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Compact CPW Fed Switchable UWB Antenna as an Antenna Filter at Narrow-Frequency Bands

Mansour Nejatijahromi[1], Mahdi Naghshvarianjahromi[3, *], and MuhibUr Rahman[2]

Abstract—The aim of this paper is to present a compact coplanar waveguide (CPW) fed switchable UWB antenna as an antenna filter with adjustable notched frequency bands. Novel miniaturized tunable resonators are also presented to achieve notched bands. The antenna is made tunable in notched frequency bands without any modification in the basic structure. These stopbands are made tunable just by varying values of the capacitors according to our desired applications. The antenna structure is very compact having overall dimensions of $24 \times 30.5\,\mathrm{mm}^2$ with partial ground plane. The proposed small size, variable, low cost and low weight antenna with good propagation characteristics will pave the way for UWB wireless communication applications.

1. INTRODUCTION

Due to increased demand for wireless communication devices, Ultra-Wideband (UWB) technology has received a huge amount of interest among the researchers. UWB communication covers a frequency range of 3.1 GHz to 10.6 GHz. UWB communication possesses the advantages of high data-rate, low-power short-range communication, and immunity to multipath effects. Current development in UWB technology requires UWB devices to be small, planar and compact [1].

Miniaturized size, acceptable gain, consistent radiation pattern, and wide impedance bandwidth are some of the important challenges that need to overcome while designing UWB antennas. Formerly, wideband antennas have been used in applications, such as ground penetrating radar (GPR) [2, 3]. Also, in [4], they have proposed applications of UWB technology in radio frequency identity tags (RFID), impulse radar and position finders. The variable antenna can meet the demands of complex systems without any change in the shape or electrical behavior. Other important features in modern antennas are polarization variation, wide impedance bandwidth, interference mitigation, and clean radiation pattern over the complete operating band [5].

Previously wideband antennas have tended to be associated with antennas specified by an angle such as spirals, cones and tapers. The term 'slow wave' has been applied to the generic family of antennas, and many of them were physically bulky and often required balanced feed for better performance. For wideband technology a challenging aspect of antennas required is to be multi-octave in response. Additionally, it must miniaturize dimensions to be applicable to portable devices. For UWB to satisfy these constraints, various wideband antennas have been developed and explained [5–10].

In this paper, a CPW-fed switchable antenna acting as an antenna filter in narrow frequency bands is implemented. The notched bands are achieved by introducing novel small size resonators at both sides of the feedline. The resonators can create two notched frequency bands. By introducing two variable capacitors at these resonators, these notched bands can be made tunable to our desired frequency. The size of the antenna is $24 \times 30.5\,\mathrm{mm}^2$, including partial ground plane, and fabricated as well. The

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* Corresponding author: Mahdi Naghshvarianjahromi (naghshvm@mcmaster.ca).
[1] Department of Electrical Engineering, Islamic Azad University Tehran South Branch and Shahidsattaryeronatical University of Science and Technology, Tehran, Iran. [2] Division of Electrical and Electronics Engineering, Dongguk University, Seoul, South Korea.
[3] Department of Electrical and Computer Engineering, McMaster University, Hamilton ON, L8S 4L8, Canada.

simulation and measurement of the antenna are carried out, and clean radiation pattern of the antenna is observed.

The arrangement of the paper is in the following manner. Section 2 contains a brief description and experiments of the related work in this area. Section 3 contains the configuration of the proposed antenna including dimensions and monograph. Section 4 presents the simulated results of the proposed antenna at a different value of capacitors. Section 5 deals with the experimental results. Section 6 concludes the simulations and experiments carried out.

2. RELATED WORK

Some multiple UWB band notch antennas have been introduced in [2–5]. In [2], the author developes a UWB antenna that has the capability to offer the solution for interference caused by narrow interfering frequency bands. In [3], they present an aperture UWB antenna with an E-shaped slot with multi-cuts. The pair of rectangular slots in E-shaped sectoral patch tunes the spacing between fundamental and next three higher order modes to realize triple frequency response. The proposed antenna yields variable frequency ratios of 1.5 to 1.7 at 1st and 2nd modes, 2.0 to 3.5 at 1st and 3rd modes, and 2 to 2.5 at 1st and 4th resonance frequency modes, with almost 2% bandwidth at individual modes

The inspection of a new configuration of multiband-UWB antenna is carried out in [4]. The antenna comprises a V-shaped patch with unequal electromagnetically coupled arms. Six multiband operations are achieved due to different lengths and widths of the V-shaped patch as well as the two coupling slots. Two more modes can be added by loading the triangular planar inverted F-antenna (PIFA) with the V-shaped slot. Also, in [5] a compact printed UWB monopole antenna with dual band-notched characteristics is presented. By adjusting the size of the CSRR inserted in the radiating patch, they have achieved two stopbands. This design uses a structure with two capacitors in aground plane which is responsible for tuning the frequency band of the antenna.

