

Design of Compact Monopole Ultrawideband Frequency Reconfigurable Antenna

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ABSTRACT

The wideband frequency spectrum, such as UWB, also consists some narrowband services like WiMAX and WLAN. Therefore, the possibility of interference between wideband and the narrowband services increases. Generally, an additional filter is used to overcome the interference issues, but, the use of additional filter increases the cost and complexity of the system. Earlier, a truncated patch antenna with C-shaped slot has been proposed to optimize the cost and complexity, but, it fulfils the band rejection requirement for WLAN (5-6 GHz), while, it does not support the reconfigurability. An optimized planar ultra-wideband (UWB) antenna with WLAN band-reconfiguration characteristic fed by a 50 Ω coplanar waveguide (CPW) has been proposed in this paper. In this proposed structure, the truncated metal patch consists two additional symmetrical open stubs and the patch and the stubs are connected through MEMS switches to achieve the reconfigurable property. The overall dimension of the antenna is $19 \times 18 \times 1.6$ mm³ and integrated on FR4 substrate. The proposed design has shown wideband impedance matching in terms of radiation pattern and gain along with reconfigurability.

Keywords: Band-notched UWB antenna, coplanar waveguide (CPW), C-shaped slots, frequency reconfigurable, LCR circuit, MEMS switch

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INTRODUCTION

The reconfigurable, printed monopole antennas for multiband and wideband applications are in great demand now a days, due to their compact size, omnidirectional radiation pattern, unipolar configuration, wide impedance bandwidth and low power consumption. Since, some of the active

narrow band services, such as, wireless local-area network (WLAN) IEEE802.11a operating in the 5 GHz to 6 GHz band and WiMAX operating in the 3.4 GHz to 3.8 GHz are existing in the UWB range as per the first report and revised order of part 15 of the commission's rule FCC 02-48 (Federal Communications Commission, 2002), therefore, the co-existing bands create the interference and it needed to be dismissed to minimize the interference. Hence, the antenna systems become complex and costly, due to the use of additional filters (Zaker et al., 2008; Cho et al., 2006; Lee et al., 2006). Many more design structures and methods have been reported regarding the printed UWB antenna (Liang et al., 2005; Song et al., 2010; Ray & Tiwari, 2008). The UWB antennas have the filtering property at 5 GHz – 6 GHz and are used to minimize the interference. A compact dual band notched CPW fed planer UWB antenna with notching at 3.4 GHz (3.3–3.8 GHz) and 5.5 GHz (5–6 GHz) has been proposed by Chu and Yang (2008). The radiating patch of the proposed antenna has the dual band notch feature, which is obtained by introducing the two C-shaped slots. A good wideband impedance matching in term of radiation pattern and gain has been observed, but, the antenna does not offer the reconfigurable property (King et al., 2013; Yan et al., 2014; Singh et al., 2016; Qiu et al., 2013; Khalichi et al., 2013; Singh et al., 2017). Due to the attractive advantages of coplanar waveguide (CPW) feed line such as, lesser dispersion characteristics at higher frequencies, wider impedance bandwidth and ease combination with active devices, over the conservative microstrip feed lines (Anderson et al., 2005; Das et al., 2012), a coplanar waveguide feed line technique has been used for the design of reconfigurable printed monopole antenna in this work (Kishan et al., 2012; Zivkovic & Scheffler, 2013)

A single band notched with wideband/narrowband frequency reconfigurable antenna has been reported in this work for UWB application. Two identical compact rectangular slots have been introduced in ground plane of proposed antenna to enhance the impedance bandwidth. Furthermore, to enhance the impedance bandwidth, the slot width and the feed position are also important parameters. The higher bandwidth could be achieved by using wider slots, while the good impedance matching can be achieved by an optimal feed position. The proposed design has a C-shape slot in radiating patch to achieve the frequency notching at 5.5 GHz and to get the frequency reconfiguration at the same band (5.5 GHz) the two symmetrical open stubs of length $\lambda/4$ of 5.5 GHz, which are connected with radiating patch through the MEMS switches have been introduced (Gupta et al., 2008; Kim et al., 2006). The proposed antenna has been designed and simulated using HFSS v14 tool.

MATERIALS AND METHODS

The dimensions of the proposed design are given in Table 1. The length 'T1' and width 'W1' play important role in setting up the wideband impedance bandwidth of the antenna system (Chiu et al., 2012). The dimension 'T1' and width 'W1' are taken half wavelength of

lower frequency (3.1 GHz) for the FR4 substrate. The substrate height is 1.6 mm, dielectric constant is 4.4 and loss tangent is 0.02. The optimization for the said parameters has been done for the most suited impedance bandwidth and quality factor (Q). The wideband/narrowband frequency reconfigurable property depends on the position of integrated RF-MEMS switches position i.e. ON or OFF, and also helps to minimize the interference level between WLAN and UWB.

RESULTS AND DISCUSSION

The structure of proposed monopole antenna with rectangular slotted ground plane without notch/reconfigurability is shown in Figure 1 (a). The rectangular slots in ground plane provide the additional path for current, which helps to enhance the impedance bandwidth. The variation in impedance at input, caused by the variation in inductance and capacitance. The VSWR for the proposed design has been simulated with and without rectangular slots in ground plane shown in Figure 2. It was observed from the simulated VSWR that these slots played the important role to enhance the impedance bandwidth of the structure.

