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A UWB Fractal Slot Patch Antenna with Ground Optimization

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Abstract

A miniaturized patch monopole ultra-wideband (UWB) antenna of size 18mm x 12mm x1.6mm on commercially available FR4 material with dielectric constant 4.4 is proposed. The antenna consists of insertion of fractal slot geometries to obtain the desired very large band characteristics. While the modification in the various patch length provides perfect match of impedance bandwidth. Therefore, it provides a very ultra wide band from 1.55 to 12.0 GHz inclusive of all associated applications released by FCC. Choice of suitable filter makes the antenna widely useful for particular band of operation. The proposed structure consists of several half wave length slots interconnected with each other. In this article, the variation of ground geometry with respect to slot insertion is depicted. The design validation is made through successive simulation and proposed antenna is fabricated for measurement of return loss and VSWR parameters. The radiation properties are also found consistent over the ultra wide band.

Keywords: Ground defects, UWB, fractal, resonant frequency, slotted antenna.

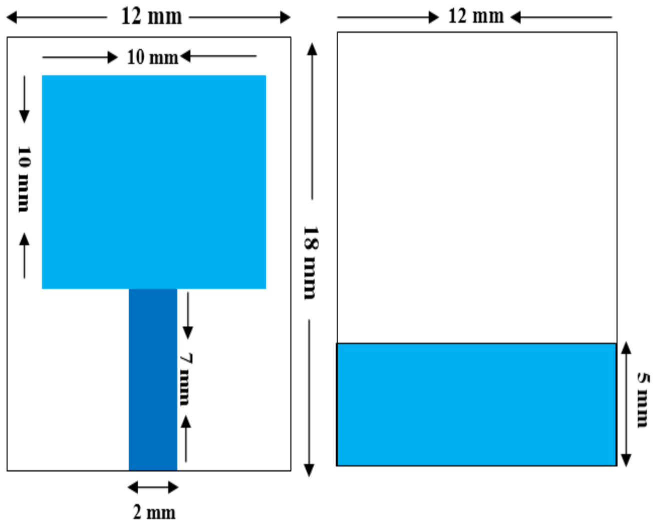
INTRODUCTION

The Federal Communication Commission has declared an unlicensed band of frequency from 3.1 to 10.6 GHz for UWB wireless communications. This has enticed many researchers to put their efforts in this field. A typical UWB is defined in principal to occupy more than 500 MHz bandwidth [1]. Interestingly UWB systems has a sequence of short pulses of several pulses per second, results in wide bandwidth with extremely low power transmitted enabling UWB systems to be suitable with extensive low power applications.

Several methods have been employed by which an UWB antenna can be obtained. The widely used method is to create shaped slots in the radiating patch and to ground base. Multiple geometries have been reported like U, H or C-shaped slots [2]–[6]. While, few of them have been developed for one or more notched band. UWB device has become the key factor for market for high-bit-rate, short-range wireless products for home networking, wearable computing and wireless desktop [7]. Microstrip antennas are becoming more interesting due to their advantages for simple structure, ease of design and cheap in cost. While, a certain frequency range for UWB systems may cause interference to the existing frequency range from 5.15-5.35 GHz and 5.75-5.85 GHz which is for Wireless Local Area Network (WLAN). This can be stopped by band filters and can be added to eliminate interference. Therefore it is always the main course to design a compact antenna having stable radiation property with good wideband characteristics for the complete operating range. This paper introduces fractal symmetry over the radiating structure along with optimized ground geometry to design a compact UWB antenna. The slot is so sequenced to obtain the resonance of antenna in much lowered frequency of operation. The ground is stepped in multiple folds to achieve desirable performance of the antenna. It is also observed that the loading of parasitic patch works as band stop filter in [8]–[11], additionally also causes to significant decrease to the lower edge frequency of the radiating element and justifies the impedance bandwidth as reported in [12]–[15]. In the proposed antenna, the main resonating structure can significantly resonate at the fundamental frequency and the slotted fractal symmetry of patch is used as a main resonator, which is mutually coupled to the slotted structure of the patch. With respect to the physical structure of an antenna, in principle, the electric or magnetic field causes effective changes in the actual electric length of the antenna due to inductive or capacitive loading. The same phenomenon also persists in parasitic loading but may cause to over coupling between patches may result in decrease in lower edge of bandwidth [16]-[20]. Hence, by avoiding the above discussed effect, the mutual coupling is controlled by introducing slot geometry to change overall electrical length of the radiating element and impedance matching is done by deformed ground structures in its multiple mode of resonance.

