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SLOTLINE FED ULTRA COMPACT DIRECTIONAL ANTENNA FOR LTE/ISM/GSM 850, 900 AND WIDE BAND APPLICATIONS

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Abstract
A novel slot line fed ultra compact antenna with a wide bandwidth, operating in 900MHz range is developed and discussed. Antenna offers a frequency band of operation ranging from 792 MHz to 1.05 GHz with a percentage bandwidth of 28% which is much more than FCC specified bandwidth limit for wide band antennas. Overall size of the antenna is of the order of 0.059λg × 0.059λg × 0.007λg which is very compact and this compactness obtained without any lumped RLC elements. Developed antenna structure is characterized by directional radiation pattern, good gain and moderate radiation efficiency. FDTD model and equivalent RLC model of the antenna is also developed and analyzed.

Keywords:
Slot line fed, Circular slot, Circular patch, GSM, ISM, LTE

1. INTRODUCTION

Antenna is the interface between communication gadget and the physical world. Just like sense organs in a human body, it will connect the entire communication circuitries in the device with the atmosphere to receive or transmit signals. Nowadays we are witnessing a rapid reduction of size of the communication gadgets with increase in data rate capacity. This situation makes a simultaneous challenge and opportunity for engineers and scientists who work in antenna design. They are compelled to design a very compact antenna with cost effective design and without sacrificing radiation characteristics.

A compact dual mode antenna with a circular patch inside a rectangular patch is discussed in [1] whose design is very complicated. An X shaped antenna with suitable for WiMax with large size is presented in [2]. A wearable antenna suitable for WBAN applications is presented in [3] which have reduced gain with a complicated structure. In [4-5] the authors discuss about a meta-material based defective ground structure antenna with reduced gain and huge structure. A very complicated slot antenna having L and J shaped slot structure is presented in [6]. A compact antenna is presented in [7] whose size reduction is obtained using a 3D spiral array. A shorting Vias based compact antenna is presented in [8] which also possess structural complexities. A microstrip patch antenna resonating at 900 MHz based on multi elements is designed and discussed in [9]. Ali. Esraa et al in [10] discuss a patch antenna operating at RF range which is not compact and also with poor efficiency. A large elliptical antenna operating at 900 MHz and suitable for energy harvesting is presented in [11]. In [12], a bow tie microstrip antenna with high directivity and huge size is discussed. A huge and high gain base station antenna for GSM 900 is developed and discussed in [13]. A lumped Schottky diode-based loop antenna operating at low frequency is discussed in [14] with reduced radiation efficiency. A PIFA based on magnetic material is presented in [15] whose fabrication is not cost effective. In [16] a folded dipole antenna is presented which is bio implantable with reduced gain. A Koch fractal dipole antenna with multi band suitable for GSM 900 applications is discussed in [17]. A flexible antenna resonating at 950 MHz is presented in [18] having very narrow bandwidth. A triple patch based array antenna is discussed in [19] which have a high gain but the area occupied by the antenna is very high. Anyhow all these paper is of complicated structure or with huge dimension or with poor radiation characteristics. Some of the antennas discussed are bi-planar structure and some even are not planar too.

In this paper we are introducing a novel and ultra compact slot-line fed antenna with a wide bandwidth, operating in 900MHz range. Antenna offers a frequency range from 792 MHz to 1.05 GHz with a percentage bandwidth of 28% which is much more than FCC specified wide band limit. Operating frequency range is wide enough to cover many applications specific bands like GSM 850, LTE 850, GSM 900, ISM 900, WLAN 802.11ah and WiFi 900. Overall size of the antenna is of the order of 0.059λg × 0.059λg × 0.007λg which is very compact, and this compactness obtained without any lumped RLC elements. Developed antenna structure is characterized by directional and uniform radiation pattern, good gain and high radiation efficiency. FDTD modelling of the antenna is also developed and analysed.

