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ANALYSIS OF CROSSED DIPOLE ESA FOR WIRELESS COMMUNICATION APPLICATIONS

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ABSTRACT

A compact size of (35mm x 35mm) single band ESA has been simulated and fabricated for wireless communication applications like Bluetooth, cordless phone etc. The Design consists of a circular slot and it is embedded with cross type structures. The overall dimensions of this antenna are reduced to satisfy the rules of ESAs, two dipoles are arranged in a cross shape (plus shape) on the surface of the substrate inside the circular patch to achieve impedance bandwidth. The simulation of the ESA is done through HFSS and it is fabricated on FR4 with a thickness of 1.6mm, ε_r of 4.4mm and the size of ESA is 35mmx35mm. The return loss(S11) of the Simulated and fabricated proposed antenna is greater than -10db which is acceptable for practical applications and there is a good agreement between the simulated and fabricated results.

Keywords: *ESA, Cross shape, Circular slot, Return loss and Bluetooth.*

1. INTRODUCTION

Now a day's demand for wireless devices is increasing day-by-day. Especially the reduction of the size of antenna plays a vital role in wireless communications. Miniaturization of an antenna is simply said to be ESA. Electrically Small Antennas are meant to minimize the dimensions of the antenna in high-frequency ranges. ESAs are easily integrated into small devices. Technically, an ESA is whose maximum dimension can be fitted in an imaginary sphere of radius 'a' such that ka<1, k is wavenumber which equals 2 where 'l' is the wavelength of Antenna and 'a' is the radius of Imaginary sphere bounding the maximum dimensions of the antenna. The Basic Principles of normal antenna and ESAs are the same. Researchers are interested in ESAs because of its little size, easy integration and multiband features [1]. The demand for small multiband resonating antennas in wireless systems is growing day by the day. Using diverse methodologies, researchers have proposed a variety of ESAs for various uses and in the literature, several single-band ESAs have been proposed. The authors have presented a 2.4GHz antenna that is electrically compact and has a partial ground plane for biomedical applications [2]. [3] presents ESA' in the form of active antennas based on superconductive arrays for 200MHz band. [4] shows a compact slotted ESA for MIMO applications with a construction that combines a meander line with a semi ground plane antenna. For a 2.4GHz frequency band application, a trident form with an electrically tiny meandering line antenna is proposed [5]. [6] presents a 2.4 GHz electrically compact scalable antenna constructed on a thin circuit board. [7] proposes a small antenna with high gain and circular polarization that can be used for WiMAX and it is made of Taconic TLY-5 conducting material, as the complexity of devices increases so the demand for multiband antennas also increases. As a result, numerous types of dual-band and tri-band antennas have been reported for diverse purposes. [8] proposes a dual-band ESA with a PIFA shape that operates at 100 MHz and 500 MHz and is suitable for handheld use. [9] proposes a dual-band circularly polarized four short stubs loaded microstrip patch antenna for wireless applications, although it is not classified as a compact antenna due to its size. For UWB applications, a new antenna with dimensions of 41 x 41 mm2 [10] is proposed that uses carbon composite as a conductive adhesive. [12] proposes a compact UWB slotted antenna with dual band notched features. [13] proposes a parasitic electrically tiny dipole antenna with near-field resonance and 300 MHz wide-band characteristics achieved by including a non-foster element. For circular polarization, cross shaped fractal slots are used, with four cross shaped slot formations

