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COMPACT SLOTLINE FED QUARTER-CIRCULAR SLOT UWB ANTENNA

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Abstract
A slotline fed gain enhanced ultra wide band radiator having a quarter circular slot is designed and discussed. The -10dB bandwidth of the antenna is found to be 9.2GHz covering a range of frequencies between 2.9 and 12.1 GHz. Proposed structure possess high radiation efficiency of the range of 96% with an enhanced gain in upper frequencies. Polarization of the antenna is found to be linear and is similarly oriented in the entire band. Antenna offers radiation patterns with bore sight oriented in same direction within the range of frequencies of interest. Overall dimension of the antenna is very compact and is 10×24.3×1.6 mm^3, when fabricated in FR4 substrate.

Keywords:
Open Ended Slotline, Slot Line Fed, Uni-Planar, UWB Antenna, Quarter Circular Slot, Directional Pattern

1. INTRODUCTION

In recent years we are witnessing a drastic development in the field of communication. The size of the device reduces in one part of this scenario while the speed and data rate capacity is increasing on the other part. This made literarily a challenge cum opportunity to antenna design engineers, because they have to design compact antennas suitable for this small gadgets without compromising the radiation characteristics and data rate capacities. Compact UWBs are one of the solutions for this condition, in which the antenna posses a high range of band width which will provide the transmission or reception capacity more. Various UWB designs are already presented in literature and are discussed as follows.

A circular shaped compact planar UWB antenna with reduced radiation efficiency is presented by authors in [1]. In [2] dual element based UWB antenna for MIMO applications is developed and discussed which is of with structural complexities. A circular radiator based low-profile planar wideband antenna is presented in [3] in which the radiation characteristics are non-uniform within the band. K. Kumar and others in [4] presents a wide band radiator with a V slot introduced into a trapezoidal shaped patch and with a quasi curved ground plane. UWB antenna with single band-notched characteristic based on rectangular slotted GND plane monopole is discussed in [5]. A UWB monopole suitable for sensing applications of various spectrums, which is derived from a hexagon slot, is presented by T Gayathri and others in [6]. A compact UWB monopole antenna with circular plate is given by the Authors in [7]. In [8] a high isolation planar UWB antenna for MIMO based wireless application is discussed. A planar UWB antenna for on-body communication application is presented in [9]. A notched microstrip line fed UWB structure design is discussed by L Guo and others in [10]. In [11], a modified edge elliptical antenna with UWB characteristics is presented. A ground-independent planar UWB antenna designing is discussed in [12]. Novel design of a planar UWB antenna with enhanced gain is presented in [13] but the size of the antenna is too high. A four element planar UWB array with a complicated structure is discussed in [14]. An UWB antenna based on meta-material of miniaturized geometries is presented in [15] but in these antennas, radiation patterns are non uniform. A planar rectangular monopole based UWB radiator with reduced gain is presented in [16]. A wideband radiator suitable for WBAN is presented in [17] but they are not suitable for normal communications. Modified circular shaped planar monopole UWB antenna with a large radiating patch is presented in [18]. Printed monopole for wide band communication access system is presented in [19]. In [20] the UWB design is attained with the help of a centrally slotted metallic patch whose edges are corrugated, which is very complicated design. In [21] the authors present another slotline fed antenna with a semi circular slot on it to create UWB characteristics.

In this paper, we are discussing an ultra compact UWB radiator with excellent impedance and radiation characteristics. The 2:1 voltage standing wave ratio bandwidth of the antenna is found to be extended from 2.9 to 12.1 GHz. Antenna possesses an average radiation efficiency is of the order of 96% with an enhanced gain in upper frequencies and moderate gain in lower frequencies. Polarization of the antenna is uniformly linear and radiation patterns with bore sight oriented in same direction. Overall dimension of the antenna is very compact and is 10×24.3×1.6 mm^3, when fabricated in FR4 substrate.