2. EVOLUTION OF THE ANTENNA

Different stages of evolution of the proposed antenna structure are depicted in Fig.1. The structure is developed from a conventional slot line whose top end is shot circuited as shown in structure 1. As shown in structure 2, a circular slot is created on the centre of closed end slot line first. Inside the circular slot, a circular patch is fabricated, and which is shown as Structure 3. To obtain the final structure, a narrow slit is introduced perpendicular to feed direction, in the outer part of structure 3.

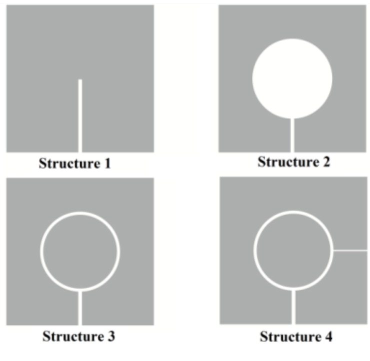

Fig.1. Evolution of the Antenna Structure

Reflection co efficient curves of all the four different stages discussed above are depicted in Fig.2. From figure it may infer that the final structure has a highly matched resonance at low frequency nearly around 0.9 GHz. To optimize the design, dimensional analysis is performed and is discussed as next session.

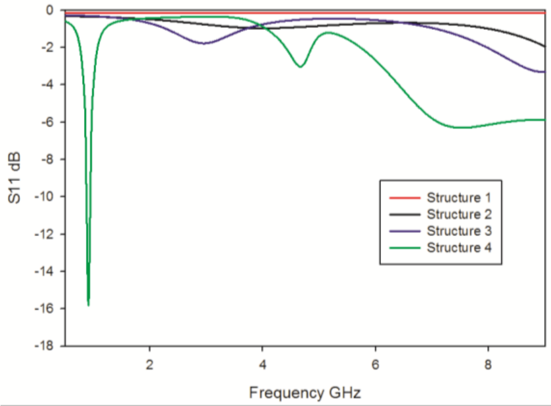

Fig.2. S11 of All the four discussed Structures

2.1 OPTIMIZATION OF DIMENSIONS

The developed antenna structure is dimensionally optimized for getting maximum bandwidth with good matching with the help of parametric analysis. Commercially available high frequency simulation software Ansoft HFSS is used for this purpose.

As the first step, the effect of length of the slot line on resonant frequency is analysed. S11 curve of the antenna for different L is shown in Fig.3. From the figure it is clear that resonant frequency shows an up shift with reduction in impedance matching as L increases. This is due to the fringing field concentration phenomena in slot line as explained in [20]. As length of the slotline increases, fringing field will concentrate near the slot and wavelength tends to reduce and thus the frequency shows an up shift.

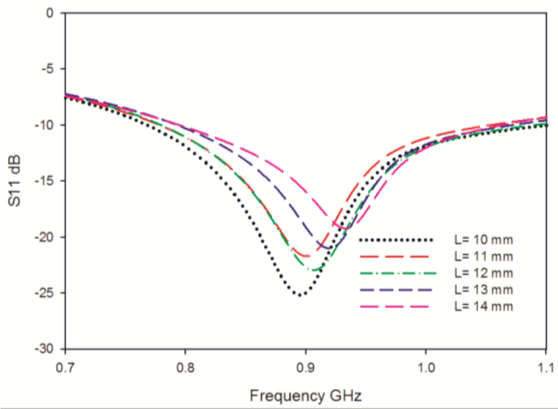

Fig.3. Effect of L on Resonant Frequency

Effect of slot line width on resonant frequency is shown in Fig.4. Here the resonant frequency shows a gradual down shift with increase in W. This may due to the increase in surface current path length with W. Impedance matching also reduces as a result of increase in w.