ANTENNA GEOMETRY

Among the multiple shapes and structure for the patch to obtain the UWB antenna, a square shape antenna is chosen as base geometry for design evolution as shown in figure 1.Also, the multiple ground symmetries are also obtained for the figure 1(b), which are useful to model a miniaturized antenna with improved impedance matching. The basic design evolution structure of proposed antenna is shown in figure 2. The proposed antenna is designed using FR4 substrate with ε_r=4.4, h=1.6 mm on area of 12x18 mm^2. On this substrate a square patch (10x10 mm^2) with reduced ground dimensions is designed. On the top of the patch is evaluated with diversified U slots in fractal form geometry. Respectively the ground is optimized for each patch design evaluation by variation of physical length. The expended structure of this U-slot utilizes the electric current distribution to change electric length of patch more on the edges near to feed strip and obviously less effective on capacitive top loading. This has an additional diversification of internal slot of complimentary geometry to produce tunable inductor and capacitor passive element by dominating length variation. This model is feed with 2 mm wide strip to obtain the perfect source impedance matching. The structure modeling and the multiple parameters are simulated on High Frequency structure Simulator for evaluated deigns.



(a) (b)

Figure 1. (a) Square shape antenna **(b)** ground structure

The Antenna design evaluation is shown in figure 2 consisting the selection of the substrate to design validation, followed by equivalent diagram in figure