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achieving a wide band [14]. Metamaterial structures, single pole antenna with disc structure, alternating currents fed structure, 3D shaped structures and conducting ring base structures have all been recommended in the literature as ways to improve performance [15, 16]. Another way for increasing gain is to use a cavity type antenna with complementary SRR, which is primarily tuned for 2.45 GHz and has a 70x70 mm^2 dimension [17]. Electrically Small Antennas are meant to minimize the size of the antenna in high-frequency ranges. ESAs are easily integrated into small devices. Technically, an ESA is whose maximum dimension can be fitted in Imaginary sphere of radius 'a' such that ka<1, k is wavenumber which equals 2 where 'l' is the wavelength of Antenna and 'a' is the radius of Imaginary sphere bounding the maximum dimensions of the antenna [18-25]. The Basic Principles of Normal Antenna and ESAs are the same. The design goals of Electrically Small Antennas include good impedance match (low VSWR), high radiation efficiency, low Q, and wide bandwidth. In this mainly Q and bandwidth are compared to check the working of the Designed Antenna [26-34]. There are varieties of Antennas in the current Wireless communication world. Due to the very high popularity of miniaturization in electronic devices the demand and utilization of Microstrip Patch Antenna increased day by day. Microstrip patch consists of 3 parts mainly Radiating patch, substrate layer and ground plane. The radiating patch is etched on the top of a Di-electric substrate. In general, copper is used as an etching material. Microstrip patch Antennas have many advantages when compared to conventional microwave Antennas [35-38]. Microstrip patch antennas with wide range of applications because of their apparent advantages of a lightweight, low profile, low cost, planar configuration, easy of conformal, superior portability and ease of fabrication [39-43]. The common structure of patch antennas is of rectangular and circular in shape. A microstrip patch antenna (MPA) consists of a conducting patch of any geometry on one side of a dielectric substrate and a ground plane on another side [44-48]. The ground plane is of the size of the substrate which is covered under the substrate of the antenna. The Di-electric substrate is of thickness h and has relative permittivity. Substrates are generally made of Di-electric material. In general, Substrate typically has a height between 0.002l0λ-0.005l0λ [49-50]. The thickness of the substrate greatly impacts the size boundaries of the antenna. The di-electric substrate used for this design is FR4 epoxy has a relative permittivity of 4.4, Thermal conductivity of 0.29 W/(mK). Fr-4 epoxy is made is fiberglass with epoxy resin.FR stands for flame resistant.

An ESA having single band features is designed by utilising 2 rectangular bars embedded in a circular slot feeded by a 50Ω line. This circular slotted antenna resonates at 2.4GHz applicable for blueooth applications. The dimensions are very small for this rectangular bars in a circular slotted antennas when compared to the other ESAs available in the literature.

2. Fundamental dimensional limits of small antenna

Wheeler's fundamental definition an ESA is one whose maximum dimension is less than λ/2π. also, this relation is expressed as:

$$ka<1 \qquad (1)$$

k = 2π (Wave number)
λ= wavelength in free space(meters)
a= small antenna can be surrounded by a sphere of radius 'a'.

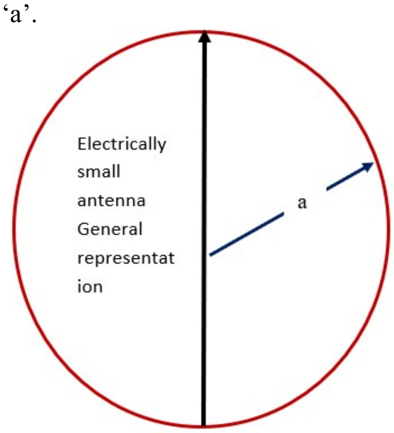

Figure 1: General Radian sphere which encloses the ESA with a circular slot in free space

Fujimoto, Henderson, Hirasawa and James have proposed the summarized approach used for designing monograph ESA in 1987 [5]. Also, they analyzed theoretical limitations of small antennas. ESA are the one having high and small impedance bandwidth. Efficiency of the antenna is another important parameter and it is determined by the losses in the conductors and the losses related with the other materials used in the antenna construction compared with actual radiation property. It can be represented as

$$\eta_a = \frac{R_r}{R_r + R_m} \qquad (2)$$

η_a = Antenna efficiency
Rr = Resistance associated with radiation(Ω)
Rm = Resistance corresponds to Material Loss (Ω)
In general Z_{in} of ESA is reactive(capacitive). To improve the power transferred to the antenna,

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impedance matching network is essential. The overall efficiency of the antenna including matching network is given as:

$$\eta_s = \eta_a \eta_m \quad (3)$$

η_s =Overall system efficiency (including antenna and matching network)