Various other band-notching techniques have also been incorporated within UWB planar antennas such as etching slots of different shapes, inserting quarter wavelength stubs, and placing parasitic elements in the vicinity of radiating structure [12]. The approach of preventing the effect of strong signals on a UWB system by means of the antenna as a band-notch filter is proposed in [13]. The authors implement an open loop resonator (OLR) on the back side of the substrate to introduce filtering behavior.

It is the requirement of the modern UWB communication that antennas must have a continuously switchable notched band so that one antenna can perform tasks of multiple systems. In this regard, various tunable band-notched UWB antennas have been reported over the last decade [14–23]. These UWB antennas actually implement the strategy of PIN diodes, shorting circuits, microelectromechanical switches (MEMS), stepper motors, and optically controlled switching techniques. Also, their switching technique is based on conventional ON and OFF statuses. Similarly, in [22] they embed tunable voltage and current elements (varactors) to continuously tune the stopbands. However, the reported antenna only operates at fixed notched band which can be turned ON and OFF using the status of the switch. The frequency shifting agile property to continuously shift those filtered bands cannot be achieved with such techniques. To solve such a problem, a continuously tunable band-notched UWB antenna is reported in [24]. They introduce lumped elements within the structure of an antenna to control notch bands by controlling the value of lumped elements. However, as the value of the lumped elements increases, the Q-factor of the notched bands decreases continuously.

Recently, a novel tunable monopole antenna with a switchable integrated feed network for UWB and WLAN (2.4 GHz and 5.8 GHz) is proposed in [25]. The frequency reconfiguration is realized by integrating two bandpass filters with UWB antenna circuit. Similarly, in [26] they proposed a novel reconfigurable monopole switchable antenna for UWB/WLAN having filtering characteristics by utilizing three switchable states. The antenna operates in three states with three independent ports for UWB, WLAN (2.4 GHz), and WLAN (5.8 GHz) frequency bands. The first narrowband (2.4 GHz) is produced by using a microstrip filter of first order with open loop resonator (OLR), and the second narrowband (5.8 GHz) is generated by including hairpin bandpass filter of third order in RF path. The reconfiguration is performed using dc-controlled PIN diodes, and the overall dimensions of the antenna are $38 \times 40\,\mathrm{mm}^2$.

3. CONFIGURATIONS OF THE PROPOSED ANTENNA

The designed antenna geometry is shown in Figure 1 while its fabricated monograph is shown in Figure 2. This antenna is constructed on a Rogers RO4003 substrate with a thickness of 1.5 mm and relative dielectric constant of $\varepsilon_r = 3.38$ which has a dimension of $24 \times 30.5\,\text{mm}^2$ (i.e., $w_{sub} \times l_{sub}$). Parameters of the proposed antenna are mentioned in Table 1.

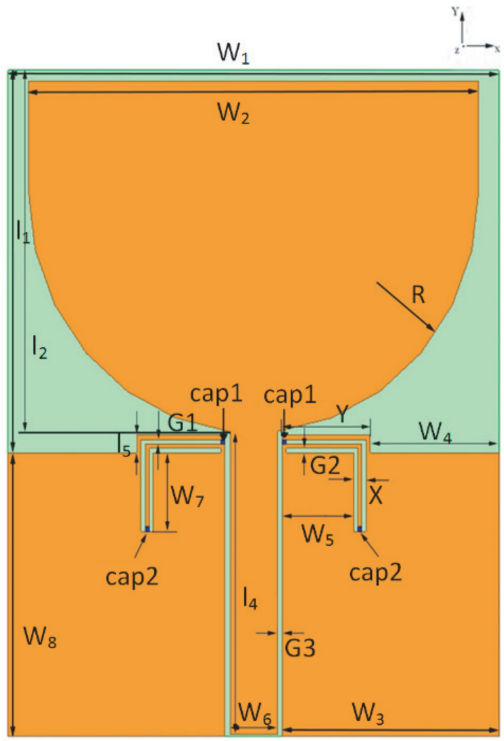


Figure 1. Geometrical parameters of the proposed antenna.

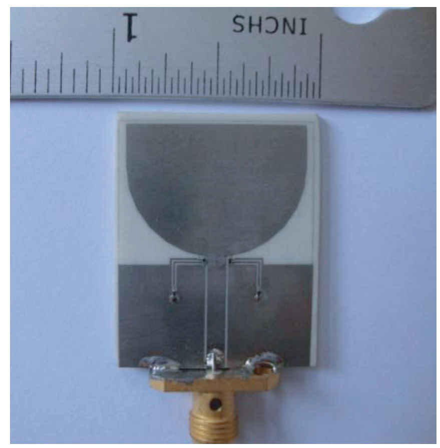


Figure 2. Fabricated monograph of the proposed antenna.

Table 1. Dimensions (in Millimeters) of the proposed antenna.

Parameters	L_1	L_2	L_4	T	H	X
Value (mm)	17.5	16	13.865	0.017	1.5	0.6
Parameters	Y	W_1	W_2	W_3	W_4	W_5
Value (mm)	4.3	24	22	10.6	6.3	3.5
Parameters	W_6	W_7	W_8	$G1$	$G2$	R
Value (mm)	2.3	3.6	13	0.25	0.5	11

In this article, we use four capacitors according to ATC design kit labeled as Cap1 and Cap2 in Figure 1. Cap1 is considered as a fix value having 0.1 pf, and Cap2 is considered variable. The value of Cap2 is changed from 0.1 pf to 1.6 pf, and their corresponding frequency response is observed and analyzed at specific values.