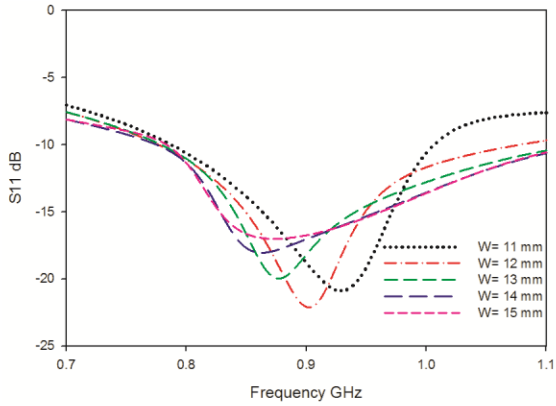

Fig.4. Effect of W on Resonant Frequency

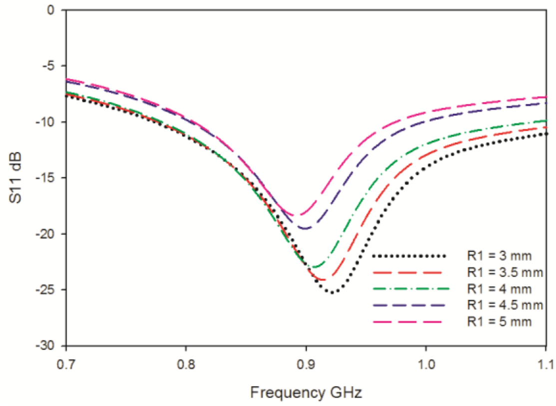

Fig.5. Effect of R1 on Resonant Frequency

Variation in S11 of the antenna with radius of circular slot is analysed as next step and the curves obtained are shown in Fig.5. Here also the resonant frequency shows a lover shift with increase in R1. The impedance matching and hence bandwidth of the antenna drastically decreases with increase in R1. As R1 increases, the slot width increases and thus the capacitance reduces which increases the Q factor of the structure. This may be the reason for the bandwidth reduction and impedance matching variation.

Effect of patch radius R2 on resonance and bandwidth are studied and obtained reflection coefficient curves is shown in Fig.6. Here the frequency shows a narrow down shift with almost similar impedance matching.

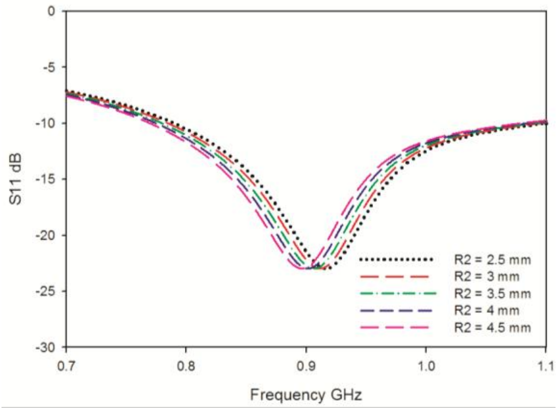

Fig.6. Effect of R2 on Resonant Frequency

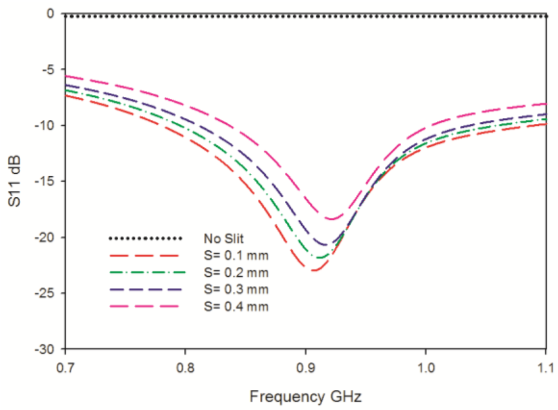

Fig.7. Effect of S on Resonant Frequency

Variation in reflection coefficient of the antenna with newly introduced slit width S is shown in Fig. 7. There is no resonance at lower frequencies when slit is absent. As a slit of width 0.1mm is introduced, a new resonance is created and as slit width increases, the resonance gets a regular up shift due to reduction in resonating current path length.