Table 1
Optimised parameters of proposed antenna

Parameters	Dimensions	Parameters	Dimensions
H	2 mm	W3	4.5 mm
T1	18 mm	W4	1 mm
T2	12 mm	W5	3 mm
T3	10 mm	g	0.5 mm
T4	1.86 mm	tt	2.6 mm
T5	7.57 mm	tt2	7.6 mm
W	6.5 mm	ww	2.9 mm
W1	19 mm	t1	0.3 mm
W2	7 mm	Θ	48°

The geometry of the proposed UWB antenna with notch feature and the integration of RF-MEMS switches to achieve the frequency reconfigurable property has been shown in Figure 1 (b) and Figure 1 (c) respectively. The relation between notch frequency and length of the slot is given in equation (1).

$$f_{notch} = \frac{C}{2L\sqrt{\epsilon_{eff}}} \quad (1)$$

There is no further tuning in dimension is required of Figure 1(a), even after the integration of C-shaped slot for band notching and the open stubs for the frequency reconfiguration.

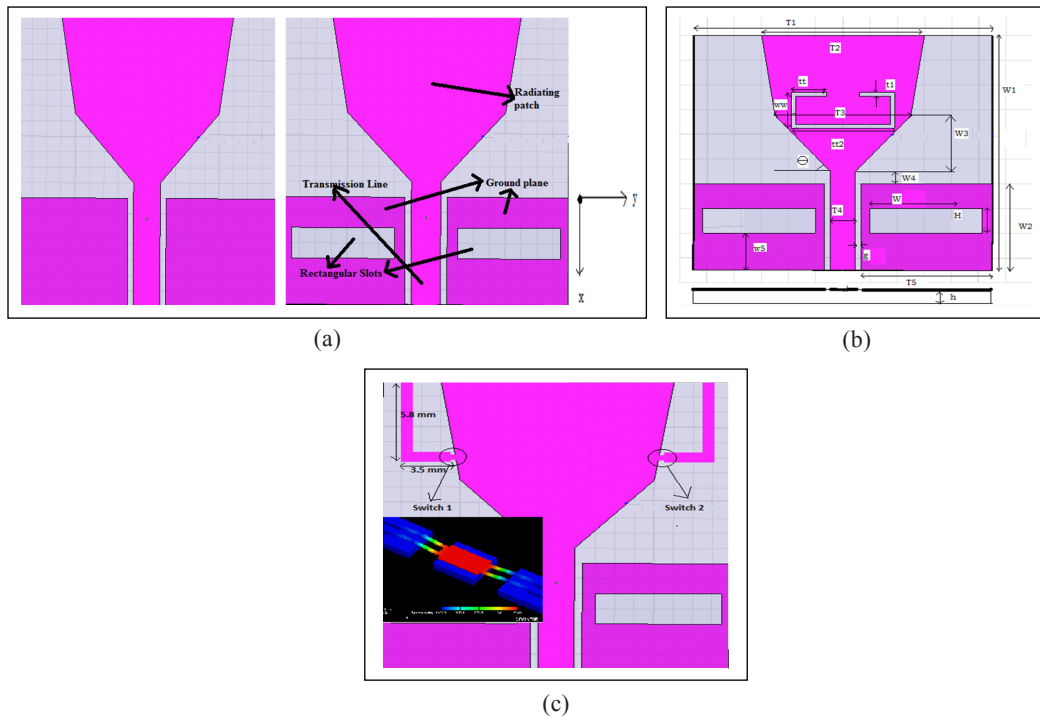


Figure 1. Proposed structure of the antenna (a) without notch (b) with notch and (c) with open stubs for frequency reconfiguration

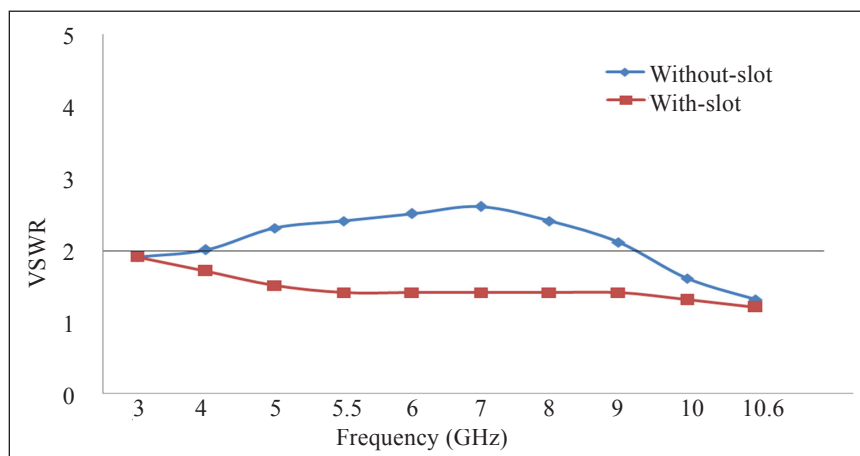


Figure 2. Simulated VSWR of antenna, shown in Figure 1 (a) with and without rectangular slots in ground plane

Both lengths of slots and open stubs are the same. The C-shaped slot length is 18.6 mm and the stubs length is also $9.3 \times 2 = 18.6$ mm, which have been obtained from equation (1). Based on the aforesaid concept, Figure 3 shows the simulated current distributions in the antenna structure at different frequencies.