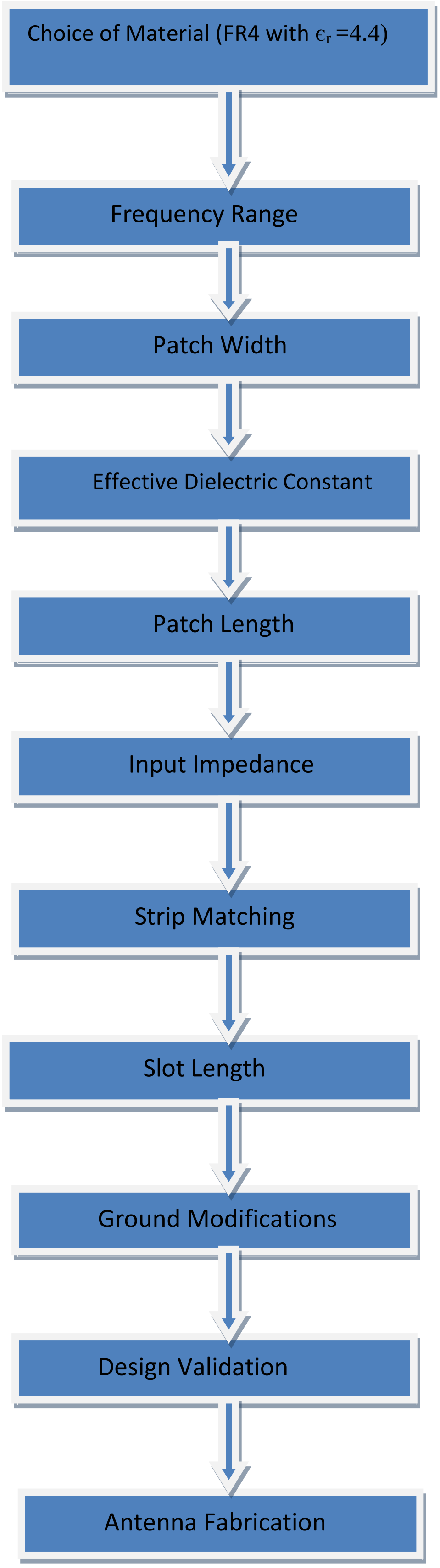


Figure 2. Block diagram of design evolution

$$W = \frac{c}{2\,f_o\sqrt{\frac{(\varepsilon_r+1)}{2}}} \qquad (1)$$

$$\varepsilon_{reff} = \frac{\varepsilon_r+1}{2} + \frac{\varepsilon_r-1}{2}\left[1+12\frac{h}{W}\right]^{-\frac{1}{2}} \qquad (2)$$

$$\Delta L = 0.412h\,\frac{(\varepsilon_{reff}+0.3)\left(\frac{W}{h}+0.264\right)}{(\varepsilon_{reff}-0.258)\left(\frac{W}{h}+0.8\right)} \qquad (3)$$

$$L = \frac{c}{2f\sqrt{\varepsilon_{eff}}} - 2\Delta L \qquad (4)$$

$$L_o = L + 6h \qquad (5)$$

$$W_o = W + 6h \qquad (6)$$

The common terminology used for equation

f = Operating frequency

ε_r = Permittivity of the dielectric

ε_{eff} = Effective permittivity of the dielectric

W = Patch's width

L = Patch's length

h = Thickness of the dielectric

L_0 = Length of ground plane

W_0 = Width of ground plane

The figure shows the physical equivalence of microstrip in transmission line model diagram. The input admittance at the radiating edge is given by;

$$Y_{in} = Y_{slot} + Y_0\,\frac{Y_{slot}+jY_o\tan\beta(L+\Delta L)}{Y_o+jY_{slot}\tan\beta(L+\Delta L)} \qquad (7)$$

At Resonance, Y= 2G

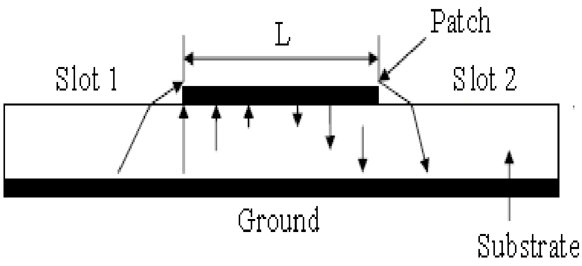


Figure 3. Equivalent physical model of patch

The design evolution is shown in figure 4. It is clearly depicted here that a basic patch can be resonating at much lower and higher band of frequency by evolving the suitable changes in the patch geometry. More, interestingly the effect of ground length could be more helpful in determination of perfect impedance matching with respect to obtain bandwidth of applications. Systematic designs have been made for observations of return loss parameters with sustainable far field patterns.