From the parametric analysis results obtained, design equations of the antenna are developed in terms of guided wavelength, with the help of well-known statistical curve fitting equation methods and are as follows.

$$L = 0.0591\lambda_g \quad (1)$$

$$W = 0.0591\lambda_g \quad (2)$$

$$R_1 = 0.0197\lambda_g \quad (3)$$

$$R_2 = 0.0182\lambda_g \quad (4)$$

where λ_g is the guided wavelength corresponding to resonant frequency and the relation between guided wavelength and free pace wavelength λ_0 is obtained as,

$$\lambda_g = \frac{\lambda_0}{\sqrt{\varepsilon_{\text{eff}}}} \quad (5)$$

where $\varepsilon_{\text{eff}} = \frac{\varepsilon_r + 1}{2}$ is the effective dielectric constant.

Validity of the developed equations are also analysed for various substrates and for various bands. The dimensions of various antennas designed for equation validation and obtained results are depicted in Table.1.

Table.1. Calculated Antenna parameters and obtained resonant frequencies for validation of Design equations

	Antenna A	Antenna B	Antenna C	Antenna D
Laminate	Rogers 5880	FR4 Epoxy	Rogers 5880	FR4 Epoxy
ε_r	2.2	4.4	2.2	4.4
Designed Frequency	5.2 GHz	2.4 GHz	1.8 GHz	900 MHz
L (mm)	2.69	4.5	7.79	12
W (mm)	2.69	4.5	7.79	12
R1 (mm)	0.89	1.5	2.59	4
R2 (mm)	0.83	1.38	2.40	3.7
g (mm)	0.1	0.3	0.1	0.3
Obtained Frequency	5.15 GHz	2.405 GHz	1.79 GHz	903 MHz

From the table it can be found that all the antennas are operating in a resonant frequency very close to that of designed one. This indicates that the developed design equations are valid for all types of substrates and for all frequency bands too.

3. EXPERIMENTAL RESULTS AND DISCUSSIONS

For experimental validation of the simulated results, a prototype of the radiator is developed using the well-known chemical etching process. Before chemical etching, the substrate coated with a thin layer of copper is processed with photo lithographic method to form a mask pattern of the proposed design above the copper plating. Using ferric chloride, chemical etching is done to create prototype from the processed substrate. Structure of the developed antenna with notations are depicted in Fig.8 and the dimensional and substrate parameters are given in Table.2.

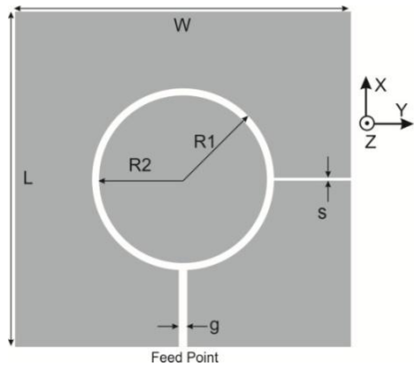

Fig.8. Structure of proposed Antenna

Table.2. Parameters of Fabricated Antenna

Laminate	**εr**	**h (mm)**	**L (mm)**
FR4	4.4	1.6	12
W (mm)	**R1(mm)**	**R2(mm)**	**g (mm)**
12	4	3.7	0.3

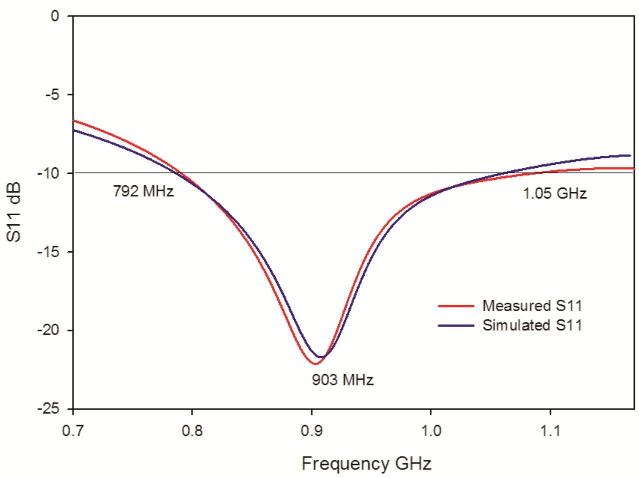

Fig.9. Simulated and Experimental S11

Experimental studies of the antenna are performed using Agilent HP8510C Network analyser calibrated using standard OPEN, SHORT and Perfectly Matched Load (PML) connectors to make the measurements error free. Simulated and measured S11 of the antenna is given are compared and obtained curves are given in Fig.9.