The origin and operation of the resonator is based on the concept discussed in [27]. The length of the resonator is calculated based on the equations provided in [27], which actually creates two resonance frequencies (odd and even mode). The width of the resonator is then optimized using parametric analysis in Ansoft HFSS. As can be seen in our analysis, the corresponding even mode frequency controls and shifts the upper notched band while the odd mode resonance frequency controls the lower notched frequency band. This effect makes the resonator advantageous to control two notched frequency bands at the same time.

Simulation of the proposed antenna has been performed with Ansoft HFSS and validated using CST Microwave Studio suite. The antenna is also fabricated as shown in Figure 2. Good agreement has been observed between the simulated and measured results. The slight discrepancy between the simulated and measured results is because of connector losses and hand welding inaccuracy in soldering.

4. SIMULATIONS OF THE PROPOSED ANTENNA

The antenna has been simulated with Ansoft HFSS for VSWR, reflection coefficient, input impedance (Real and Imaginary part), radiation pattern, antenna efficiency and gain. The simulated VSWRs of the proposed antenna at different values of capacitors are plotted and compared in Figure 3. It clearly shows the comparison of VSWR at 0.1 pf capacitor, which clarifies that antenna operates from 3.1 to 10.6 GHz frequency bands while successfully rejecting the 3.5 GHz and 7 GHz frequency bands. It is also clear that antenna acts as an antenna filter at 10.6 GHz. By increasing the value of the capacitor from

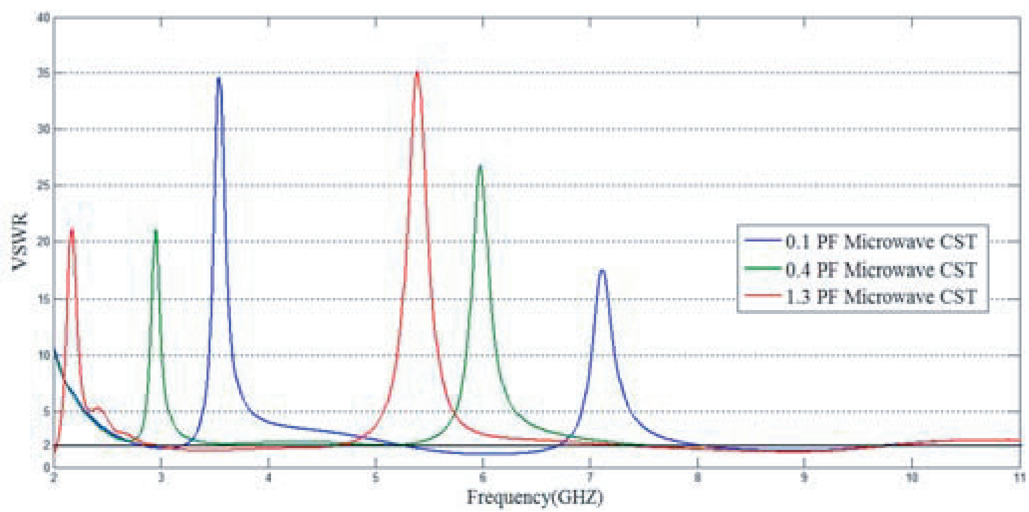


Figure 3. VSWR plot of the proposed antenna at different notched frequencies.

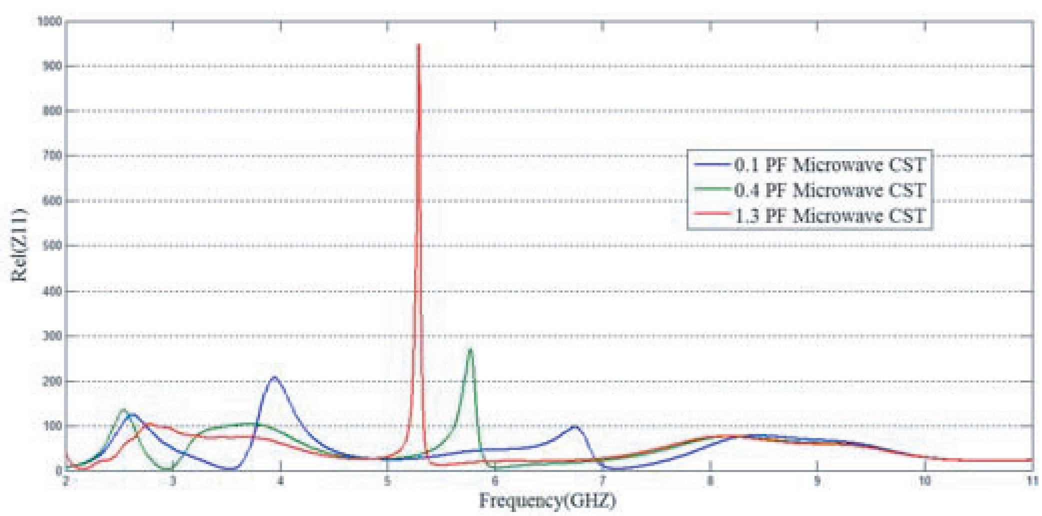


Figure 4. Re[Z_{11}] plot of the proposed antenna at different notched frequencies.