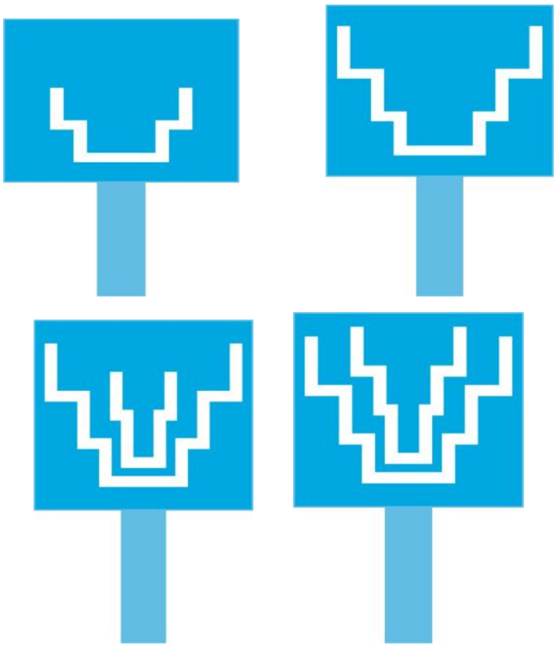


Figure 4. Steps for design evolution

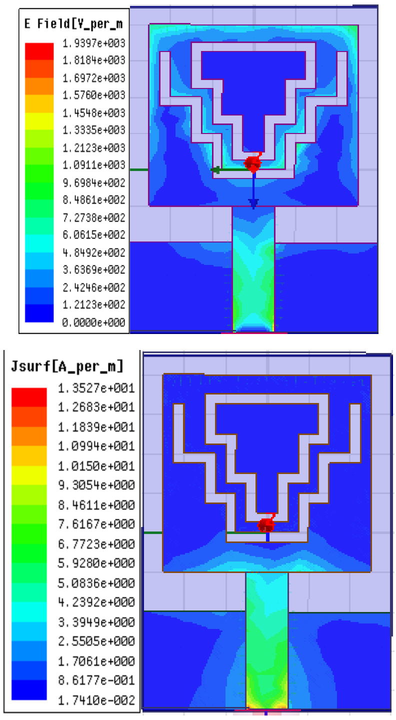


Figure 5. Current distribution at resonant frequency 3.33 GHz

With respect to the defect is being createdin the normalized geometry of ground, the defects of length is varied while keeping the other dimension constant with respect to substrate width. Length of the ground Lg = 5 mm and the width of the ground is same as the substrate W_g= 12 mm. The detailed dimensional statistics is shown here;

Table 1: Design Statistics

Parameter	W	L	Wg	Lg	L_p	W_p	S_l	S_w
Value(mm)	12	18	12	K λ	2	4.25	jλ	0.5

In addition to use of usual meaning of abbreviations S_l and S_w are for the length and width of the slotted geometry, which creates the major difference in the parametric property of designed patch. Lg = K λ, depending upon the K factor in proportion to wavelength and therefore for S_l = j λ. The surface current distributions of the proposed antenna are shown in Figure 5

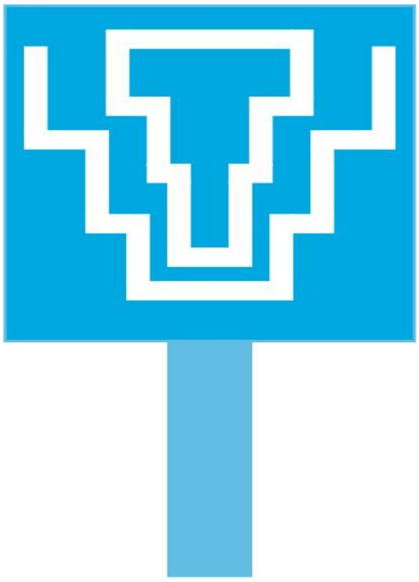


Figure 6. Proposed antenna geometry

Through successive design iteration the final architecture of the antenna is found suitable for the fabrication of the patch. The antenna is fabricated through printing on both side of the optimized geometry as shown in figure 7. The Proposed architecture is consisting fractal expansion of the slot geometry along with the altered dimensions of the ground.

This modification has observed through modeling on high frequency structure simulator using iterative design methodology.

The interesting movement of ground length with respect to successive insertion of slots is seen in the process of development of desired prototype of ultra-wideband antenna.

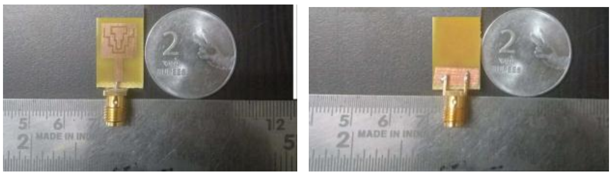


Figure 7. Proposed prototype antenna

RESULTS AND DISCUSSIONS

The designs iterations are shown in figure 8. The effect of change in the ground length is represented graphically. From the observations interestingly, that that by decreasing the gap we are getting one more frequency notched bands from in multiple bands respectively along with frequency notch bands.

