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COMPACT COPLANAR STRIP FED UWB ANTENNA WITH ENHANCED GAIN

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Abstract

A coplanar strip fed enhanced gain directional radiator with a V shaped slot suitable for FCC specified ultra wide band application is developed. The 2:1 VSWR bandwidth of the antenna is nearly 9GHz ranging from 3.1 to 12 GHz. Proposed structure possess average radiation efficiency greater than 90% and a larger gain of 5 dBi in the entire range of frequencies of operation. Radiation patterns and polarization characteristics of the antenna are also uniform in entire band. Measured group delay of the structure is very minute and thus antenna has an excellent time domain performance. Transmitted and received pulses by the antenna are almost similar and thus the dispersion will be minimum.

Keywords:

Coplanar Strip fed, Uniplanar, Dipole Antenna, UWB, V Slot, Directional

1. INTRODUCTION

Due to the lack of multipath interference and the capacity to possess high data rate, UWB antennas attain a high position in communication technology. According to FCC spec, the ultra-wide band ranges from 3.1 to 10.6 GHz [1]. This high bandwidth is a simultaneous challenge and opportunity to engineers working in this field. The main challenge is to cost productively introduce a stable radiation and impedance matching performance in a wide frequency range within a compact sized structure.

The authors [2] [3] introduced a tapered slot antenna and an antipodal tapered slot antenna in which UWB response is attained by merging more than six resonances. This structure has many geometrical parameters and the obtained radiation patterns in different frequencies are not stable too. Hoods et al. [4] presents a UWB structure which is a bi planar one and offers a small gain with non uniform radiation patterns. In [5] authors introduce a compact UWB antenna in which the band width enhancement is done through two semi circles. In [6] the UWB operation is obtained by introducing an additional ring structure with slot. A hybrid slot feeding network based UWB antenna is discussed in [7]. UWB characteristics obtained by creating a U slot in the ground plane of a micro strip feed is presented in [8]. Shameena et al. [9] introduces an CPW fed UWB in which a step shaped slot with many dimensional parameters are used to attain UWB characteristics. C Vinisha et al. [10] presents an electrically small CPW fed UWB in which an annular ring is used to obtain ultra-wide bandwidth. S. Nicolaou and others in [11] discussed a UWB radiator with a slot in the shape of an exponential tapering with a very large size and small gain. A non-uniformly radiating, small gain UWB dipole antenna is presented in [12]. It offers a poor and highly distorted pulse response. A directional UWB suitable for medical imaging application is discussed in [13] with a very large size and non-uniform radiation pattern. All the above discussed antennas are however with large size or complicated in structural behaviour or with non-uniform radiation characteristics in the band of operation. Gain of all the discussed antenna is also found to be less than 3 dBi.

In this research article we are introducing a novel, simple and compact coplanar strip fed dipole radiator in which a V slot is introduced to attain UWB characteristics with enhanced gain. Developed radiating structure offers a 2:1 VSWR bandwidth of 8.9GHz ranging from 3.1 GHz to 12 GHz. A good impedance matching is occurring in the entire FCC specified frequency range for UWB applications. In all the resonating frequencies, antenna exhibits uniform radiation patterns with directional behaviour. The polarization of the antenna is found to be linear and is uniform in entire band of operation. Antenna offers minimum group delay which indicates its excellent time domain performance. The signal dispersion of the antenna is also found to be negligible.

2. EVOLUTION OF ANTENNA GEOMETRY

Geometry of proposed directional UWB radiator is shown in Fig.1. Structure is resulted from an open ended slotline of strip dimensions $L_s \times W_s$ whose upper portion is linearly flared to introduce additional resonances and to increase the bandwidth.