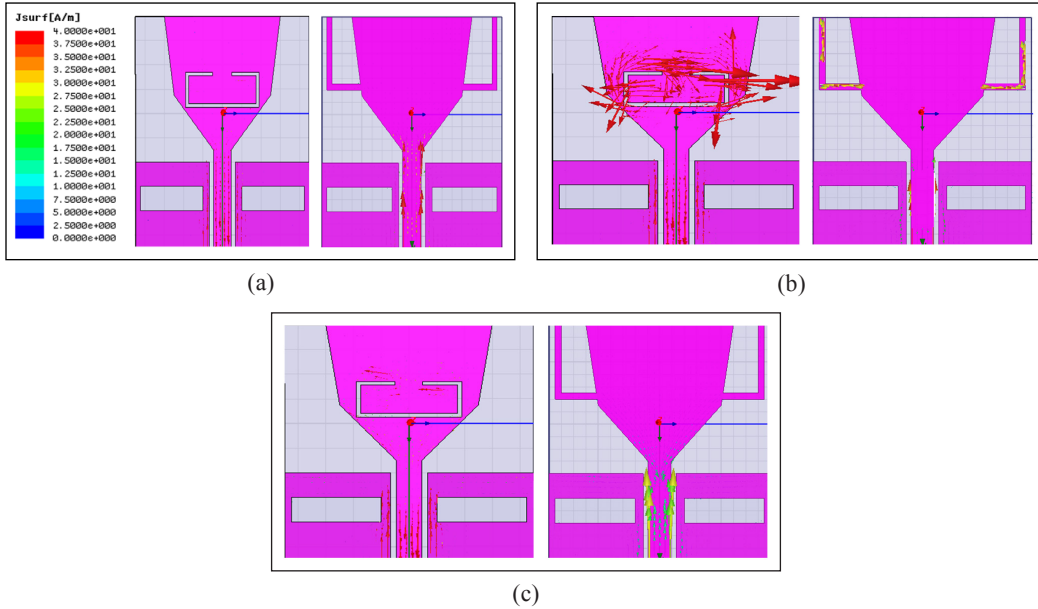


Figure 3. Current distributions in antenna at frequencies (a) 3.5 GHz, (b) 5.5 GHz and (c) 8 GHz

It was observed that the at 3.5 GHz and 8GHz, the current was distributed along the feed path and the radiating patch as depicted in Figures 3 (a) and (c), while at 5.5 GHz, the current was distributed in C-shaped slot in patch and in region of open stubs as shown in Figure 3 (b). This indicates that a destructive interference occurs in the antenna system for the excited surface. This also indicates the impedance mismatch due to large reflection at the desired notched and reconfigurable frequency near the feed-point.

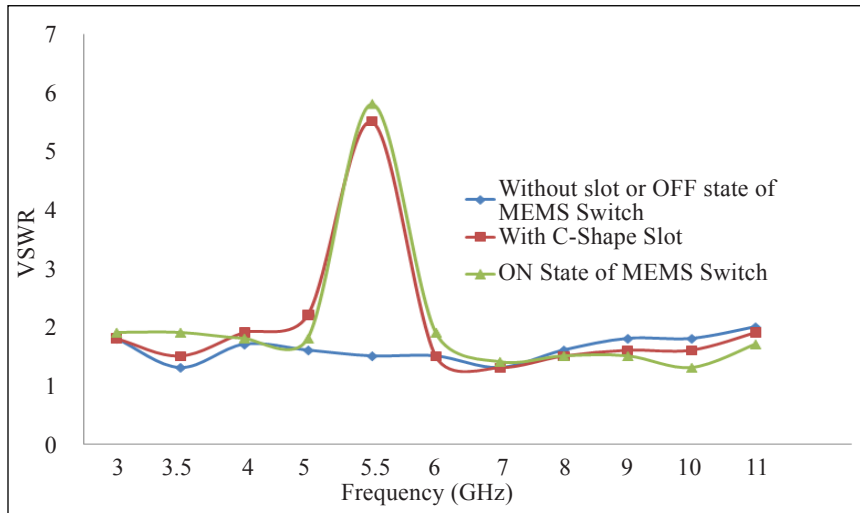


Figure 4. Comparison of simulated VSWR for the antenna structures, shown in Figure 1 (a, slotted ground plane), 1 (b) and 1 (c)

The simulated VSWR for the antenna design shown in Figure 1 (a), (b) and (c) have been shown in Figure 4. It was observed that, the C-Shaped slot and the open stubs had efficiently introduced the desired filtering capacity and frequency reconfigurable property in the proposed antenna system without introducing any additional filter. The VSWR of the proposed design, shown in Figure 1 (b) with the variation of W_4 , Θ , W_5 and H had been simulated and shown in Figures 5, 6, 7 and 8 respectively.

It was observed from the results shown for the proposed design that the single band-notched characteristics at 5 GHz to 6 GHz for the antenna was obtained along with its frequency reconfigurable property. Apart from this, it was also observed that the design showed a good impedance matching in UWB band.