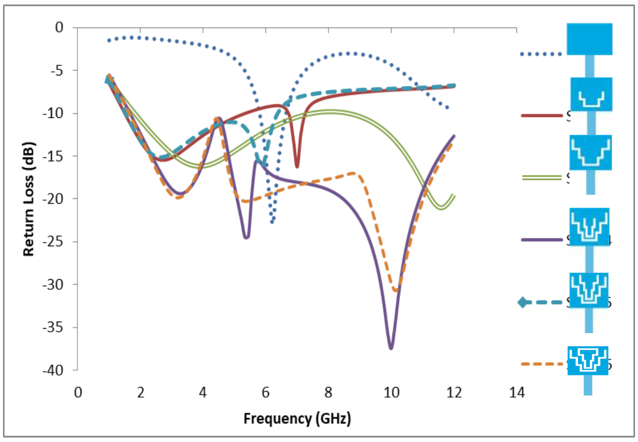


Figure 8. Return loss versus frequency with respect to designs

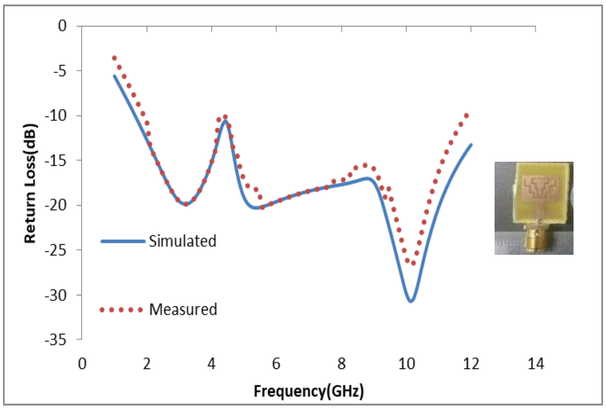


Figure 9. Simulated and measured results

The basic target is to achieve extremely large wide band with a compact geometry. It is observed that the frequency band is matched when the ground length is varied in absolute proportion of half wave length of operating frequency for the optimized value i.e. 5 mm and frequency band is obtained when the ground length selected is for the optimized value. At the same the time the respective variation of the slot length gives surprising parameters being observed for multiple design variations.