0.1 pf to 0.4 pf, the antenna rejection bands shift from 3.1 to 2.9 GHz and 7 GHz to 5.8 GHz, respectively. By further increasing the capacitor value, the lower and upper notched bands shift towards the lower frequencies. So it is advantageous that we can easily tune our desired frequency band just by changing the value of the capacitor without any alteration in the basic structure of the antenna.

The real and imaginary parts of Z [11] vs. frequency are plotted in Figures 4 and 5, respectively. The input impedance of the antenna is maximized at filtering bands as predicted from Figure 4. The value of the maximum impedance shifting is also observed by changing the value of capacitors as can be seen from Figure 4. Similarly, the shifting of input reactance is also observed in Figure 5. These properties confirm the continuous switching of notched bands.

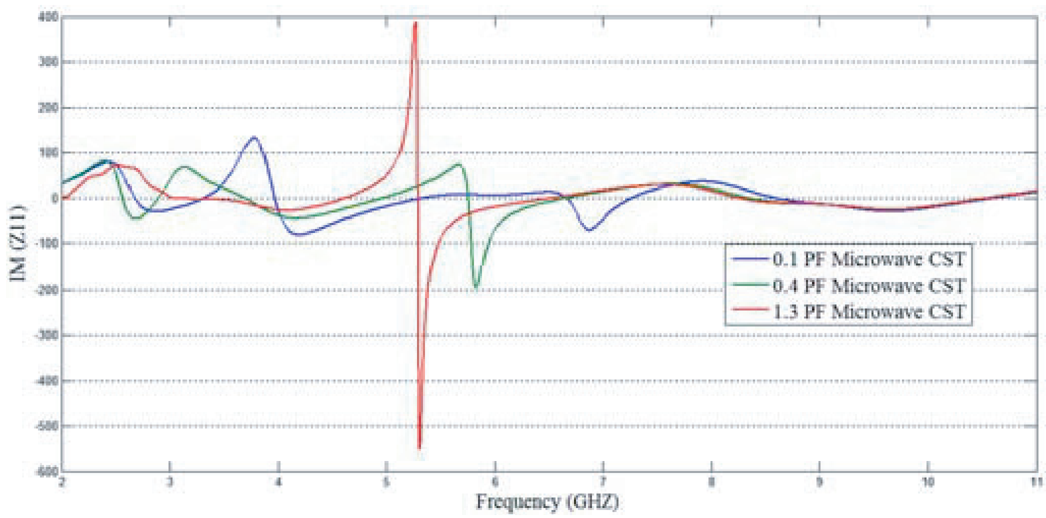
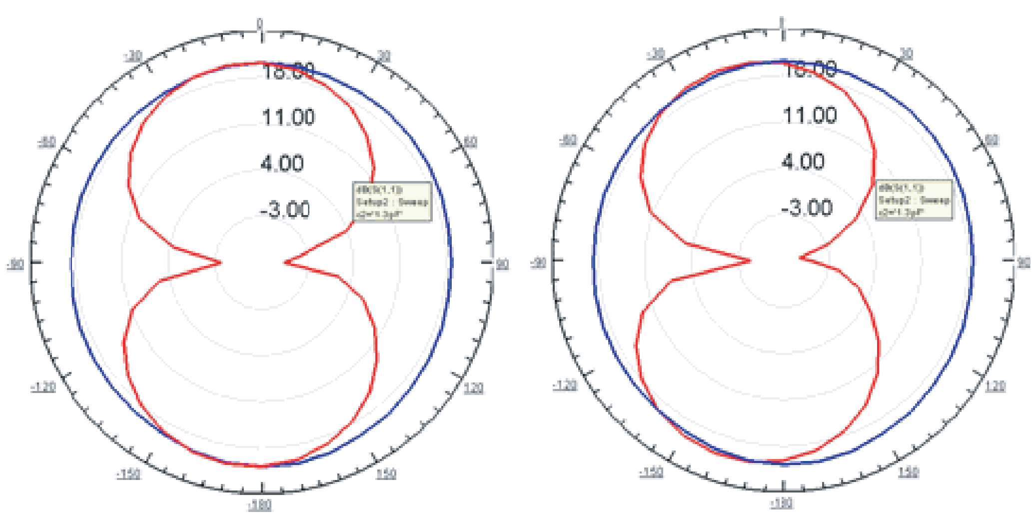