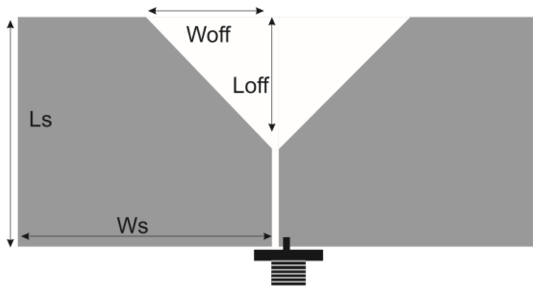

Fig 1. Proposed Antenna Structure

Flaring is introduced by removing right triangle shaped portion of altitude dimension L_{off} and base dimension W_{off} from both the metallic strips of slotline.

2.1 PARAMETRIC OPTIMIZATION

For the dimensional optimization of the radiating structure and to obtain the design equation for the structure, a set of parametric analysis is performed on all the dimensional specification of the structure given in Fig.1. Commercially available Ansoft High Frequency Structure Simulator is used as the simulation tool.

The effect of L_s on reflection characteristics of the antenna is presented in Fig.2. Three resonances were affected with L_s. 1st resonance shows slight shifting towards right with L_s. This is due to the near slot fringing field concentration in open ended slotline [14]. The 2nd and 3rd resonance shows a down shift with L_s which is due to the increased current path length.

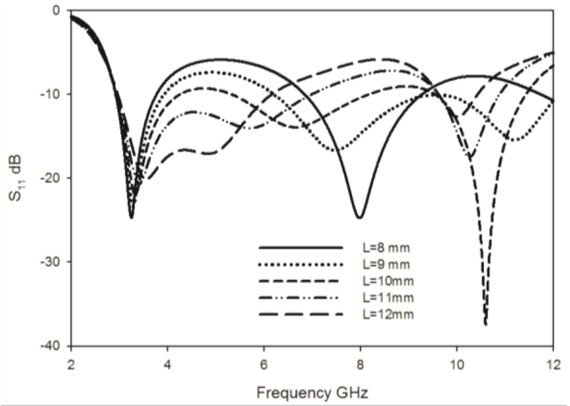

Fig.2. Effect of Ls on S11

The Fig.3 depicts effect of *Ws* on reflection co-efficient. All the three resonating frequencies exhibits a left shift with *Ws*. As *Ws* increases, the surface current path length increases which in turn reduces the resonating frequencies and can be verified from the magnitude of surface current (given in Fig.10).

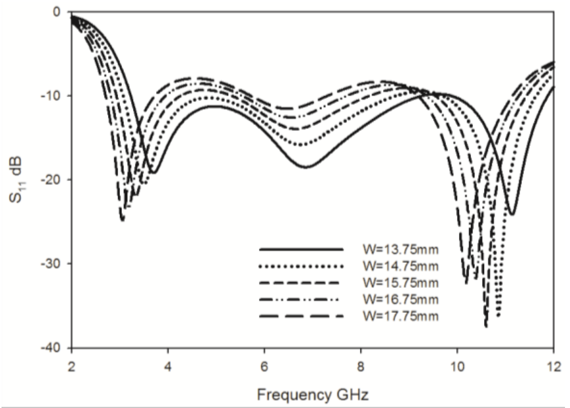

Fig.3. Effect of *Ws* on S11

The effect L_{off} in reflection characteristics is shown in Fig.4. Here, as Loff increases, 1st and 3rd resonance shows a lowering which is due to surface current path length increasing. As L_{off} increases, the vertical current path length (Ls) decreases and thus the 2nd resonating frequency increases with increase in this parameter.