η_m = efficiency of only matching network

matching network is also reactive impedance network, and its efficiency is expressed as

$$\eta_m = \frac{\eta_a}{1+\frac{Q_a}{Q_m}} \quad (4)$$

Q_a = Antenna Quality factor (ESA)

Q_m = Matching network Quality

3. GEOMETRY AND DESIGN METHADOLOGY

The proposed design and geometry of the patch antenna are in Figure 1 as shown below. The design parameters of the circular slotted cross shaped ESA are given in Table-1. The designed Antenna is fabricated on FR4 substrate which has 4.4 ε_r. The center frequency of the cross shaped circular slotted antenna is 2.4GHz. By placing a different structure in the circular slot can improve the efficiency of ESA when compared to a conventional microwave antenna. A slot can enhance gain, bandwidth, reduce return loss.

Circular patch radius is given by

$$a= \frac{F}{\sqrt{1+\frac{2h}{\pi \varepsilon_r}[\ln\left(\frac{\pi f}{2h}\right)+1.7726]}} \quad (5)$$

Where, F is

$$F = \frac{8.791+10^9)}{f_r\sqrt{\varepsilon_r}} \quad (6)$$

f_r is center frequency

substrate length and width are given by

$$W= \frac{V_0}{2F_r}\sqrt{\frac{2}{\varepsilon_r+1}} \quad (7)$$

$$L=\frac{C}{2F_r\sqrt{\varepsilon_{reff}}} - 2\Delta l \quad (8)$$

Where Δl is Extension in length due to Fringing effects

$$\Delta l = 0.412h\frac{(\varepsilon_{reff}+0.03)(w+0.26h)}{(\varepsilon_{reff}-0.258)(w+0.8h)} \quad (9)$$

Where Δl=Extension in length due to fringing effects

The effective dielectric constant is given by

$$\varepsilon_{reff} = \frac{\varepsilon_r+1}{2} + \frac{\varepsilon_r-1}{2}\left[1+\left[\frac{12h}{w}\right]\right]^{-1/2} \quad (10)$$

The actual length and width of the ground plane can be calculated by using the formulae shown below.

$$L_g=6h+L \quad (11)$$

Where L=Length of the patch

h= Thickness of the substrate

$$W_g=6h+W \quad (12)$$

Where W=Width of the patch

h= Thickness of the substrate

Length and width of the feed line is calculated by using the formulae shown below.

$$B=\frac{60\Pi^2}{\sqrt{\varepsilon_r Z_C}} \quad (13)$$

Where Z_c= Characteristic impedance

ε_r=Relative permittivity of the substrate

$$L_f=\frac{\lambda_0}{4\sqrt{\varepsilon_{eff}}} \quad (14)$$

Radius of the patch is calculated by using the formulae shown below

$$a=\frac{F}{\sqrt{1+\frac{2h}{\Pi\varepsilon_r}[\ln\left(\frac{\Pi f}{2h}\right)+1.7726]}} \quad (15)$$

$$F=\frac{8.791*10^9}{f_r\sqrt{\varepsilon_r}} \quad (16)$$

The top view of the substrate contains a circular patch of radius R_1 with a cross-slot (plus symbol) of dimensions L_1 x W_1. To obtain the proposed center frequency at -10db point we have introduced a circular slot of width 0.2mm with the radius of R_2. Etching of the radiating patch on the substrate is done using copper using a regular mechanism. In general, there are two types of feeding techniques for a microstrip Antenna. The selection of the antenna feeding method plays a vital role because it affects the gain, return loss, bandwidth, and other important parameters of an antenna. Based on these specifications and factors HFSS is used to obtain further design simulate, optimize the antenna dimensions

TABLE-1: Dimensions of circular slotted cross shaped antenna

Parameter	Value(mm)	Parameter	Value(mm)
L	35	W_2	4
W	35	R_1	16.8
L_1	16	R_2	14.6
W_1	1.5	R_3	8

Efficiency of an antenna is obtained by 2 rectangular bars and the circular slot in the antenna provides capacitance effect. The major challenge of the ESA is impedance matching and because of the small antenna size leads to minimum radiation and high reactance. This circular slot and 2 rectangular bars provide capacitance and inductance. The resonant frequencies of the filter are varied by changing the dimensions of the circular slot and rectangular bars. In according to that an ESA with a circular slot at the top plane has been designed and it is resonating

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at 2.4GHz for wireless communication applications like Bluetooth.

