Progress In Electromagnetics Research Letters, Vol. 75, 97–103, 2018

Continuously Tunable WiMAX Band-Notched UWB Antenna with Fixed WLAN Notched Band

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

Abstract—This paper presents a CPW-fed UWB band-notched antenna having continuously tunable WiMAX rejection band and fixed WLAN rejection band. As the WLAN frequency band is fixed all over the world, it is made fixed with the use of a newly designed resonator in the radiating patch. As the main problem is that the WiMAX band is different in different countries of the world, between 3 and 4 GHz, it is made continuously tunable by using a novel miniaturized implemented resonator in the partial ground plane with variable capacitors. Altering the values of these capacitors tunes the 3–4 GHz rejection band continuously.

1. INTRODUCTION

Researchers have taken a keen interest in the UWB technology due to increase speed demand for wireless communication devices. The UWB frequency range is tightly allocated from 3.1 to 10.6 GHz according to FCC rules. High data rate, immune to multipath fading, and low power consumption are some of the advantages of UWB communication [1].

As UWB communication falls within the 3.1 to 10.6 GHz frequency band, within this range there also exist some narrow frequency bands such as WiMAX and WLAN frequency bands. As WLAN frequency range is fixed from 5–6 GHz all over the world while the WiMAX band varies from country to country, ranging from 3 to 4 GHz, we need an antenna that has the capability to operate in the UWB frequency range but continuously tunable in the WiMAX frequency range of 3–4 GHz and having fixed WLAN rejection band in WLAN frequency band. This antenna will help to minimize the jamming effect on UWB communication by filtering these narrow frequency bands, accordingly.

Typically, the signal having interference fluctuates with the spatiotemporal setup of the environment. So, in terms of the rejected or notched bands, the tuneability is one of the important characteristics that must be introduced in order to completely reduce this unwanted interference. As the bias voltage of the varactor diode can be changed by changing the capacitance, which provides the tunability of the rejected bands, generally, some sort of resonators or matching network is loaded with varactor diodes to tune the rejected band, continuously [2, 3]. However, this technique requires much more space on the circuit so as to decrease the possibility of multi-rejection bands. This makes the technique limited to single band-notched antennas.

Also, different tunable antennas having filtering capabilities are also proposed in [4–10]. The tuning is performed using the microelectromechanical switches (MEMS), PIN diodes, stepper motors, shorting circuits, and optically controlled switches. As they have used switches in the design, they simply need to be swapped between their ON and OFF statuses. Most recently, a continuously tunable band-notched UWB antenna that has the capability to notch the WiMAX and WLAN bands has been proposed

Received 8 January 2018, Accepted 7 February 2018, Scheduled 2 May 2018
* Corresponding author: Mahdi Naghshvarianjahromi (naghshvm@mcmaster.ca).
[1] Department of Electrical Engineering, Islamic Azad University, South Tehran Branch and Shahid Sattary Aeronautical 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.

in [11]. They introduce the lumped elements within the structure of the antenna to control the notch bands by controlling the value of the lumped elements. By changing the capacitor value, the WLAN frequency band can be adjusted properly having fixed WiMAX frequency band. Also, when the value of the capacitor increases, then the performance of filtering degrades continuously in the WLAN frequency range.

Also, the demand for fixed frequency band antennas has been decreasing because of the lack of flexibility to accommodate new services. In this regard, researchers have tried to integrate multiple wireless standards in a single platform by designing reconfigurable antennas [12]. Similarly, a frequency tunable antenna to generate two frequency bands for WiMAX operation is presented in [13]. The antenna operates in fixed 2.4 GHz frequency band with continuously tunable operating band within 3.3–3.8 GHz.

Recently, a novel tunable monopole antenna with a switchable integrated feed network for UWB and WLAN (2.4 GHz and 5.8 GHz) has been proposed in [14]. The frequency reconfiguration is realized by integrating two bandpass filters with a UWB antenna circuit. Ref. [15] 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 a 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 $38 \times 40\,\mathrm{mm}^2$.

In this paper, we propose a CPW-fed UWB antenna that has fixed WLAN band and continuously tunable WiMAX notched-frequency band. The WiMAX band can be easily tuned properly in 3–4 GHz frequency range depending on the location and application requirements. Also, the implemented resonator has occupied a very small size as compared to other reported designed resonators. Moreover, the proposed antenna has a very clean radiation pattern in both E- and H-planes due to the placement of resonator in the ground plane.

2. THE GEOMETRY OF THE PROPOSED ANTENNA

The proposed antenna is designed, and the dimensions of the proposed antenna are shown in Figure 1. The proposed antenna is also fabricated, and the fabricated monograph is shown in Figure 2. The dimensions of the proposed antenna are also shown in Table 1. The antenna is designed 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 $30 \times 31\,\mathrm{mm}^2$ (i.e., $w_1 \times l_1$). For WLAN band-notching the resonator is introduced in radiating element and is fixed, while for WiMAX band notching the resonator is introduced at the partial ground plane with two variable symmetrical capacitors. The capacitors are responsible for continuous tuning in 3–4 GHz frequency range.