Both the curves are in good agreement and the antenna is found to be resonating at 903 MHz with a wide range of operating band starting from 792 MHz to 1.05 GHz. Percentage bandwidth of the antenna is obtained as 28.57% and which is much greater than the required bandwidth of FCC specified wideband antennas. The antenna's operating band is wide enough to cover many applications specific bands like GSM 850, LTE 850, GSM 900, ISM 900, WLAN 802.11ah and WiFi 900.

Measured principal plane radiation patterns of the antenna in both co and cross polarization orientation is given in Fig.10. Radiation patterns are measured using HP8510C using standard horn antenna in a turn table. Both E and H plane co polarization pattern are pointed towards Y direction as discussed earlier. A cross polar purity of greater than 20 dB is present in both the patterns which indicates antenna is a linearly polarized one. Since the radiation null is lies along X direction, polarization also will be in the same direction. A front to back ratio nearly 9 dB is present in E plane pattern and that of H plane is found to be 9 dB which indicates that the antenna is highly directive towards positive Y direction.

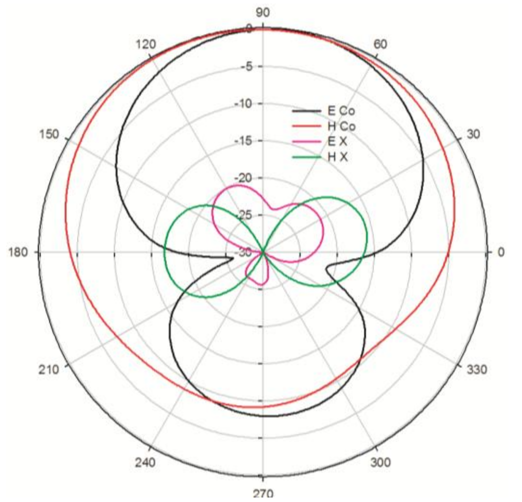

Fig.10. E and H Plane Radiation Patterns of the Antenna

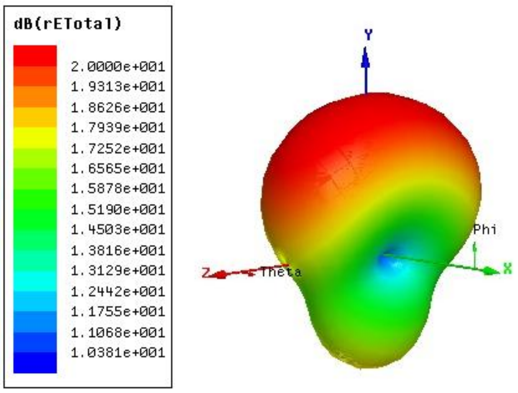

Fig.10. Three Dimensional Radiation Pattern of the Antenna

Three-dimensional radiation pattern of the antenna which gives a clear picture of spatial distribution of radiated electromagnetic energy around the antenna is Given in Fig.10. Developed antenna is a directive radiator which radiates maximum energy towards the positive Y direction.

Vector surface current distribution analysis of the antenna is very useful to reveal the radiation mechanism in the developed antenna structure. Simulated surface current plot of the antenna at 903 MHz is depicted in Fig.12. A clockwise circulating current is present at the outer part of the antenna while an anti clockwise circulating current is present at inner circular patch. Both these currents contribute to radiation mechanism. Since all the parts of the antenna are excited with surface current, its radiation efficiency should be normally very high, but in this case there are two anti parallel current paths through either edges of circular slot, whose radiation will cancel each other in far-field, which will cause a slight reduction in radiation efficiency.