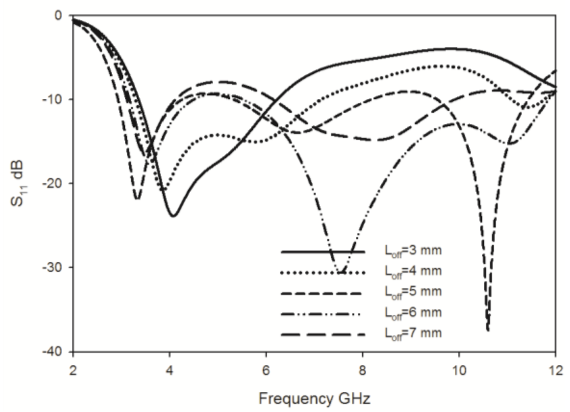

Fig.4. Effect of L_{off} on S11

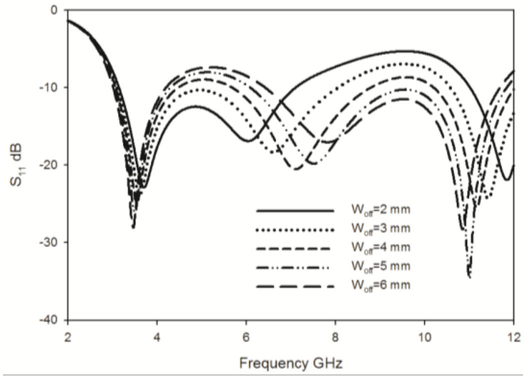

Fig.5. Effect of W_{off} on S11

The Fig.5 shows the variation in S11 with W_{off}. A similar variation that explained in the case of L_{off} is also present here. As W_{off} increases, the average surface current path length corresponding to 1st and 3rd resonating frequencies increases and thus they get lowered. But the positions of second resonance get increased due to reduction of horizontal path length (*Ws*) with increase in W_{off}.

From the parametric analysis performed, the design equations for various dimensional specifications of the structure are obtained and are as follows:

$$\left(W_S - W_{off}\right) + \sqrt{L_{off}^2 + W_{off}^2} \cong 0.315\lambda_{g1} \quad (1)$$

$$\left(L_s + W_s - L_{off} - W_{off}\right) + \sqrt{L_{off}^2 + W_{off}^2} \cong 0.91\lambda_{g2} \quad (2)$$

$$\left(L_s + W_s - W_{off}\right) + \sqrt{L_{off}^2 + W_{off}^2} \cong 1.58\lambda_{g3} \quad (3)$$

where λ_{gn} corresponding to the guided wavelength corresponding to n^{th} resonance and is calculated from free space wavelength λ using the expression:

$$\lambda_g = \frac{\lambda}{\sqrt{\varepsilon_{eff}}} \quad (4)$$

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

$$\varepsilon_{eff} = \frac{\varepsilon_r + 1}{2} \quad (5)$$

Developed design equations are validated with the help of simulation tool HFSS. As part of validation, four different antennas on four different substrates are designed and simulated. All the antennas are designed to resonate at f_1=3.5 GHz, f_2=7 GHz and f_3= 11 GHz. The structural parameters of the antennas resonating at above specified f_1, f_2 and f_3, obtained from design equations are depicted in Table.1.

Table.1. Dimensional parameters obtained Using Design Equation

Name	**Substrate**	ε_r	**Ls (mm)**	**Ws (mm)**	**L_{off} (mm)**	**W_{off} (mm)**
A	FR4	4.4	10	15.75	4	5
B	Rog 5880	2.2	13.8	20	6	6.75
C	Rog 6010	10.2	6.75	10.93	2.43	2.85
D	RO3006	6.15	8.6	13.75	3.2	4.3

Obtained simulation results are compared with designed values and are depicted in Table.2. All the antennas having three resonances which are in close vicinity of designed theoretical values and which indicated the validity of design equation.

Table.2. Comparison between theoretical and obtained resonance

Antenna Name	Designed F1=3.5 GHz, F2=7 GHz and F3= 11 GHz.		
	Obtained F1 GHz	Obtained F2 GHz	Obtained F3 GHz
A	3.52	7.15	11.175
B	3.475	7.085	11.2
C	3.53	7.158	11.195
D	3.53	7.146	11.175

Curves obtained by simulating all the above-mentioned antennas are depicted in Fig.6. All the antennas possess three resonances, and all the resonances are merged to create UWB characteristics.