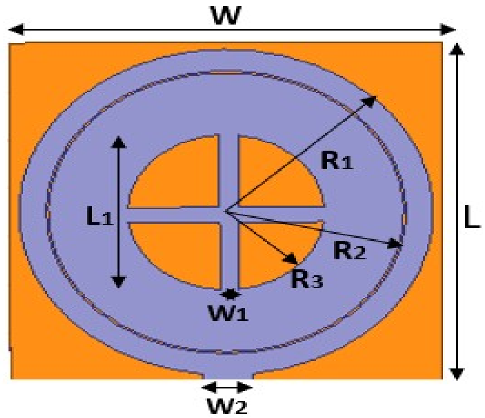
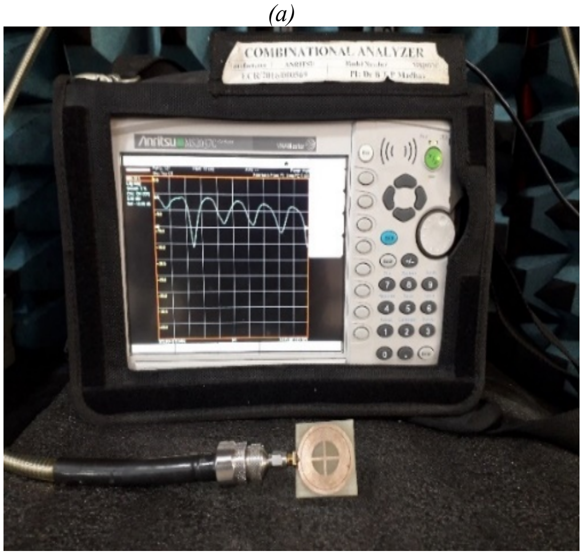


Figure 2: Schematic diagram of circular slotted cross shaped ESA

(a)



(b)

Figure 3: Circular slotted cross shaped ESA (a) Fabricated image (b) Measurement of ESA with an Anritsu combinational analyzer

4. RESULTS AND DISCUSSION

Simulated and fabricated S_{11} is represented in figure 3 for a single band ESA with a circular slot at the center. S_{11} of an antenna is measured by using MS2037C Anritsu combinational analyzer. It is noted that the fabricated and simulated results show a good understanding and minor variation is observed because of the manufacturing tolerances. Simulated S_{11} of circular slotted cross shaped ESA is -13dB at 2.4GHz. Fabricated bandwidth of circular slotted cross shaped ESA for S_{11} <-10dB are 2.35-2.67GHz (bandwidth 0.32GHz) of the single band ESA. In general VSWR should be less than 2 for any antenna and it is defined as the power delivered from source of antenna to the load. VSWR for ESA with a circular slot is <2 and it is of 0.79. The radiation pattern of ESA with a circular slot is represented in figure 7 and by observing those radiation patterns we can easily say that the antenna is having omni directional radiation pattern in terms of Φ and having a bidirectional radiation pattern in terms of θ and when $\theta=90^0$ 180^0.