1.1 EVOLUTION OF THE STRUCTURE AND PARAMETRIC OPTIMIZATION

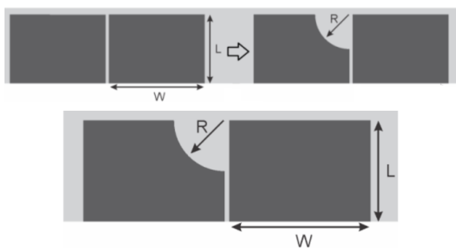

Fig.1. Evolution and Derived Structure of UWB Antenna

Antenna structure is resulted from removing a quarter circle of radius 'R' from one plate of a symmetrical open ended slotline (OES) of plate dimensions L×W. The evolution and resulted structure with all the dimensional specifications is given in Fig.1. Introduction of this slot will reduce the resonance frequency of OES and increases its bandwidth. By carefully selecting the dimensional parameters, we can attain the UWB characteristics from this structure. To optimize the dimensions, a number of parametric analysis is carried out and is explained as follows.

Effect of L on resonance is depicted in Fig.2. First resonance shows higher shifts while the second, third and fourth resonances shows drastic downshift with L. The reason for higher shift of first resonance with L is due to confinement of fringing field near the vicinity of slot of open ended slotline as its length increases [22]. The second and third resonance decreases due to the increase in resonant current length with this parameter.

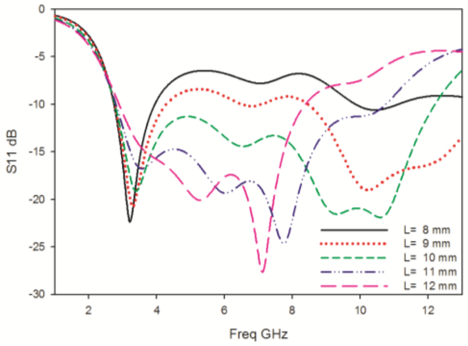

Fig.2. Effect of L on Resonant frequency

S11 shows a considerable variation with variation in W, and is shown in Fig.3. All the resonant current path length increases with w and thus all the frequencies show a down shift with this parameter. Impedance matching of the antenna is also found to be varies with W.

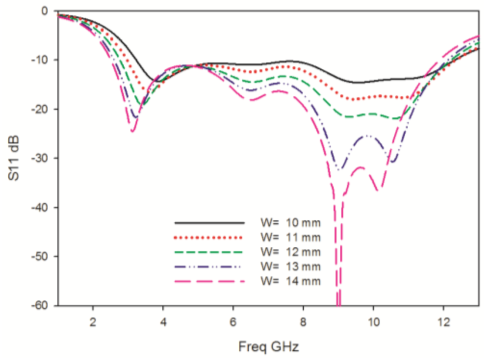

Fig.3. Effect of W on Resonant frequency

As R increases, the higher resonances show a drastic down shift while the decrease in first resonant frequency is feeble (Fig.4). Matching of the antenna is also highly affected with R of the structure.

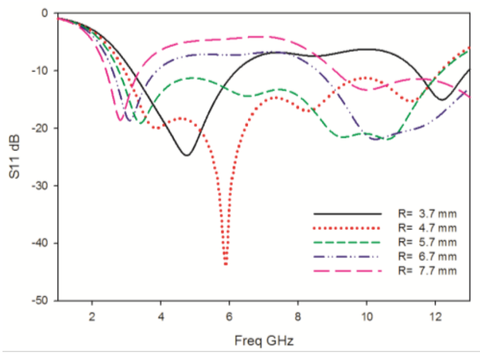

Fig.4. Effect of R on Resonant frequency

From the above analyses, design equations of the antenna are developed. Developed equations are validated using Ansoft HFSS simulation tool. Obtained design equations of the antenna are as follows.

$$2W - R + \frac{\pi R}{2} \approx 0.52\lambda_{g1} \tag{1}$$

$$2L + W - 2R + \frac{\pi R}{2} \approx 1.53\lambda_{g2} \tag{2}$$

$$2L + W - R + \frac{\pi R}{2} \approx 3\lambda_{g3} \tag{3}$$

$$2L + W - 0.5R + \frac{\pi R}{2} \approx 4.45\lambda_{g4} \tag{4}$$

where λ_{g1}, λ_{g2}, λ_{g3}, λ_{g4} are the guided wavelength corresponding to 1st , 2nd 3rd and 4th resonances and is calculated from free space wavelength λ using the expression

$$\lambda_{gn} = \frac{\lambda_n}{\sqrt{\varepsilon_{\text{eff}}}} \tag{5}$$

where ε_{eff} is the effective dielectric constant and is calculated from dielectric constant ε_r of the substrate using the equation

$$\varepsilon_{\text{eff}} = \frac{\varepsilon_r + 1}{2} \tag{6}$$

Four different antennas are designed using the developed design equation and is simulated using HFSS to validate the equations. The structural specifications of the designed antenna are depicted in Table.1.

