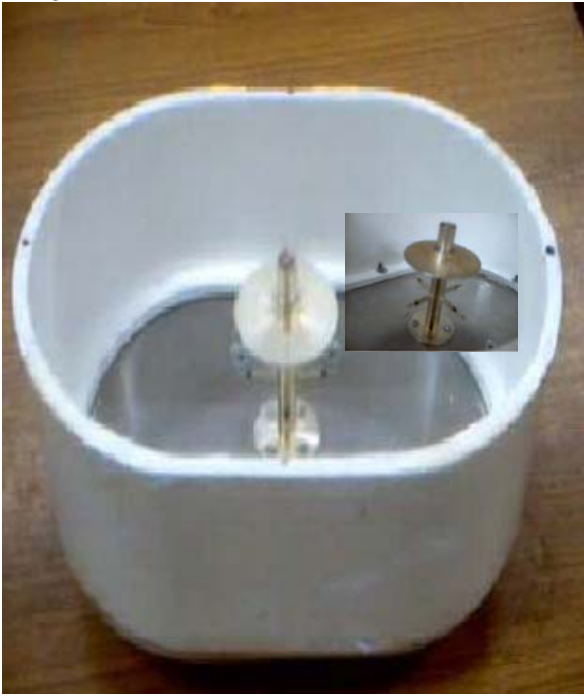


(a)



(b)



(c)

Fig.1 Short backfire antenna excited by cross dipole (a) 3-D view (b) Side view (c) Top view

Table1 lists the optimized geometric parameters of the designed SBA. The overall height of the SBA equals to be $0.677\lambda o$ and it is $2\lambda o$ in width, which is also the major diameter of the elliptical primary reflector. The minor diameter of the primary reflector is $1.5\lambda o$. The cross dipole is mounted on the outer conductor of the slotted coaxial line. The inner conductor of the line is short-circuited to the outer conductor by feeding screw. The sub-reflector is supported by the feed line and hence requires no extra support for it. Feeding and tuning screws are used for impedance matching.

TABLE I
OPTIMIZED GEOMETRICAL PARAMETERS FOR SBA

| $D_{ar}$ | Major diameter of the elliptical primary reflector | 214.0 mm ($2\lambda_0$) |
|---|---|---|
| $D_{br}$ | Minor diameter of the elliptical primary reflector | 160.5 mm ($1.5\lambda_0$) |
| $H_r$ | Height of SBA | 72.53 mm ($0.67\lambda_0$) |
| $D_{sr}$ | Diameter of the circular sub-reflector | 48.28 mm ($0.46\lambda_0$) |
| $H_d$ | Height of cross dipole from primary reflector | 26.98 mm ($0.252\lambda_0$) |
| $H_{sr}$ | Height of the sub-reflector from primary reflector | 53.96 mm ($0.504\lambda_0$) |
| $LL_y$ | Length of bigger part of dipole arm in y-direction | 12.19 mm ($0.114\lambda_0$) |
| $LL_x$ | Length of bigger part of dipole arm in x-direction | 12.19 mm ($0.114\lambda_0$) |
| $S_L$ | Length of the slot | 53.96 mm ($0.504\lambda_0$) |
| $L_x$ | Length of bigger arm of cross dipole | 54.12 mm ($0.505\lambda_0$) |
| $SL_y$ | Length of smaller part of dipole arm in y-direction | 7.11 mm ($0.066\lambda_0$) |
| $SL_x$ | Length of smaller part of dipole arm in x-direction | 9.87 mm ($0.092\lambda_0$) |
| $D_L$ | Diameter of bigger part of dipole arm | 3.0 mm ($0.028\lambda_0$) |
| $D_s$ | Diameter of smaller part of dipole arm | 2.0 mm ($0.019\lambda_0$) |
| $D_{f1}$ | Diameter of inner conductor of feeding line | 4.0 mm ($0.037\lambda_0$) |
| $D_{f2}$ | Diameter of outer conductor of feeding line | 10.0 mm ($0.093\lambda_0$) |
| $L_y$ | Length of smaller arm of cross dipole | 48.60 mm ($0.454\lambda_0$) |
| $S_w$ | Width of the slot | 2 mm ($0.019\lambda_0$) |