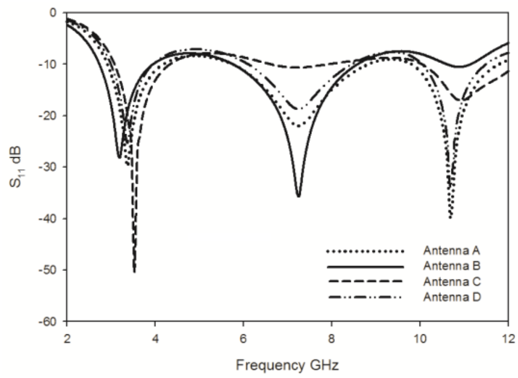

Fig.6.Validation of Design equations

3. RESULTS AND DISCUSSIONS

For testing and measurement, a prototype of the proposed UWB radiator is fabricated on a commercially available FR4 substrate having ε_r = 4.4 and height 1.6mm. The optimized dimensional parameters of the structure are *Ls*=10mm, L_{off}=4mm, *Ws*=15.75, W_{off} = 5mm, and *g*=0.3mm which is obtained from the design equation and is depicted in Table.1.

For experimental studies, vector Network analyser HP8510C is used. The Fig.7 depicts the experimental and simulated S11 of the developed structure. The experimental 2:1 VSWR band width of the antenna is obtained as 8.9GHz ranging from 3.1 to 12 GHz covering FCC and IEEE specified ultra-wide band range. This heavy bandwidth is a combined product of three resonating frequencies at 3.53GHz, 7.10GHz and 11.175GHz. A slight variation in both the curves may be due to the variations of dielectric constant in commercially available substrates.

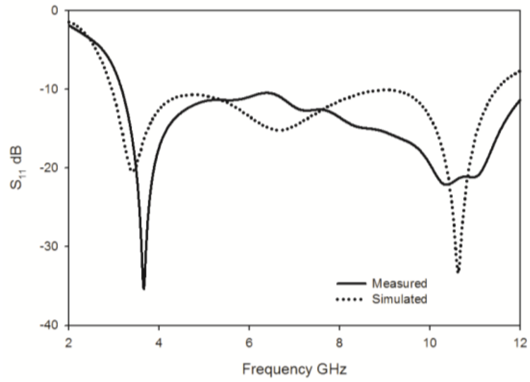

Fig.7. Measured and Simulated S11

Measured radiation patterns at three resonances are shown in Fig.8. Antenna is directive towards positive Y direction except at first resonance. At first resonance, the antenna shows an isotropic behaviour in H plane. Like a dipole, this antenna's E Plane pattern at first resonance is an 8 shaped one.

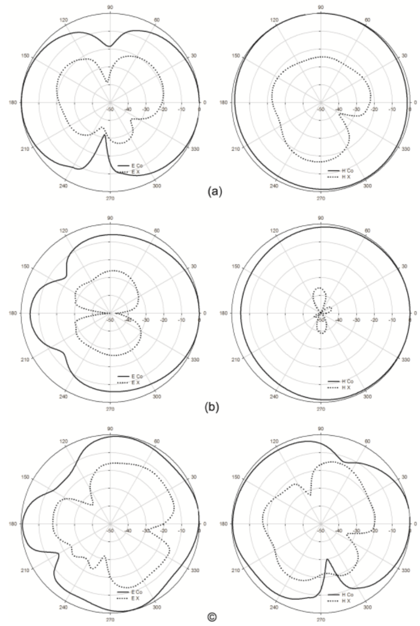

Fig.8. E and H plane Radiation patterns at three resonances

At second and third resonances, the antenna offers a directive radiation pattern. Both the patterns exhibit 10dB front to back ratio. The cross polar purity of the antenna is found to be -25dB. Cause for the directive behaviour of the antenna is easily understood from the surface current distribution depicted in Fig.10. First resonance is due to the current through the entire antenna surface. But the second and third resonating frequencies are introduced due to the current present at upper and flared edges of the antenna. Thus, for second and third resonance, the lower part of the antenna acts like a reflector which will reflect the power pointing towards negative Y direction to positive Y direction.