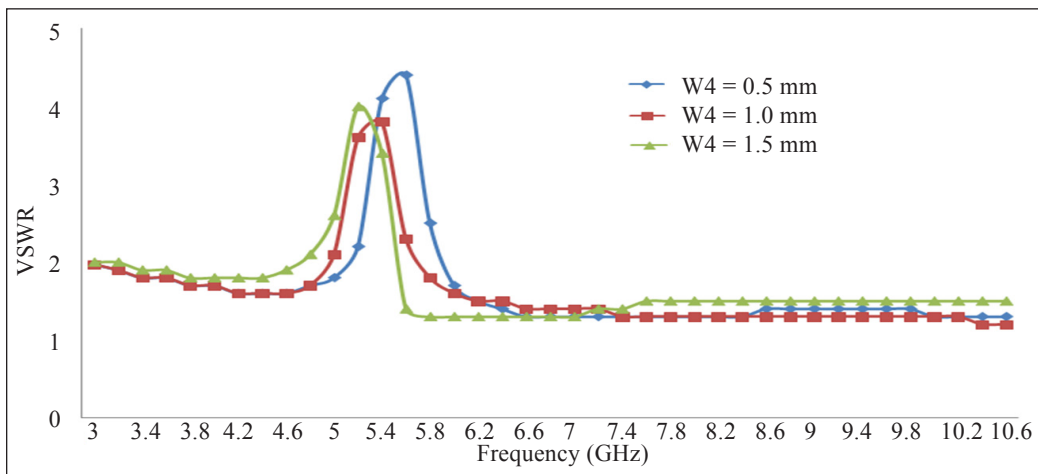


Figure 5. The VSWR with variation of W_4 of proposed design shown in Figure 1 (b)

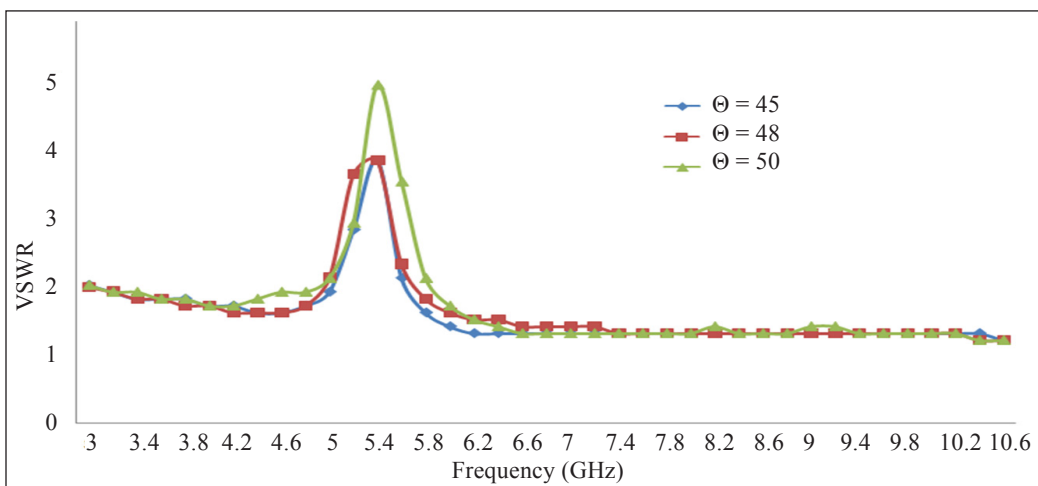


Figure 6. The VSWR with variation of Θ of proposed design shown in Figure 1 (b)

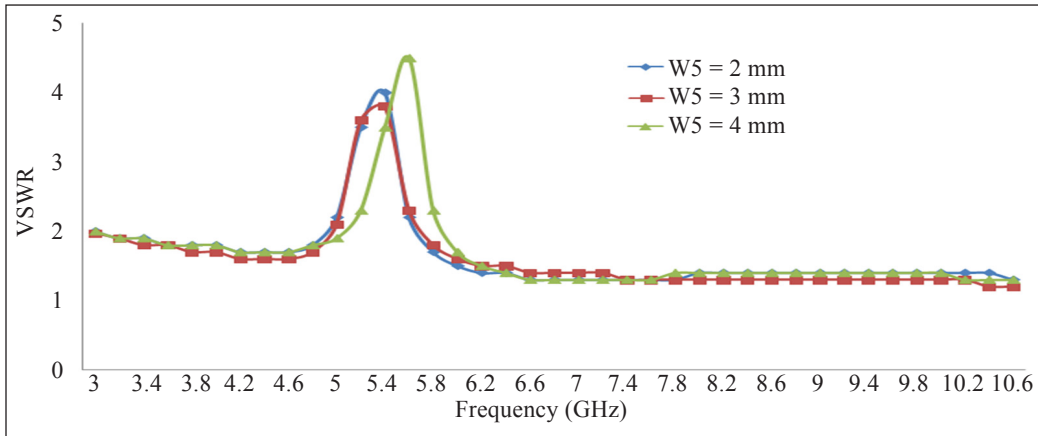


Figure 7. The VSWR with variation of $W5$ of proposed design shown in Figure 1 (b)

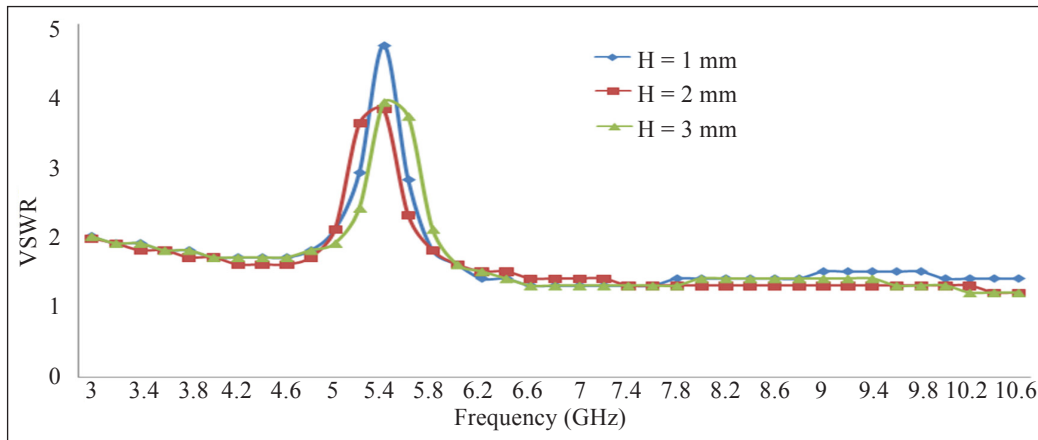


Figure 8. The VSWR with variation of H of proposed design shown in Figure 1(b)