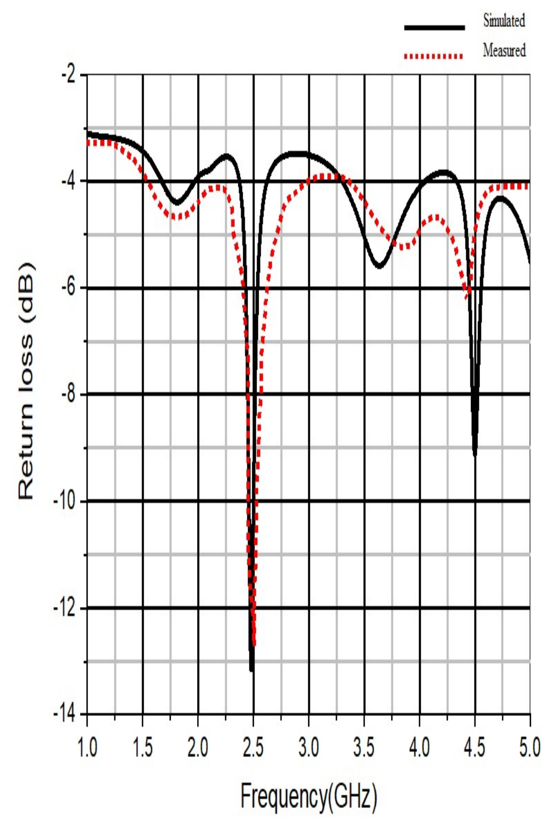


Figure 4: Simulated and fabricated S_{11} of circular slotted cross shaped ESA

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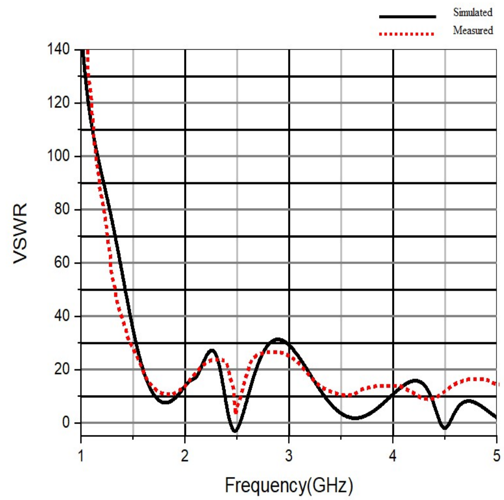
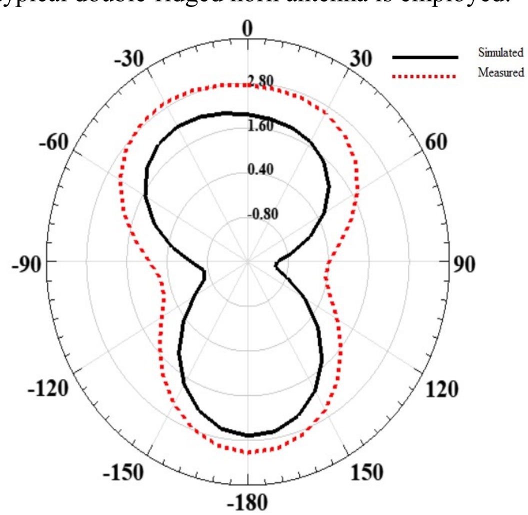


Figure 5: Simulated and fabricated VSWR of circular slotted cross shaped ESA

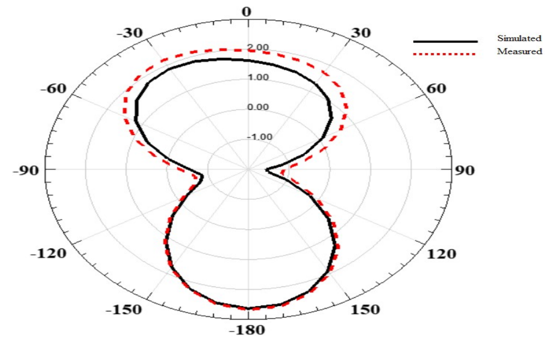
The circular slotted ESA is obtained by keeping the bandwidth of an antenna at ka = 0.512 for 2.4GHz. Chu [22] suggested Eq. (1) to compute the tiny antenna minimum sphere radius a = 14.5 mm. At 1.5GHz, Q_{chu} is 6.0007 at 2.4GHz. Chu computed the smallest ESA's minimal radiation quality factor, assuming the patch antenna is encased in a closed sphere. Chu has defined an ESA's constraint in the form of Eq. (1) based on the quality factor (Q) specification [22, 23].

$$Q=\frac{1}{ka}+\frac{1}{k^3\,a^3} \qquad (17)$$

For the resonating frequency range of 2.4GHz, the radiation patterns of the circular slotted ESA are measured using HFSS and the results are measured in an anechoic chamber using an antenna measurement equipment. As the reference antenna, a typical double-ridged horn antenna is employed.