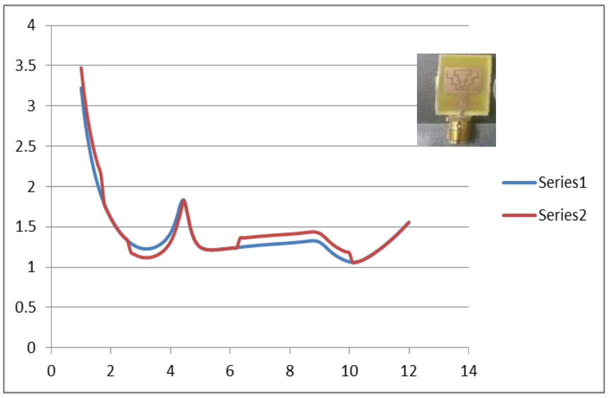
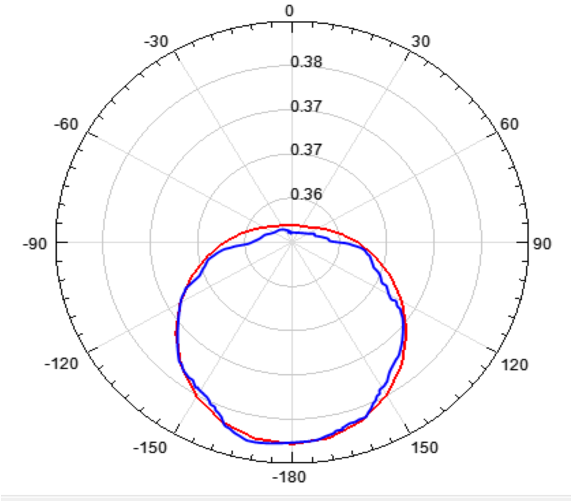
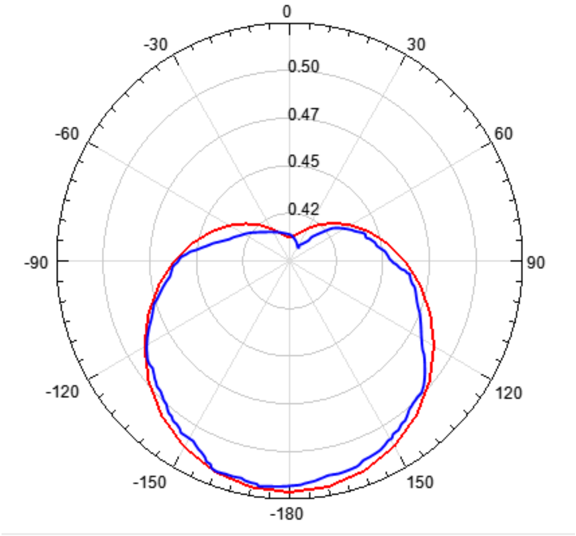


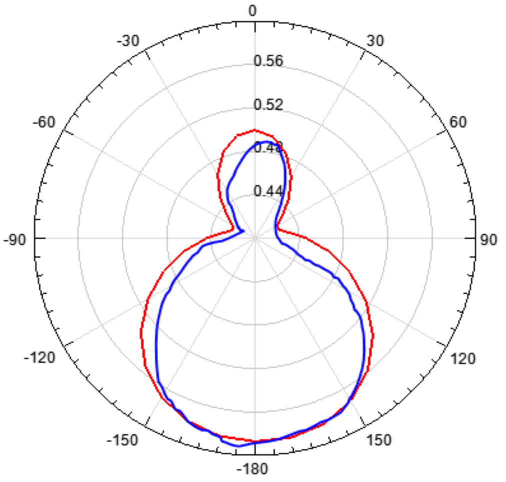
Figure 9. Simulated & measured VSWR versus frequency curve



(a)

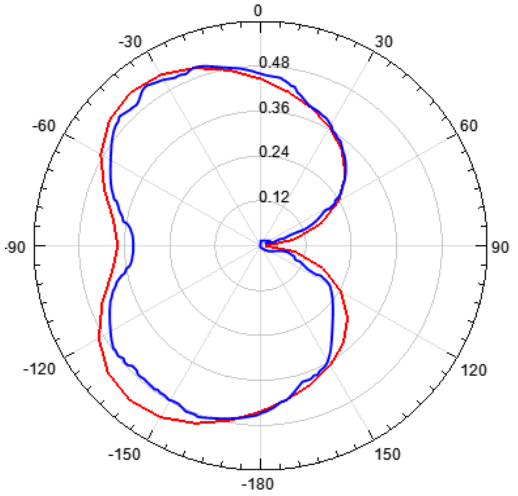


(b)

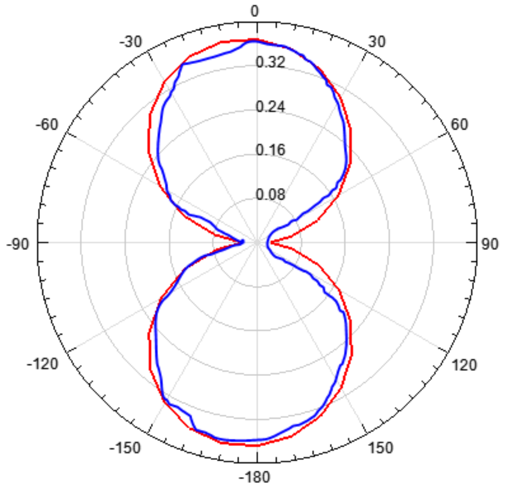


(c)