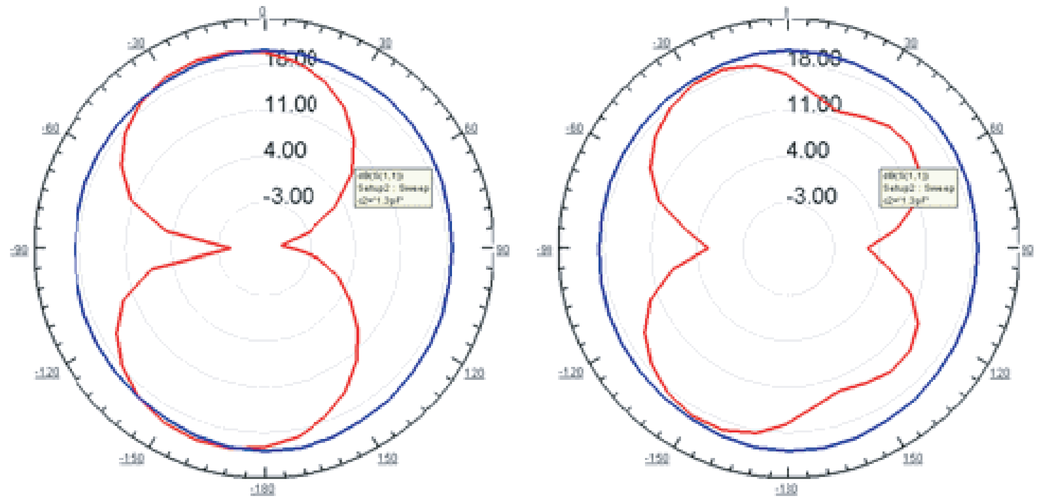
Figure 5. Img$[Z_{11}]$ plot of the proposed antenna at different notched frequencies.

The simulated radiation patterns of the proposed antenna at different frequencies are shown in Figure 6. The selected frequencies are 3.2, 4.1, 7.2 and 9.5 GHz as they cover the lower, middle and upper-frequency ranges of UWB. As can be seen from Figure 6 that very clean and consistent radiation pattern can be observed because of the placement of the resonators at the partial ground plane instead of conventional SRR and CSRR.

The peak gain (dBi) of the antenna at Cap2 = 0.1 pf is shown in Figure 7. It also clearly shows that the peak gain is very stable over most of the required frequency band except at the notched



(a) (b)



(c) (d)

Figure 6. E-plane and H-plane of the proposed antenna. (a) 3.2 GHz, (b) 4.1 GHz, (c) 7.2 GHz, (d) 9.5 GHz. (Red-Line) E-plane and (Blue-line) H-plane.

frequency bands. Suppression in gain is observed at two narrow frequency bands because of destructive interference at these frequencies and eventually creates notched bands. Also, the percentage radiation efficiency of the proposed antenna is also shown in Figure 8 which illustrates that there are two notched bands at Cap2 = 0.1 pF. The radiation efficiency plot reveals that antenna radiates over a wide band of frequency and is very stable.

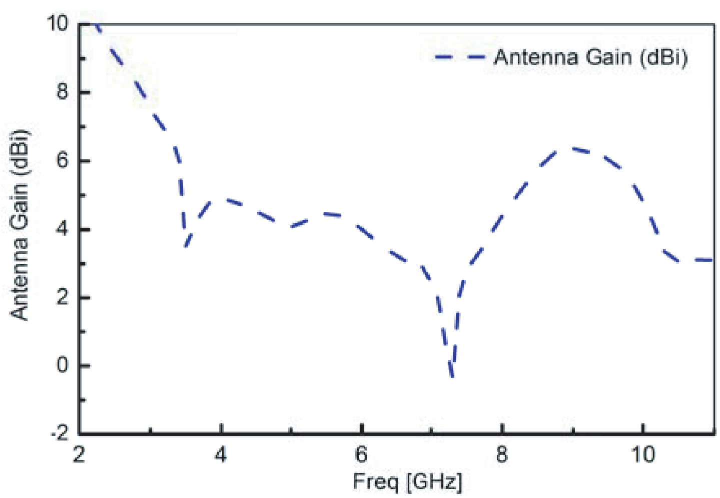


Figure 7. Gain of the proposed antenna at 0.1 pf capacitor.

5. EXPERIMENTAL RESULTS OF THE PROPOSED ANTENNA

The comparison of S_{11} performances of the antennas at CST, Ansoft HFSS and measured responses at 0.1 pf, 0.4 pf and 1.3 pf are shown in Figure 9, Figure 10, and Figure 11, respectively. These plots clarify the resemblance between simulated and measurement results. Figure 12 shows the comparison of all the antennas S_{11} responses between HFSS and measurements. Mismatching in some of the frequency bands is because of tolerance of capacitors, mounting of capacitors, and connectors effects.