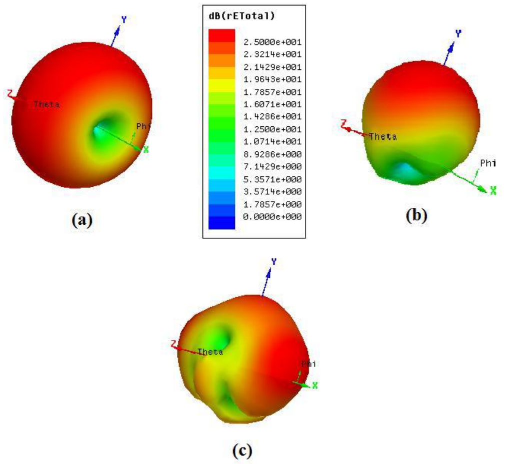

Fig.9. Simulated 3D Patterns of the Antenna

Simulated 3D pattern of the antenna is depicted in Fig.9 which is very much similar with the measured radiation pattern. All the patterns show a directional behaviour with bore sight pointing towards positive Y direction.

Vector surface current distributions of the structure obtained from simulation at three resonating frequencies are shown in Fig.10. First resonating frequency created due to a λ/2 long surface current variation through the entire surface of the antenna (Fig.10(a)). Current distribution at second resonance is given in Fig.10(b).

This resonating frequency is created by a 3λ/2 long current path at the upper and flared edges of the structure. Resonance at 11.15 GHz is created by a higher order 5λ/2 long surface current variation at upper edges of the antenna as shown in Fig 10(c). From the three current distributions, it is also inferred that the polarization is X oriented in all the resonances.

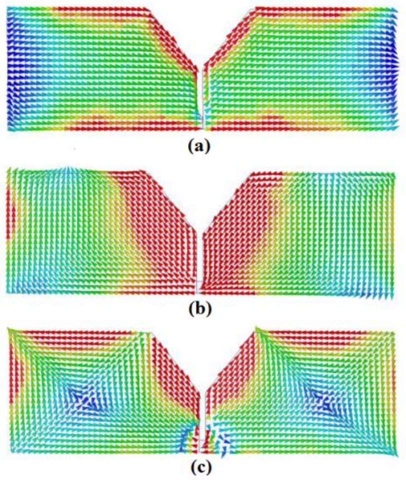

Fig.8. Surface current Distribution

The Fig.11. gives the experimental radiation efficiency and gain of the proposed antenna. Average value of radiation efficiency is found to be 90% in the band of operation.

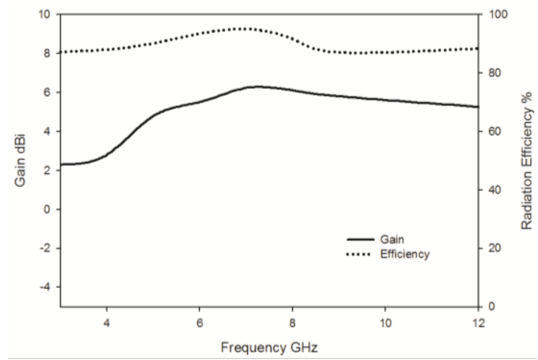

Fig.11. Measured efficiency and Gain

Proposed structure exhibits an enhanced gain with an average value of 5.1 dBi for frequency band of operation with a maximum value of 6.24dBi at second resonance. The gain at first resonance is slightly less than that in all other frequencies. This is also due to the directive behaviour of the antenna in the third and second resonances.

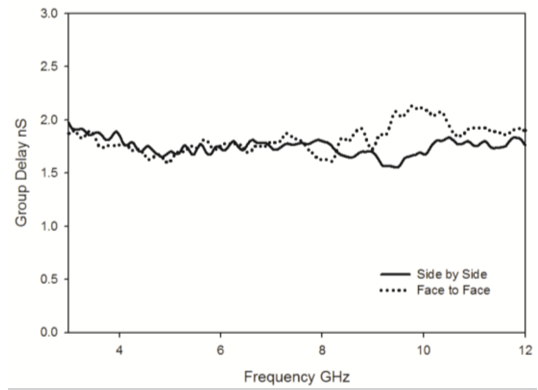

Fig.12. Measured Group delay

The group delay (GD) of the antenna measured using two identical prototypes of the antenna kept at far field distance is depicted at Fig.12. Antenna exhibits a uniform GD with a minute variation of less than 1 nS in both side by side and face to face orientation in bore sight.