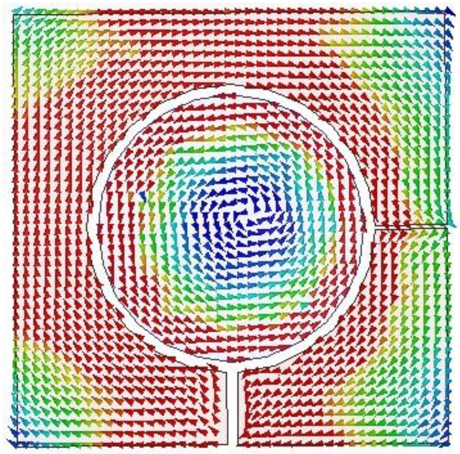

Fig.12. Vector J Plot of the Antenna

Combined directives gain and radiation efficiency plot of the antenna in entire operating frequency band are shown in Fig.13. Gain of the antenna is measured using highly accurate gain comparison method and the radiation efficiency is measured using well known Wheeler cap method. Antenna offers uniform flat gain in the band of operation with an average gain of 3.64 dBi and a peak value of 3.68 dBi at 900 MHz. The difference between maximum and minimum gain or the range of gain is only 0.06 dBi which shows that the gain is almost uniform in entire band. As discussed in surface current analysis session, radiation efficiency of the antenna is flat and is found to be nearly 86%.

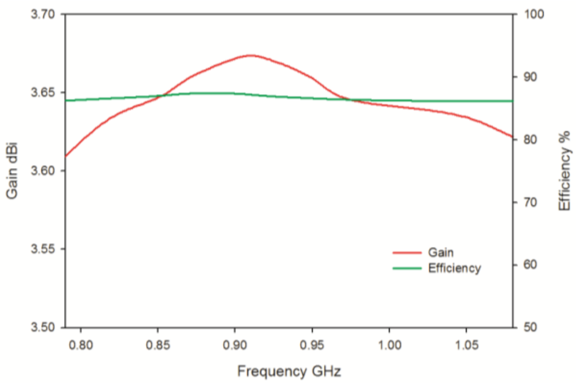

Fig.13. Gain and Efficiency Plot of the Antenna

Table.3. Comparison of Gain, Efficiency and size of the proposed antenna with existing designs

Antenna Specified in	% of increase or decrease compared to proposed antenna (+ indicate increase, - indicate decrease)		
	Gain	**Efficiency**	**Area (electrical length square)**
Ref 1	-5.36	-11.24	+15.76
Ref 2	-7.16	-4.5	+36.76
Ref 3	-10.36	-22.24	+13.68
Ref 4	-5.4	-3.39	+34.7
Ref 5	-2.24	-1.41	+12.69
Ref 6	-1.88	-11.8	+12.06
Ref 7	-2.38	-13.5	+10.62
Ref 8	-2.24	-8.49	+44.74
Ref 9	-0.85	0.53	+119.08
Ref 10	-2.83	-22.23	+24.54
Ref 11	-1.48	-9.58	+12.04
Ref 12	-2.05	-6.01	+16.86
Ref 13	-1.59	-5.71	+22.73
Ref 14	-2.38	-5.43	+28.58
Ref 15	-3.16	-5.14	+34.44
Ref 16	-3.95	-4.85	+40.3
Ref 17	-4.74	-4.55	+46.15
Ref 18	-3.03	-4.26	+52.01
Ref 19	-5.85	-3.68	+19.43

A comparison of gain, radiation efficiency and occupying area of the proposed ultra compact antenna with existing designs are done and the results obtained are depicted in Table.3. From the table it is evident that, the proposed slot line fed radiator is the most compact design with slightly enhanced gain and with good radiation efficiency.