Table.1. Dimension Derived using Design Equations

Description	**Ant.A.**	**Ant.B.**	**Ant.C.**	**Ant.D.**
Substrate	Rogers 6010LM	FR4	Rogers RO3006	Rogers 5880
ε_r	**10.6**	**4.4**	**6.15**	**2.2**
R (mm)	3.95	5.7	4.9	7.4
L (mm)	6.95	10	8.7	13
W (mm)	8.35	12	10.45	15.6

Simulated S11 curves of all the four antennas are given in Fig.5 and are found to be well matching, which indicates the validity of design equations.

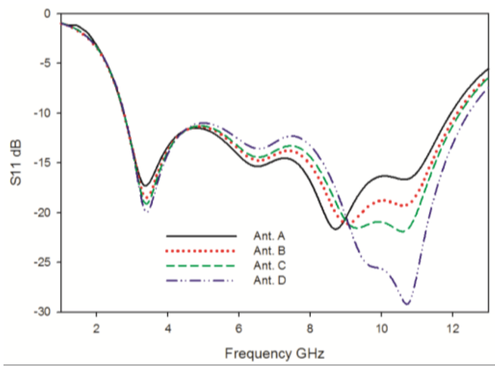

Fig.5. Validation of Design Equations

2. RESULTS AND DISCUSSIONS

For the experimental validation, a prototype of the developed antenna is fabricated and tested with the help of VNA HP8510G. Since commercially available FR4 is cheaper and easily available, “Antenna B” specified in Table.1 is selected for prototype. Simulated and Measured S11 parameters of the antenna is depicted in Fig.6 and it is evident from the figure that the antenna offers a 2:1 VSWR band width of 9.2 GHz ranging from 2.9 GHz to 12.1GHz. It can be also inferred from the figure that, the resonances placed at 3.4, 6.5, 9.3 and 10.6 GHz are merged together to attain this bandwidth specification.

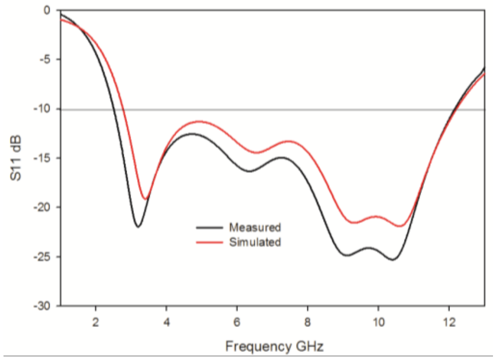

Fig.6. Measured and Simulated S11

Radiation pattern of the antenna is a plot of energy distribution around the antenna due to radiated energy. The measured principal plane radiation patterns at three resonances are shown in Fig.7. At first resonance (Fig.7.a), the antenna’s pattern resembles the pattern of a half wave dipole with an isotropic H plane pattern and a figure of eight pattern in electric plane. At higher resonances, antenna offers a directive pattern (Fig.7.b, 7.c and Fig.7.d) with bore-sight oriented towards quarter circle cut opening direction. An F/B ration more than 5 dB is present in all patterns in three frequencies. A high Cross polar purity of the order of -30 dB is found in all the patterns. One of the major speciality and main advantage of the developed UWB, that can be inferred from Fig.7. is the uniformity of bore sight direction (Beam maxima direction) in all the patterns, which is rarely found in UWBs presented in all the literatures.