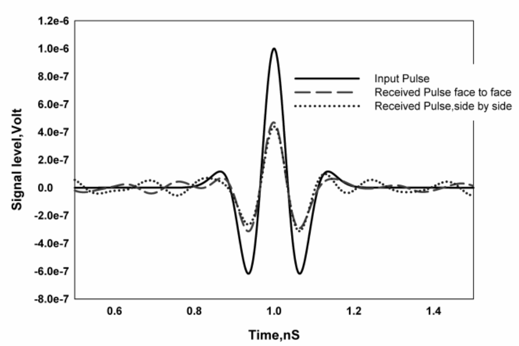

Fig.13 Pulse response of the UWB antenna

The free space received and transmitted and received wave forms in bore sight orientation are shown in Fig.13. In order to measure this, a 4th order Rayleigh pulse with 50pS pulse width factor is used as excitation. Both the waveforms are almost similar which indicates the dispersion is minimum.

3.1 FDTD MODELLING OF THE STRUCTURE

For obtaining the details of radiation mechanism in detail, FDTD analysis of the radiating structure is performed. The specifications of the analysis are ΔX=0.15, ΔY=0.2, ΔZ=0.4, Δt=0.8 ps and with 15000 number of steps. A narrow Gaussian pulse with half power width time 10 ps and an initial time delay 90ps is used as excitation. First order Absorbing Boundary Condition (ABC) proposed by Mur [15] is used to define the boundary in this analysis. Computation domain for the FDTD analysis of proposed coplanar strip fed UWD antenna is shown in Fig.14. the V groove in the structure is introduced using stair casing approach.

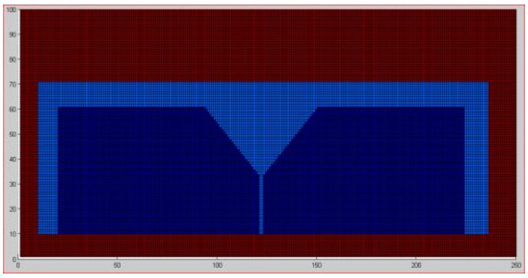

Fig.14 Computation field of Proposed UWB antenna in FDTD

Reflection coefficient curve obtained from FDTD analysis is given in Fig.15 which also have three resonances located at 3.5 GHz, 7 GHz and 11.1 GHz which also is in good agreement with measured and simulated curves.

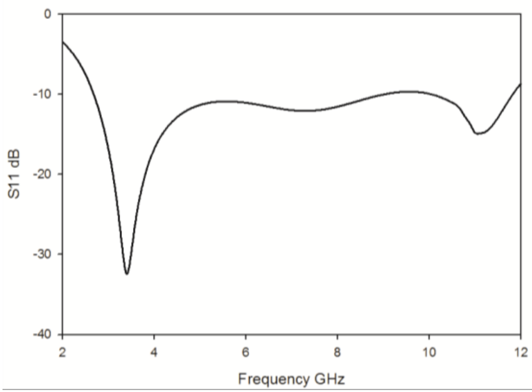

Fig.15. Reflection coefficient obtained using FDTD

4. CONCLUSION

Very compact and simple coplanar strip fed directive UWB dipole is developed, and results are discussed. Proposed dipole has a very simple structure with less structural specifications/parameters. Antenna offers huge frequency range of operation with stable radiation characteristics like pattern, gain and efficiency. Radiation patters shows directional behaviour too, and thus the structure possess an enhanced gain too. Group delay of the antenna is very small- and thus-time domain characteristics of the antenna will be excellent. Measured pulse response of the antenna give similar transmitted and received waveforms which indicates the signal dispersion in antenna is minimum. FDTD analysis of the structure is also performed, and the result obtained is presented here.

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