4. FDTD MODELING

Finite Difference Time Domain Modelling of the developed antenna structure is also developed and analysed to prove the simulation results and to further insight to the radiation mechanism inside the structure. Computational domain for FDTD are developed using the parameters given in Table.4.

Table.4. Parameters of FDTD Computational Domain

ΔX	ΔY	ΔZ	Δt
0.1 mm	0.1 mm	0.1 mm	0.2 pS
No. of Steps	**Pulse**	**Pulse T**	**Pulse Delay**
20000	Gaussian	25 pS	90 pS

In our FDTD analysis, the boundary used is the first order perfect absorbing boundary condition (ABC) suggested by G Mur [21]. Since it is an absorbing type boundary, no reflection from boundaries occurs since all the energy reached at the boundary will be absorbed there itself. It will acts like the walls of a perfect anechoic chamber. Computation domain for the FDTD analysis of proposed uniplanar dual band antenna is shown in Fig.13. For confirming the convergence, 20000 steps are run using the programme. A comparison of reflection co efficient obtained from FDTD model with experimental and simulation result is given in Fig.14. All the three curves are in good agreement which indicates the correctness of simulation and accuracy of measurement.

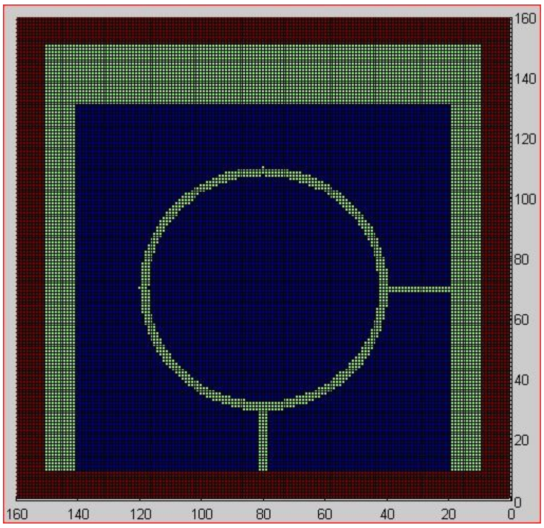

Fig.13. FDTD Model of the Antenna

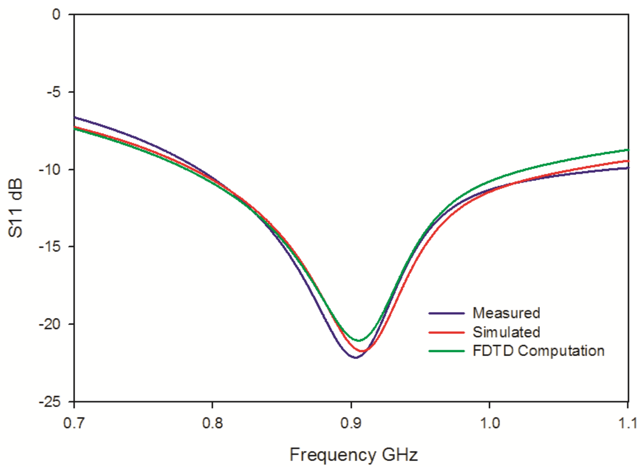

Fig.14. Comparison of reflection Co efficient

5. CONCLUSION

A novel and ultra compact slotline fed antenna with a wide bandwidth, operating in 900MHz range is developed and discussed. Measured results shows that antenna offers a frequency band of operation ranging from 792 MHz to 1.05 GHz with a percentage bandwidth of 28% which is much more than FCC specified bandwidth limit for wide band antennas and the operating frequency range is wide enough to cover many applications specific bands like GSM 850, LTE 850, GSM 900, ISM 900, WLAN 802.11ah and WiFi 900. Overall size of the antenna is of the order of 0.059λg × 0.059λg × 0.007λg which is very compact, and this compactness obtained without any lumped RLC elements. Developed antenna structure is characterized by directional radiation pattern, good gain and high radiation efficiency. FDTD modelling of the antenna is also developed and analyzed..

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