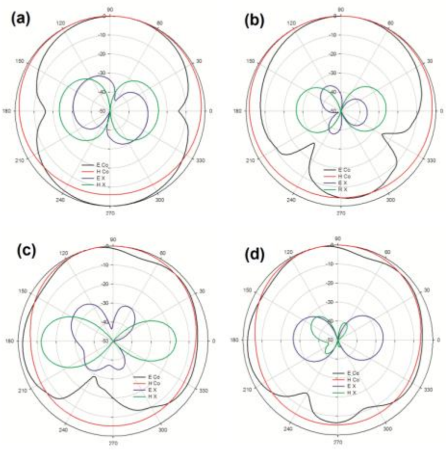

Fig.7. Measured Radiation pattern at resonances

Simulated three dimensional radiation patterns of the structure also analysed to get a technical knowhow about the spatial energy distribution around antenna and are given in Fig.8. In all the patterns the beam maxima is pointing towards same direction with beam null oriented in Z direction, which indicates the linear polarization behaviour of the structure.

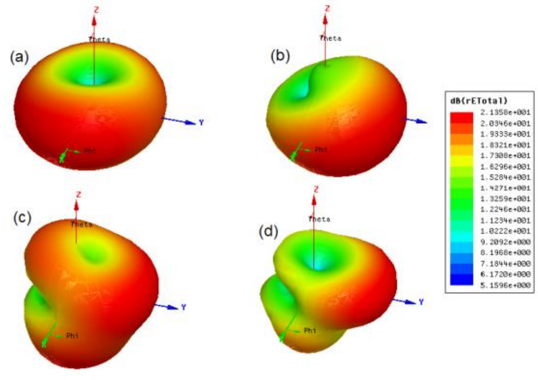

Fig.8. Simulated Radiation pattern at resonances

To get an insight to the radiation mechanism, vector surface current patterns at all resonances are simulated and analysed. Fig.9. shows the simulated current plot of the antenna. At first resonance (Fig.9.a), the current shows a half wavelength variation oriented in the direction of width ‘W’, through entire antenna surface. In Fig.9.b., a 1.5 wavelength long current variation is present through upper edge and both sides of the slot of the structure and which generates the second resonance. A 2.5 wavelength long current variation is present in Fig.9.c., which is the root cause for third resonance. A multiple folded current path is present in the surface of the antenna at 4th resonance.

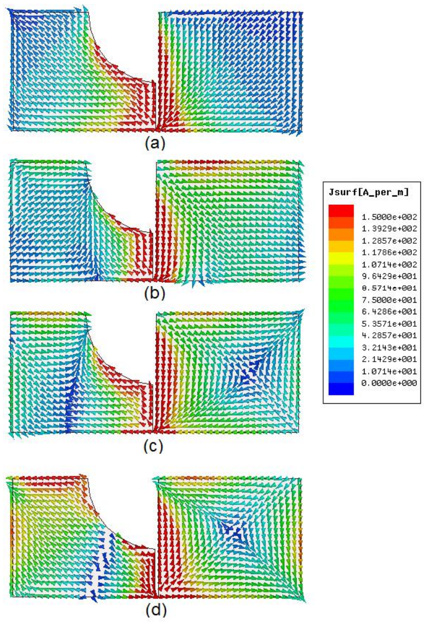

Fig.9. Vector J pattern at resonances

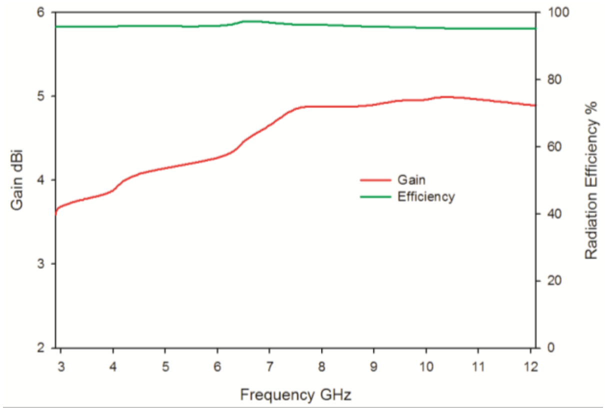

Fig.10. Measured Efficiency and Gain

Measured radiation efficiency and gain of the antenna is shown in Fig.10. Antenna offers good efficiency and gain in the band of interest. Antenna offers a uniform efficiency of greater than 95% in all frequencies. Gain of the antenna near first resonance is around 3.5 dBi while that in higher resonances is very much enhanced and the value goes beyond 5 dBi in higher frequencies. This indicates the high directivity of the antenna at these frequencies.