Since, the UWB system works in pulse communication, therefore, a constant group delay become an essential parameter to evaluate for the wideband system. The group delay for wideband system must be linear or the variation must be lie in the acceptable range, which should be less than ± 1.5 ns. The simulated phase response (group delay) of designs given in Figure 1 (b) and 1 (c) have been shown in Figure 9. The simulated result is also validated by the measured result. It was observed that the variation in group delay for the antenna design shown in Figure 1 (b) and Figure 1 (c), was out of acceptable range (more than 4 ns) in notched/reconfigurable band. However, in the remaining frequency part, the group delay variations was within the acceptable range. The aforesaid facts are showing the non-linear behaviour of the proposed design, which is suitable for notch/reconfigurable frequency band. Also, the simulated and measured gain for design shown in Figure 1 (a), 1 (b) and 1 (c) has been shown in Figure 10, and it was observed that the variation of gain in the UWB band was 4 dBi to 8.5 dBi, except in notch/reconfigurable band.

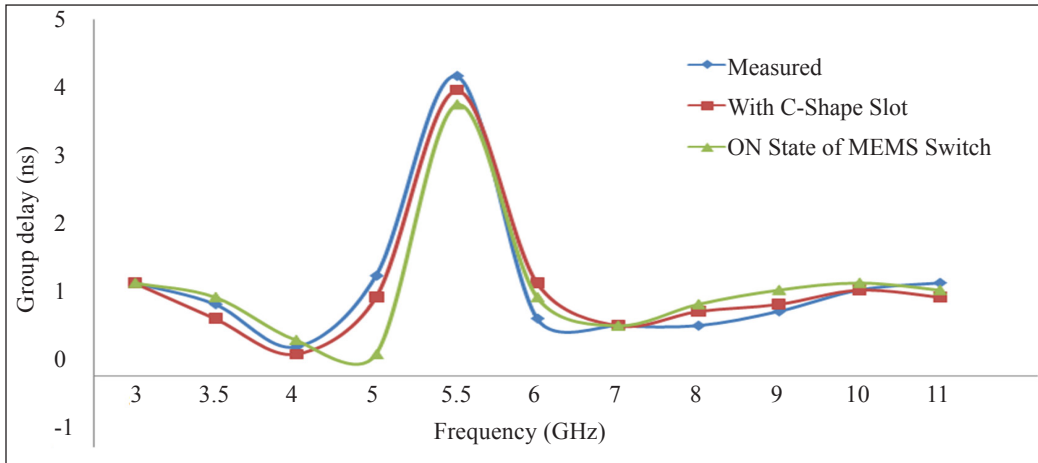


Figure 9. Simulated and Measured Group delay antenna for the antenna design shown in Figure 1 (b) and 1(c)

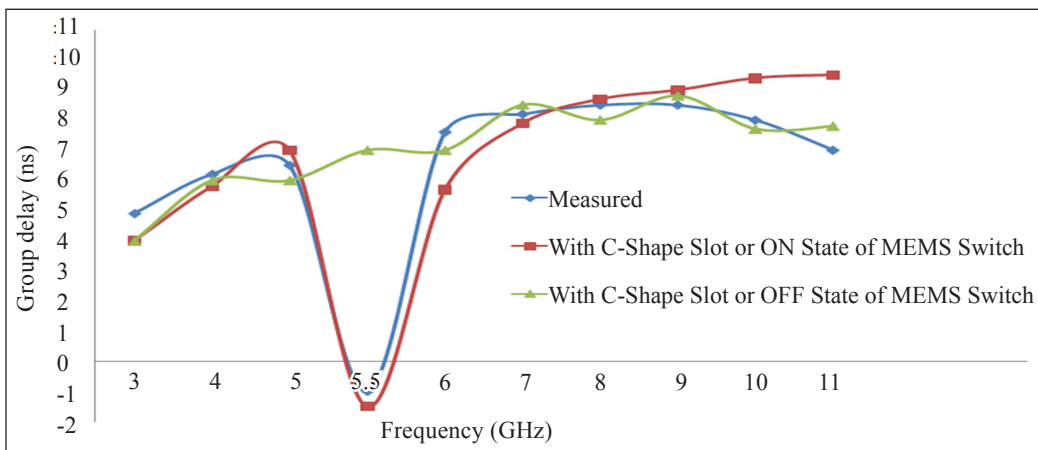


Figure 10. Simulated and Measured Gain of design shown in Figure 1 (a), 1(b) and 1(c)