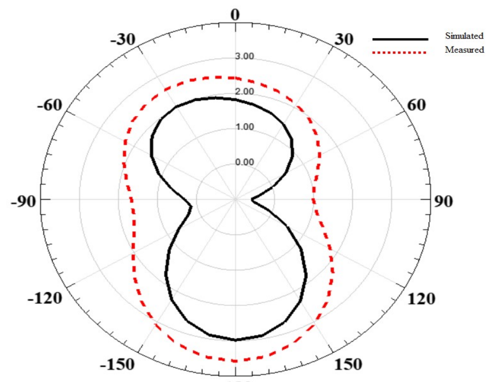


(a)

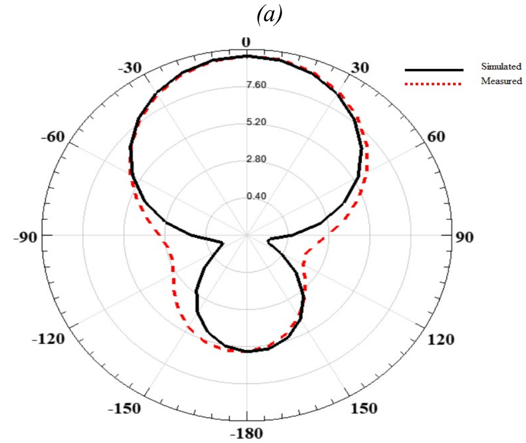


(b)

Figure 6: Simulated and fabricated radiation pattern of ESA in terms of elevation angle with a circular slot (a) θ=90º (b) θ=180º



(a)



(b)

Figure 7: Simulated and fabricated radiation pattern of ESA in terms of elevation angle with a circular slot (a) ϕ=90º (b) ϕ=180º

The Antenna efficieny of value 0.2587 is obtained which is calculated using formula by taking the values of radiated and incident power. Next, the important parameter of an antenna is Radiation pattern of the antenna. For the above designed antenna two different patterns plotted at different angles are shown in Figure 5 below. Figure 5 shows the radiation Pattern of the Antenna which is

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plotted at θ 90^0 & 180^0. Figure 6 shows the radiation Pattern of the Antenna which is plotted at ϕ 90^0 & 180^0.

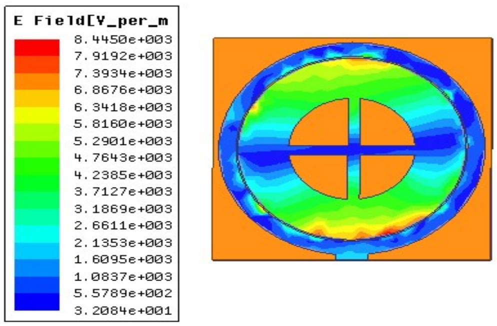

Figure 8: E-field distribution of circular slotted cross shaped ESA

Table 2: Comparison of circular slotted cross shaped ESA with the available literature

Reference	Antenna Type	Antenna Size(mm^2)	VSWR	Resonating bands
[10]	UWB	40 × 40	1.5	609MHz - 9.105GHz
[12]	UWB	35× 40	1.232	3.3–3.7GHz/ 5.15–5.825GHz
[13]	WB	158 mm (Diameter)	1.78	279MHz – 318.5MHz
[14]	UWB	40 × 40	1.398	2.42–3GHz
Proposed model	Single band	35mmx35 mm	0.79	2.4GHz

CONCLUSION

A single-band circular slotted cross shaped ESA resonating at 2.4GHz is designed and fabricated. Simulated S_{11} of circular slotted ESA is -13dB at 2.4GHz. Fabricated bandwidth of circular slotted cross shaped ESA for S_{11} <-10dB are 2.35-2.67GHz (bandwidth 0.32GHz) of the single band ESA. There is a good match between the simulated and fabricated results in terms of S_{11}, VSWR. Radiation pattern is omnidirectional for all the resonating frequencies; thus, it is suitable for 2.4GHz Bluetooth applications.

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