III. RESULTS

The simulated and measured results for return loss, S11 of cross dipole excited SBA, shown in Fig. 2, are in close agreement. The impedance band width for S11 $\leq -$ 10dB is found to be 14.28 % which is much better than the conventional cross-dipole excited SBA [19].
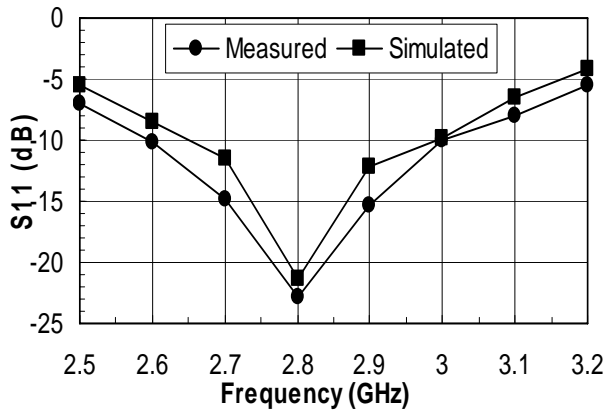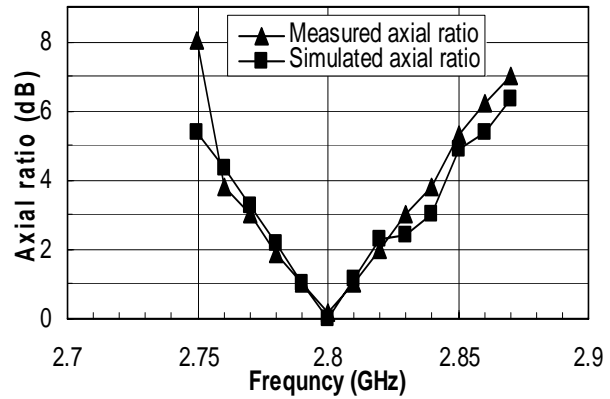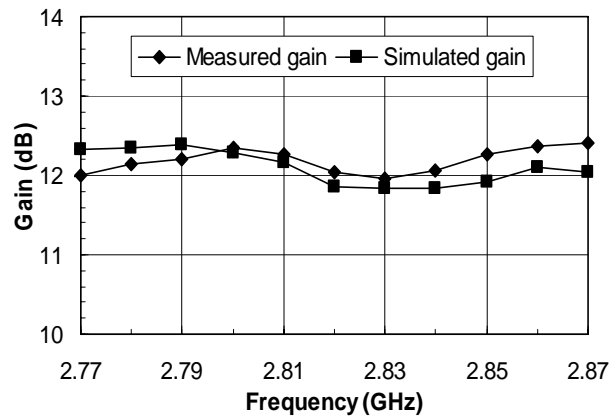
Fig. 2 Simulated and measured results for return loss of cross dipole excited SBA

To achieve circular polarization, a pair of orthogonal dipoles is used. Each arm of the dipoles is divided into two lengths, larger and smaller. The larger lengths of all dipoles are kept same and equal to 12.19mm with diameter of 3mm. The smaller lengths of the dipoles have 2mm diameter. The smaller lengths are embedded inside the larger lengths of the dipoles. Initially the length of two dipoles is same i.e. $\lambda_0/2$.

Then one dipole is made shorter and the other dipole is made longer. Circularly polarized wave is produced when the length of one dipole is $\lambda_0/2 + 0.0051\lambda_0$ and the length of other dipole is $\lambda_0/2 - 0.0464\lambda_0$. The axial ratio at broadside and the gain are plotted in Fig.3. It is seen that axial ratio is 0.2 dB with bandwidth for AR $\leq$ 3 dB of about 2.14% and the gain is 12.35 dB.

(a)

(b)