Transfer function is defined as the Fourier transformation of impulse response of the system. Fig.11 shows the measured transfer function of the antenna in all the four resonant frequencies, as a function of φ and θ. In all the plots, the maximum transfer function magnitude is located at $\varphi = \theta = 90^0$ with minimum variation which indicates the excellent performance of the antenna in both time and frequency domains.

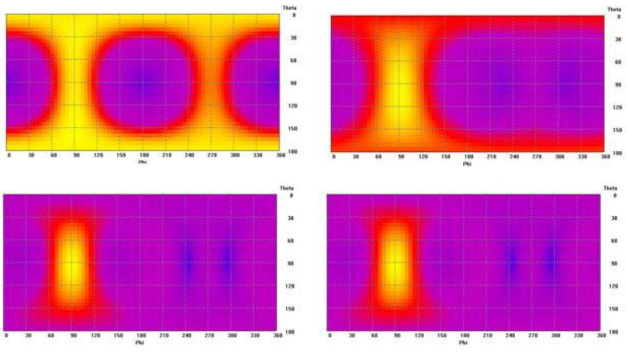

Fig.11. Measured Transfer Function

FDTD MODELLING OF THE STRUCTURE

To obtain the reason behind radiation mechanism, a mathematical modelling of the structure is formulated to using FDTD techniques. The specifications used are depicted in Table.2.

Table.2. FDTD Analysis Specifications

No. of Steps	**Pulse**	**Pulse T**	**Pulse Delay**
15000	Gaussian 1^0	20 pS	100 pS
ΔX	**ΔY**	**ΔZ**	**Δt**
0.25 mm	0.25 mm	0.2 mm	1 pS

To define the boundary, 1st order Mur's ABC (Absorbing Boundary Condition) [23] is used. Computation domain for the FDTD analysis of proposed quarter circular slot UWB antenna is shown in Fig.12.

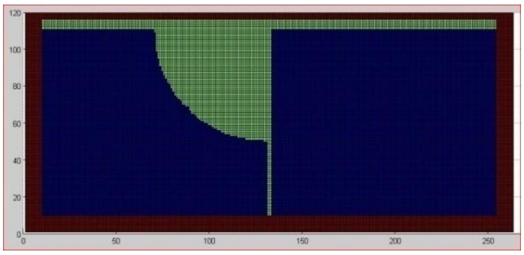

Fig.12. FDTD Model and computational Field

Measured S11 and that obtained through FDTD computations are compared and found to be in well matching and is given in Fig.13. Impedance matching in the FDTD computed curve is slightly less than measured result which may be due to curve approximation mismatching of quarter circle slot.

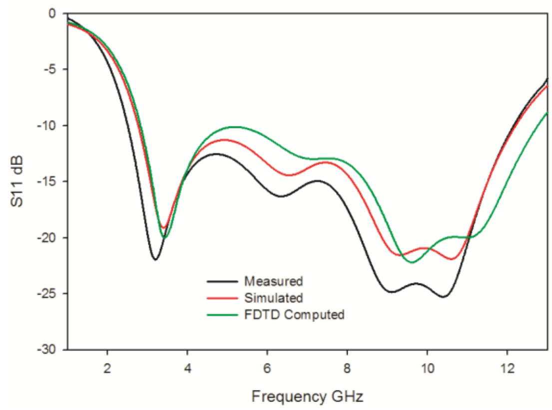

Fig.13. Comparison of Measured and FDTD calculated S11

3. CONCLUSION

A compact and highly efficient ultra-wideband radiator with enhanced gain is developed and discussed. Structure is very simple one with only three-dimensional parameters and is derived from a symmetrical open ended coplanar strip transmission line by removing a quarter-circle from top of one plate. Parametric analysis of the structure is performed and from that the design equation for the structure is developed and validated. From the measured results we can infer that the antenna is suitable for UWB applications with wide band width, uniform and directional radiation patterns, enhanced gain and with good radiation efficiency. Mathematical modelling and analysis of the antenna is also performed using FDTD method and results are found to be in well matching with experimental results.

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