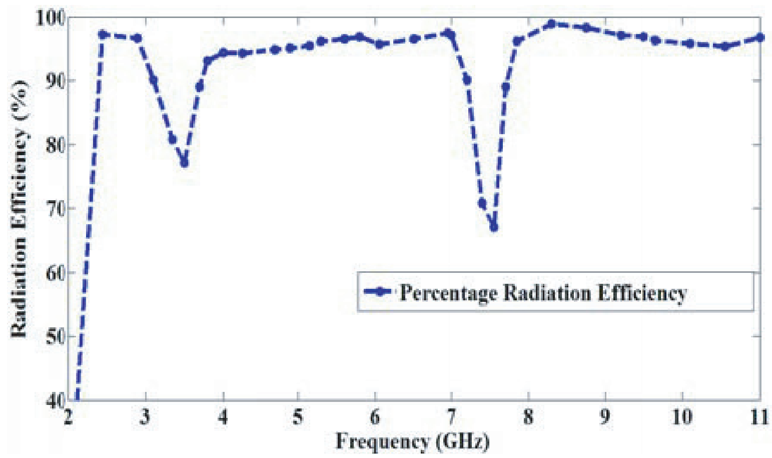


Figure 8. Rad. Efficiency (%) of the proposed antenna at 0.1 pf capacitor.

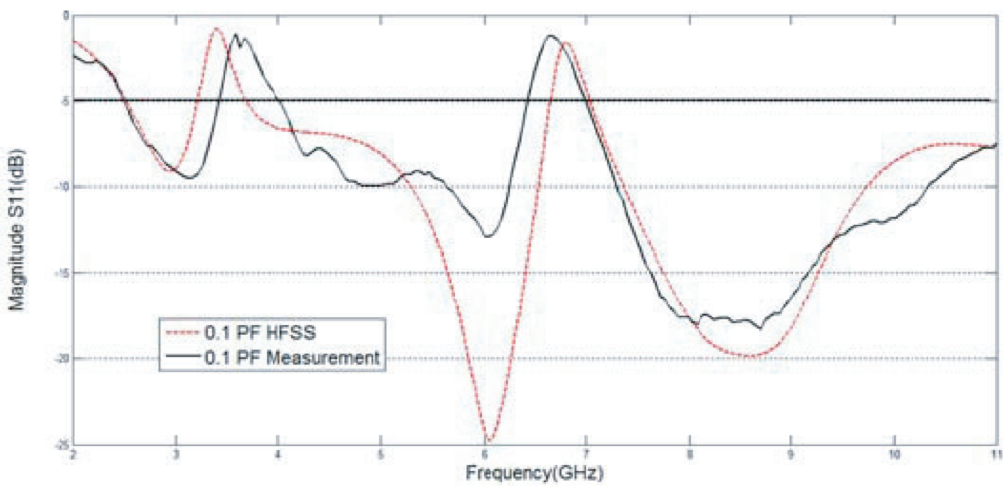


Figure 9. Simulation and measurement magnitude of S_{11} in dB. (Continuous line) measurement and (dash-line) simulation.

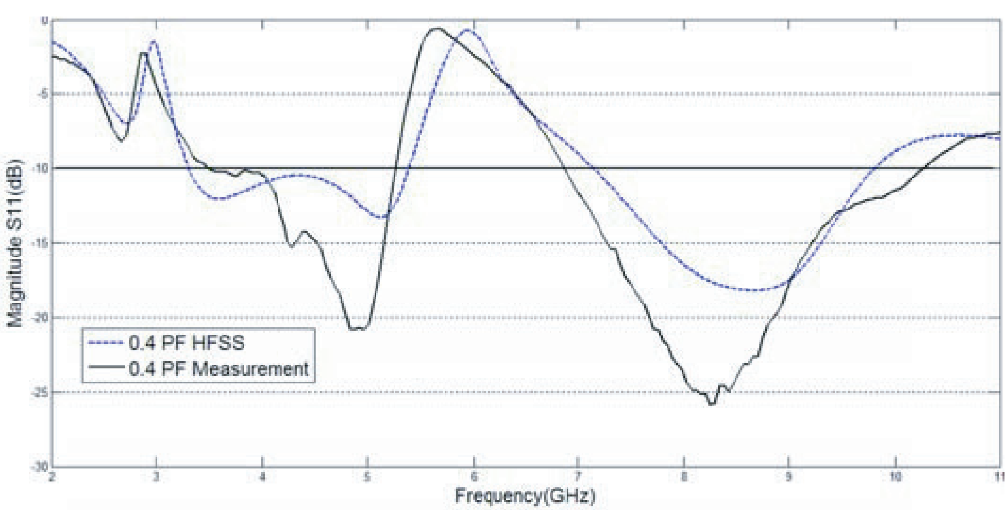


Figure 10. Simulation and measurement magnitude of S_{11} in dB. (Continuous line) measurement and (dash-line) simulation.