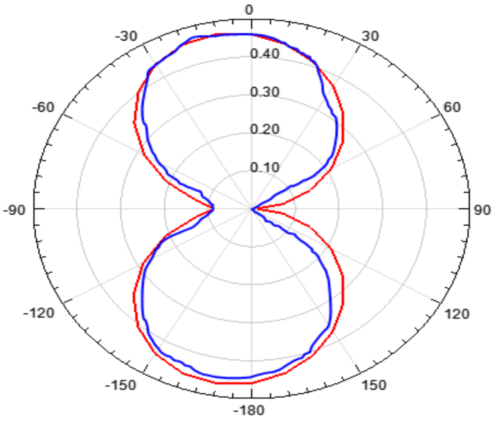
Figure 10. Simulated radiation pattern in E-plane at (a) 3.33 GHz, (b) 5.3 GHz and (c) 10 GHz



(a)



(b)



(c)

Figure 11. Simulated & measured radiation pattern in H-plane at (a) 2.33 GHz, (b) 5.33 GHz and (c) 10 GHz

The simulated and measured VSWR and return loss parameters are shown in Figure 8 and 9.The design of fabricated antenna is validated through simulated output and measured result on VNA. It is clear in validation that the ultra-wide band frequency is matched for less than -10dB and for VSWR less than 2.

Therefore in functionality the proposed antenna not only has the ultra large band of frequency but also multiple resonant bands.

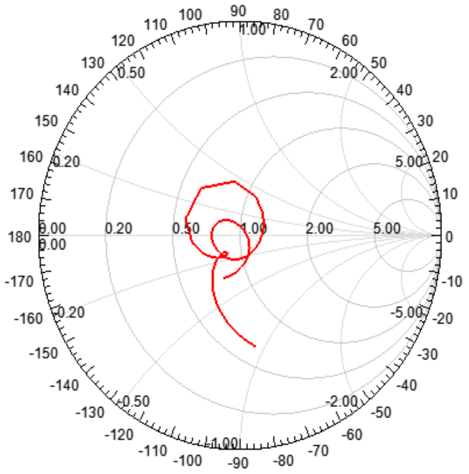


Figure 12. Simulated input impedance on a Smith chart

The characteristics of varying frequency is directly associated with the variation of geometric structure formed in patch as well as in ground. The effective radiation pattern are traced for the specific interval of the resonant frequency. It is satisfactory to find a stable radiation pattern in both the plane. Figure 10 and 11 show the simulated far-field radiation patterns in E-plane and H plane at 2.33 GHz, 5.33 GHz and at 10 GHz respectively. The radiation patterns depicted the dipole pattern in both E-plane and H- plane.

Strong current distributions are seen between the slotted geometry, which is responsible for wide band of frequency.. It is sustainable that the gain of the antenna is almost stable over UWB. The simulated input impedance is represented by smith chart of proposed antenna in Figure12. It shows that the perfect match of frequency is observed through the whole band of operation for the 50 ohm impedance.

CONCLUSION

A slotted square monopole printed antenna has been designed for UWB applications. To achieve UWB band characteristics, combination of multiple fractal symmetrical and asymmetrical slots are used. It has been depicted that the UWB band can be varied by varying the dimension of either ground or slot geometry. The antenna has a stable radiation pattern over the complete band of operation in H-plane and in E-plane. It also shows a stable radiation pattern throughout the UWB. Significant gain attenuation is observed at rejection frequencies. The results validated the design for the UWB communication system. Thus the designed antenna is perfectly suitable for the UWB applications issued by FCC.

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