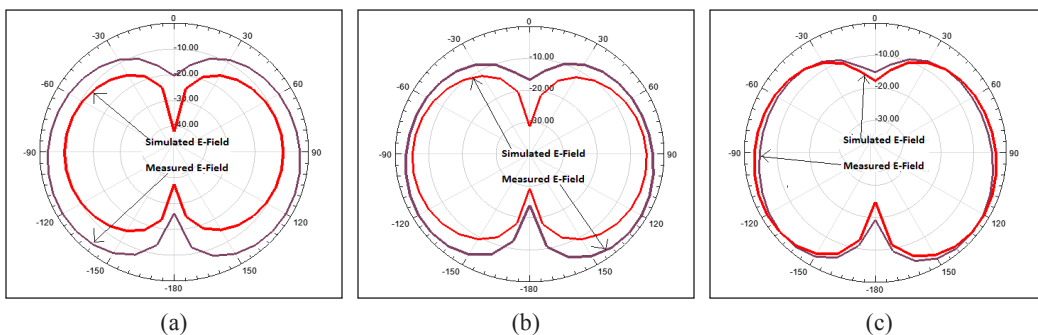


Figure 11. Far-field radiation patterns for the proposed antenna shown in Figure 1(c) at different frequency (a) at 3.5 GHz, (b) at 8 GHz, and (c) at 10 GHz

A clearer picture using simulated and measured E-plane radiation pattern at different frequency are presented in Figure 11 (a), 11 (b) and 11 (c). It is observed that, E-plane radiation patterns at 3.5 GHz, 8 GHz and 10 GHz has nearly omnidirectional like normal monopole antennas.

Equivalent Circuit Model

Electrical Equivalent for Impedance of Radiating Patch. An equivalent circuit model for proposed frequency reconfigurable/band-notched UWB antenna has been presented. Conceptually, a CPW can be assumed as a transmission line which is having characteristic impedance Z_0 . To reduce the complexity, the radiating patch of the antenna has been represented by several parallel connected LCR cells which are connected in series as shown in Figure 12 and the C-shape slot/open stubs are modelled as a series stub as shown in Figure 15 (Vuong et al., 2007; Wadell, 1991).

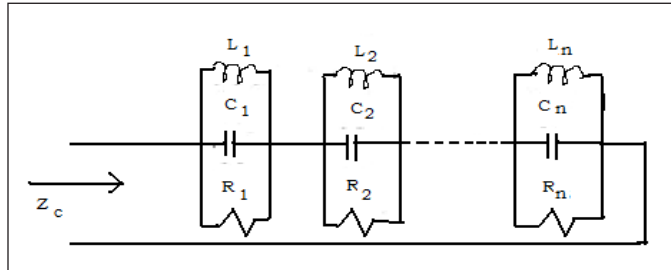


Figure 12. Equivalent electrical representation for radiating patch of proposed UWB antenna

Each LCR segment of UWB antenna has been connected in series. The input impedance for single LCR segment is given by the equation (2),

$$\frac{1}{Z_p} = \frac{1}{R_p} + \frac{1}{j\omega L_p} + j\omega C_p \quad (2)$$

The input impedance of equivalent circuit for UWB antenna is given by the equation (3),

$$Z_e = \sum_{p=1}^n \frac{j\omega R_p L_p}{R_p(1 - \omega^2 L_p C_p) + (j\omega L_p)} \quad (3)$$

Here, the real part of the input impedance is considered to realize the UWB antenna and to determine the values of LCR, and the equation (4) is used for this.

$$R_e = \text{real}\{Z_e\} = \sum_{p=1}^n \frac{R_p}{\left(1 + R_p \left(\frac{1}{L_p \omega} - C_p \omega\right)^2\right)} \quad (4)$$

The curve fitting method has been used to evaluate the values of R_p , L_p , and C_p . The real part of eq. (4) is used to obtain the impedance values at different frequencies and it is obtained from the simulation (Vuong et al., 2007).

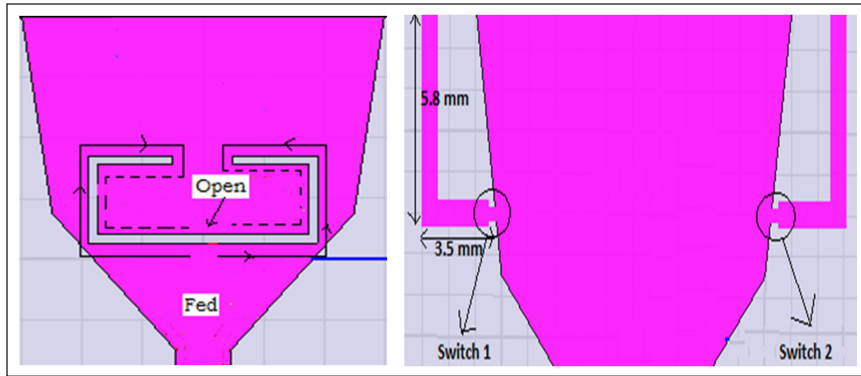


Figure 13. Surface current distribution for the C-shaped slot and open stubs (ON state of MEMS switch) of antenna at 5.5 GHz

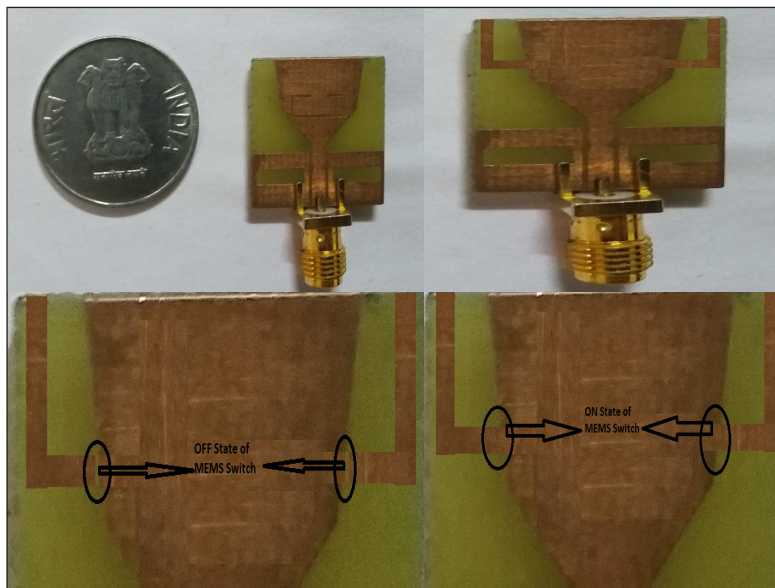


Figure 14. Fabricated prototype of the proposed antenna encapsulating a C-shaped slot and L-shaped symmetrical open stubs