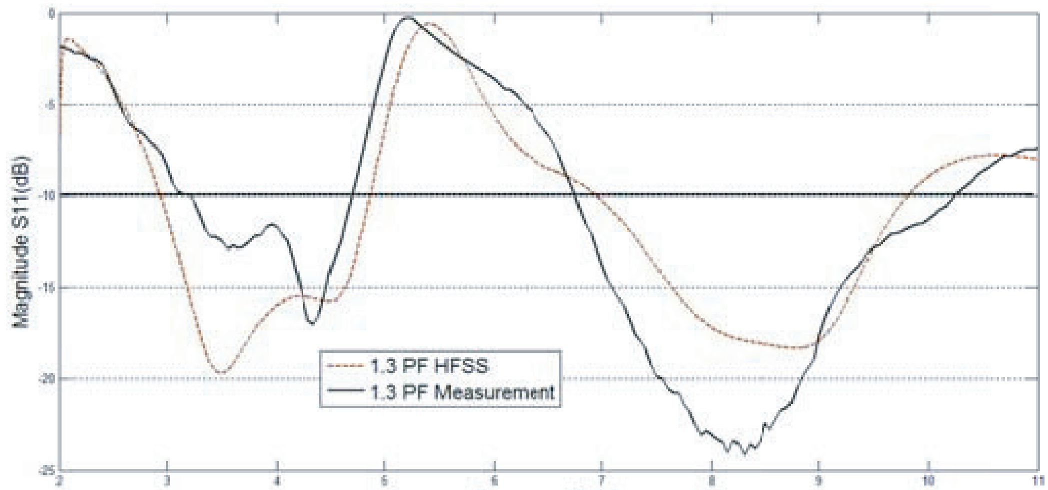


Figure 11. Simulation and measurement magnitude of S_{11} in dB. (Continuous line) measurement and (dash-line) simulation.

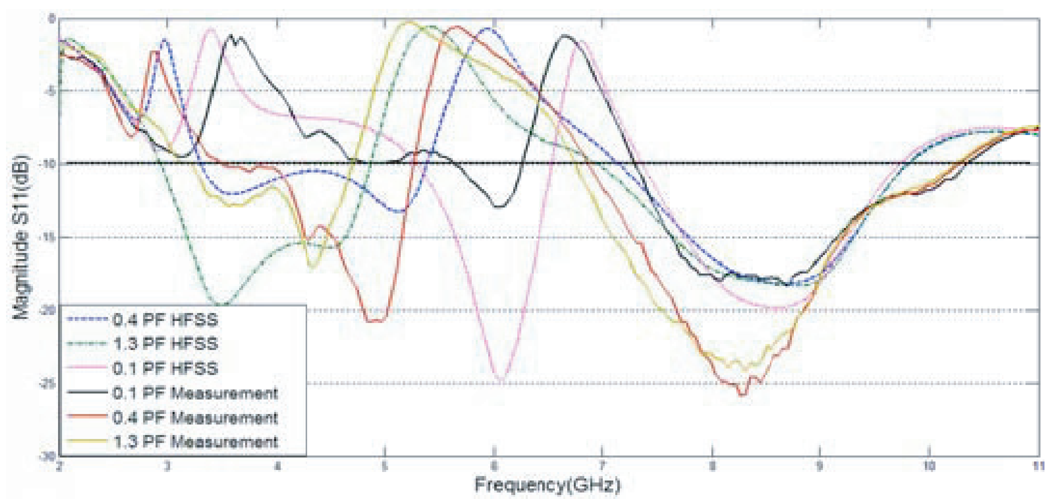


Figure 12. Simulation and measurement magnitude of S_{11} in dB. (Continuous line) measurement and (dash-line) simulation.

The result in Figure 9 shows the value of S_{11} lower than -10 dB in a 2.9 GHz–11 GHz frequency range having filtering behavior at 3.5 GHz and 7 GHz. Since 3.1 GHz–10.6 GHz spectrum is used for UWB application, this structure with a 0.1 pf capacitor is a good UWB antenna with two notched bands. As shown in Figure 10 by increasing the value of the capacitors to 0.4 pf, the response shifts towards the lower frequencies. The effect of increasing the value of the capacitor to 1.3 pf is shown in Figure 11. The notch in 3.5 GHz is shifted to 2.9 GHz, and the notch in 7 GHz is shifted to 5.1 GHz. Thus, the antenna filtering response can be made continuously tunable at two bands without any change in the basic structure of the antenna.

The antenna response is validated using CST Microwave Studio suite in correlation with the HFSS and measured response. This correlated response can be seen in Figure 13 for Cap2 = 0.1 pf, Figure 14 for Cap2 = 0.4 pf, and Figure 15 for Cap2 = 1.3 pf. It is noteworthy that in our analysis, we have only changed the value of Cap2 while Cap1 is kept constant. It also makes the antenna advantageous by controlling two notched bands by controlling only the value of Cap2. So both notched bands are dependent on Cap2 and can be switched accordingly.