Fig. 3 Simulated and measured results of SBA (a) Axial ratio (b) Gain

The axial ratio and axial ratio band width can be changed by changing the lengths of pair of dipoles. Axial ratio bandwidth is changed by moving smaller lengths, SLx or SLy, outwardly. For example, axial ratio band width is changed from 60MHz to 80 MHz by changing smaller lengths of large dipole from 8.725 mm to 9.725 mm as shown in Fig. 4. The frequency of best axial ratio is changed if the smaller lengths of the dipoles are moved outwardly by greater amount as shown in Fig.5. Hence axial ratio band width as well as frequency of best axial ratio can be controlled by dividing arms of the dipoles into two lengths, larger and smaller, embedding smaller lengths into the larger lengths giving reconfigurable circular polarization.
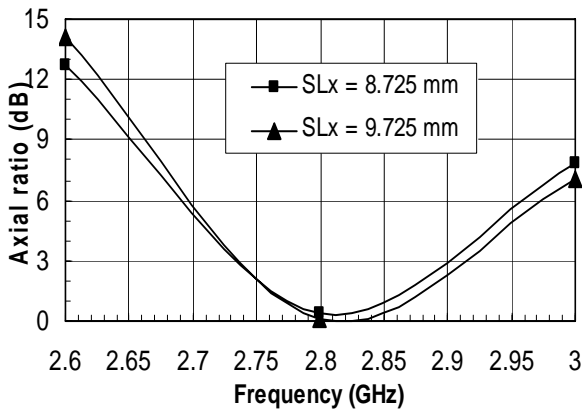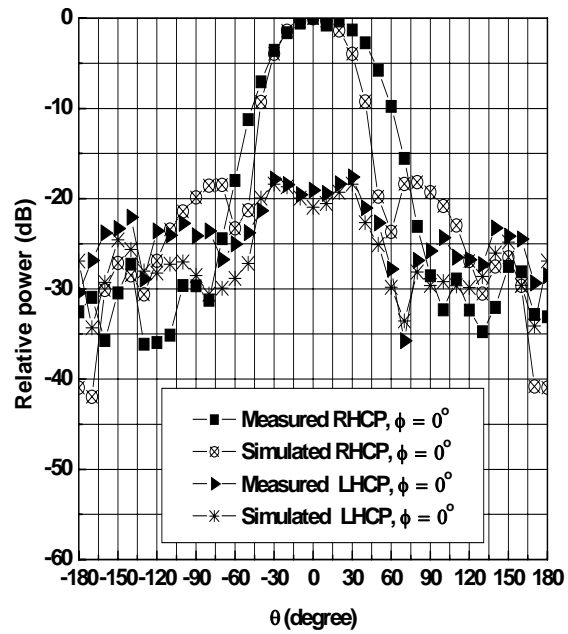
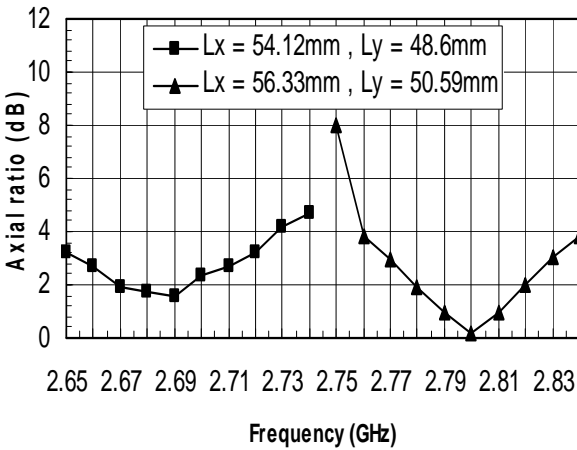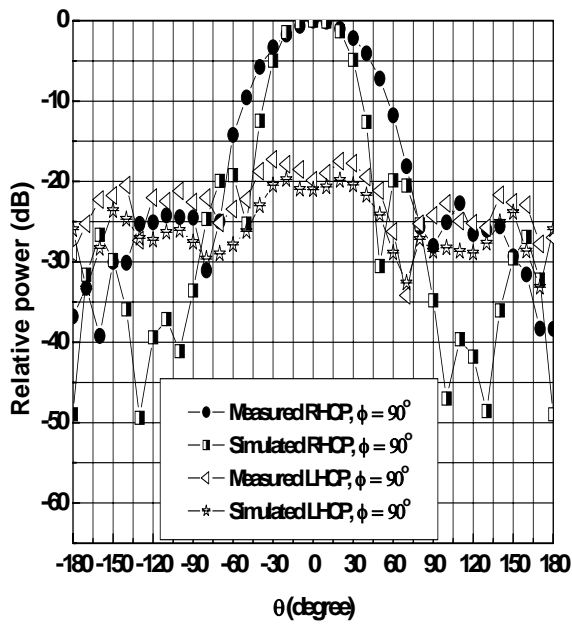Fig. 4 Simulated results showing effect of lengths of cross dipole on axial ratio bandwidth



Fig. 5 Measured results showing effect of lengths of cross dipole on axial ratio

Generally SBA uses circular primary reflector, typical diameter of $2\lambda_0$, and metallic rim to improve side lobe level. But the fabrication of the metallic rim is difficult as it is usually welded with primary reflector. Further, a separate radome is used, which is assembled with the rim, making its fabrication more complex. This difficulty is overcome by developing SBA on elliptical primary reflector with dielectric rim which is integral part of the radome of antenna. The dimension of primary reflector along y-axis is greater than that along x-axis. Hence the radiations reflected from primary reflector in two planes, xz and yz, of different sizes cause different beam widths in the two planes. The simulated and measured radiation patterns at 2.8 GHz are shown in Fig. 6. The half power beam widths are 50º and 70º in Φ = 0º and Φ = 90º planes respectively. The small size of primary reflector and dielectric rim makes antenna compact and cost effective.



(a)



(b)

Fig. 5 Simulated & measured radiation patterns of SBA at 2.8GHz
(a) Φ = 0º (b) Φ = 90º

## IV. CONCLUSION

A cross dipole excitation structure has been designed and developed for short backfire antenna to achieve reconfigurable circular polarization. The cross dipole is fed by slotted coaxial line. Impedance matching and bandwidth improvement is achieved by employing feeding and tuning screws. Circular polarization is achieved using cross dipole without employing external polarizer. The frequency of axial ratio and its band width can be controlled by changing smaller lengths of dipoles. The use of elliptical primary reflector and dielectric rim makes antenna compact and cost effective. The proposed SBA achieves voltage standing wave ratio (VSWR) bandwidth of 14.28% for 2:1 VSWR, axial ratio of 0.2 dB with axial ratio ($\leq$ 3dB) bandwidth of 2.14% and a gain of more than 12 dBi. Simulation and experimental results show good agreement.

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