The current distribution path in proposed design is shown in Figure 13 at 5.5 GHz. In case of C-shape slot, the top of the slot becomes short circuited and offer a low impedance path, while, the bottom of the C-shape slot becomes open circuited and offers a high impedance path. In case of L-shape open stubs, the L-shaped open stubs provide a low impedance path at the connecting point with the radiating patch, while, a high impedance

path at the top of the stubs. The aforesaid facts clearly explain that the variation in the impedance creates an impedance mismatching at 5.5 GHz. The C-shaped slots and the L-shaped symmetrical open stubs have been shown in the Figure 14.

Electrical Equivalent for C-Shaped Slot and Open Stubs. The sizes for the C-shaped slot and L-shaped open stubs have been chosen very precisely and in such a way that the total length of the slot and stubs be equal to the half wavelength of frequency 5.5 GHz. As discussed in previous section, that C-shaped slots provides a high impedance path at feed point of the antenna and also shown in Figure 13. Therefore, input impedance is very high at the feed point of the antenna and it is equivalent to the transmission-line-like mode. Hence, the C-shape slots and the on state of MEMS switches can be modelled as series stub transmission line (Singh et al., 2016). The electrical equivalent for the radiating element of the antenna and the electrical equivalent of C-shaped slots and symmetrical open stubs have been combined together and form the electrical equivalent for proposed single band notched frequency reconfigurable UWB antenna, which is shown in Figure 15.

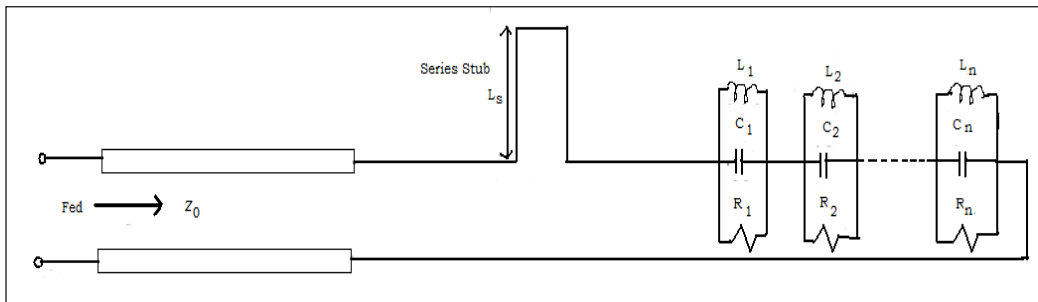


Figure 15. Combined electrical equivalent for radiating element and the C-shaped slots and open stubs of the proposed antenna

Since, the characteristics impedance of the antenna should be of the order of $50\ \Omega$ throughout the band. Therefore, to validate the characteristics impedance of antenna over the operating band, the resistance and the reactance have been simulated separately (antenna structure and equivalent circuit model) and are shown in Figure 16 and Figure 17 respectively. At 5.5 GHz, the resistance and reactance both are larger than $50\ \Omega$, which represent an impedance mismatch and hence the antenna is limited not to radiate (or non-responsible) at this frequency.

In addition, the comparison of simulated return loss and VSWR of the proposed antenna have been done with the electrical equivalent model which are shown in the Figure 18 and Figure 19 respectively. The VSWR is measured and also added to the comparison plot in Figure 19. The curves tendencies show that the proposed design is best suited for UWB band.

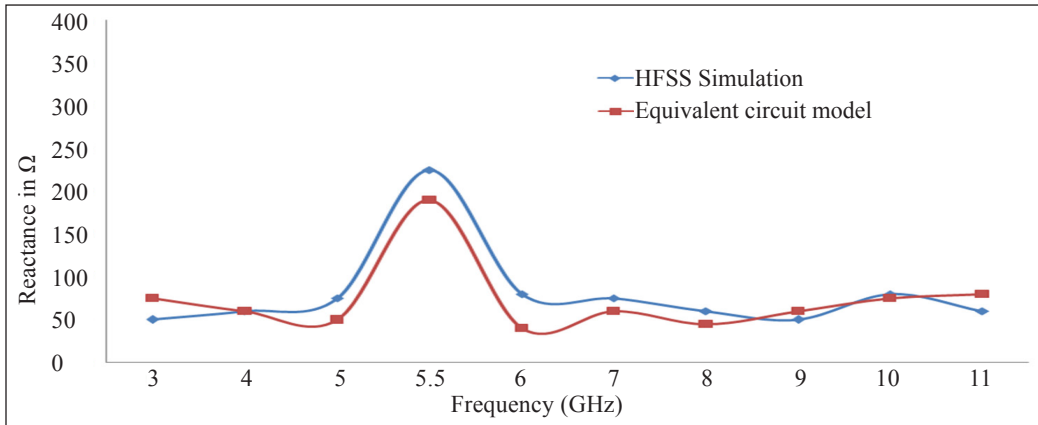


Figure 16. Comparison of simulated resistance using antenna structure and equivalent circuit in Figure 15