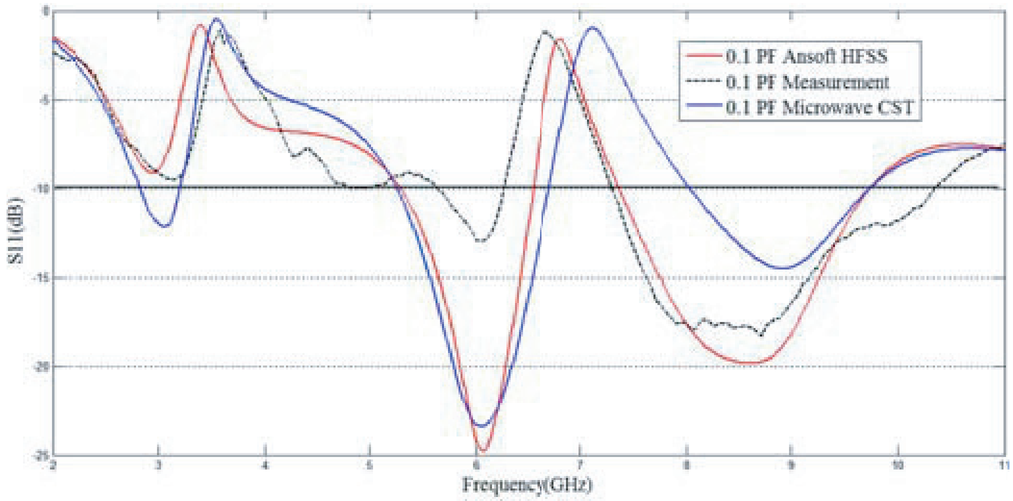


Figure 13. HFSS, CST and measurement results correlation at 0.1 pf.

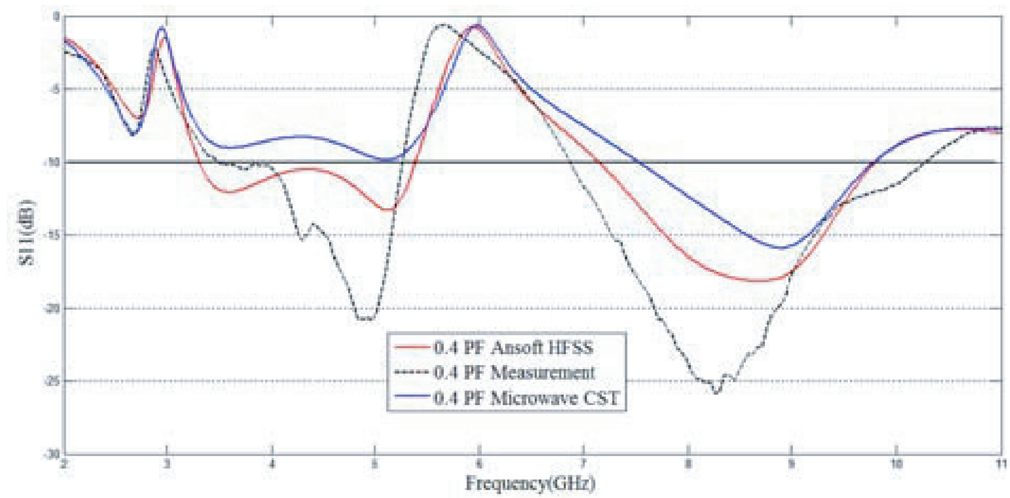


Figure 14. HFSS, CST and measurement results correlation at 0.4 pf.

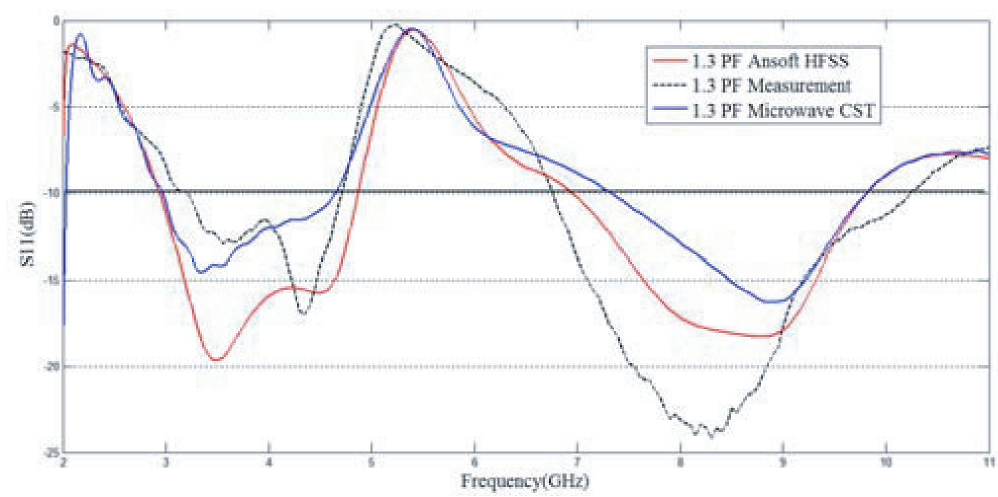


Figure 15. HFSS, CST and measurement results correlation at 1.3 pf.

6. CONCLUSION

A novel switchable compact coplanar waveguide (CPW) fed UWB antenna having filtering behavior has been presented. Also, miniaturized novel resonators have been incorporated in the partial ground plane to achieve dual notch response. The dual-notch mechanism is also made continuously tunable by introducing capacitors in the miniaturized resonators. It is also shown that the proposed antenna stopbands can also be shifted to our desired frequency bands just by varying the capacitance of the capacitor. The proposed antenna has been simulated in Ansoft HFSS and validated in CST Microwave Studio suite. The proposed antenna is also fabricated, and the measured results are correlated with the simulated ones. Moreover, the proposed antenna possesses a miniaturized size, stable gain, good radiation efficiency, and clean radiation pattern in the passband. The proposed antenna will pave the way for UWB wireless communication applications.

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