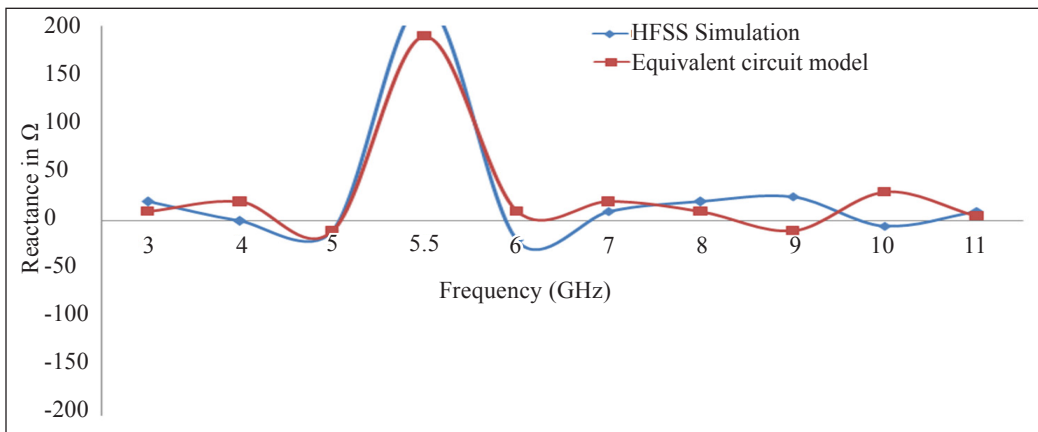


Figure 17. Comparison of simulated reactance using antenna structure and equivalent circuit in Figure 15

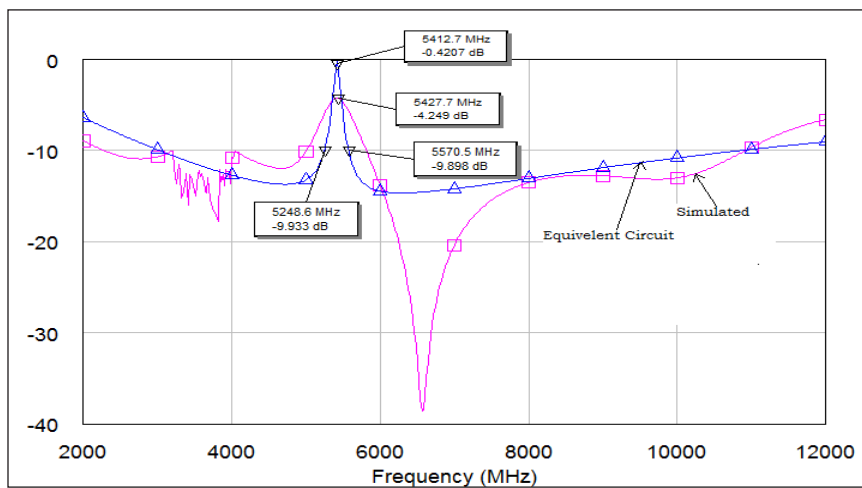


Figure 18. Comparison between the simulated return loss (S11) of antenna structure and by the equivalent circuit model

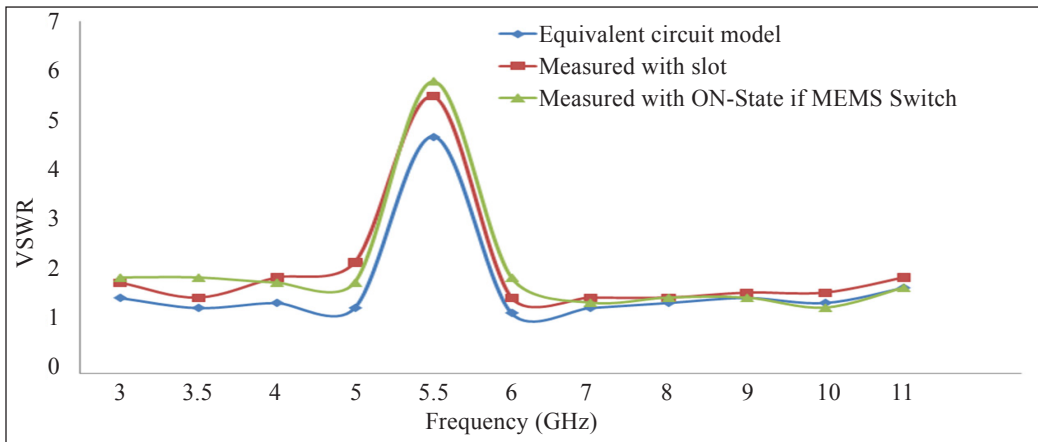


Figure 19. Comparison of measured VSWR of antenna structure and by the equivalent circuit model

CONCLUSIONS

A compact and wideband/narrowband frequency reconfigurable antenna for UWB application has been designed and validated using the simulated and measured results. The matching bandwidth of the proposed antenna has significantly improved by adding a rectangular slot ground plane. It is also validated that the C-shaped slot in radiating patch much suitable for the band rejection/filtering of WLAN band, which significantly diminished the interference between the UWB and WLAN. Also, the role of two symmetrical L-shaped open stubs connected to MEMS switch has been validated and observed that the frequency reconfigurable property in the proposed antenna design has been introduced by the open stubs. The constant gain and stable radiation pattern have observed in desired band for the proposed design. Hence, the proposed antenna design has resolved the issue of interferences between the IEEE 802.11a systems coexist with UWB services.

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