For the initial choice of the resonator placed at the radiating patch, the design equation implemented at a desired notched band frequency f_{notch} (5.5 GHz) can be calculated as:

$$W_3 + W_6 + 2(l_2 + l_{11}) = \frac{c}{2 f_{notch} \sqrt{\varepsilon_{eff}}} \tag{1}$$

where,

$$\varepsilon_{eff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left(1 + \frac{12h}{w_f}\right)^{-0.5} \tag{2}$$

For the initial choice of the resonator placed at the partial ground plane for rejecting the WiMAX frequency band it is also selected and optimized using the quarter wavelength for 3.9 GHz. Two symmetrical capacitors are placed between the resonator sections in order to achieve reconfigurability within 3–4 GHz. When there are no capacitors, and the designed resonator sections are connected, the antenna operates at the designed resonance frequency of 3.9 GHz. As the capacitors are placed between the corresponding resonator sections, it is clear from Figure 3 that at a very small capacitor value the notched band is shifting towards 3 GHz while for 0.5 pF capacitor, the notch frequency is shifted to 2.5 GHz frequency band.

Table 1. Dimensions of the proposed antenna (All values are in mm).

Parameter	Value	Parameter	Value	Parameter	Value	Parameter	Value
W_1	30	W_7	1	L_1	31	L_9	3
W_2	15	W_8	2.40	L_2	6.5	L_{10}	0.61
W_3	9	W_9	3.2	L_5	8	L_{11}	1.5
W_4	13.59	W_{10}	2.4	L_6	4	G_1	0.5
W_5	3	L	6.5	L_7	1.98	$G_2 = G_3$	0.6
W_6	2	R	8	L_8	1.8	$G_4 = G_5 = G_6$	0.2

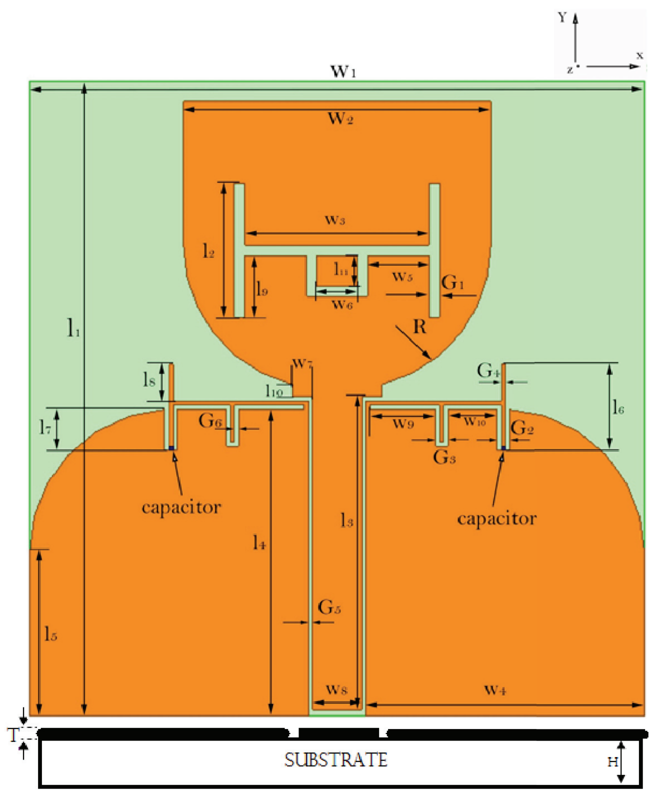

Figure 1. Geometry of the proposed antenna with dimensions.

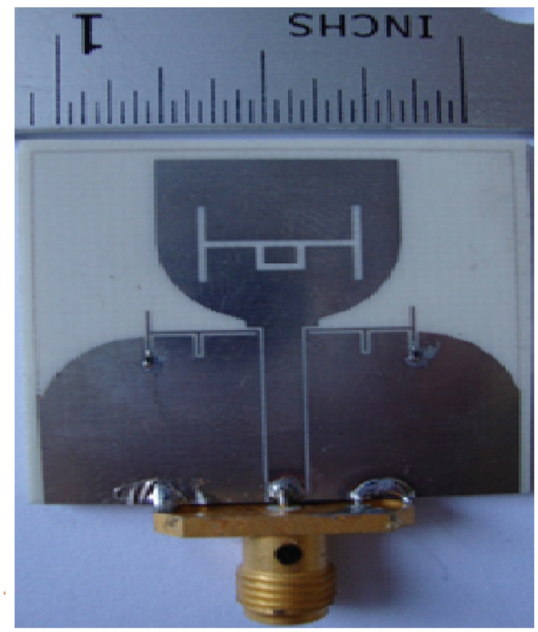

Figure 2. Fabricated monograph of the proposed antenna.

3. SIMULATION

The antenna has been simulated in Ansoft HFSS, and the corresponding S-parameters are obtained at a different value of capacitors. It is clear from Figure 3 that antenna rejects the WLAN and WiMAX frequency bands with fixed WLAN notched band and tunable WiMAX notched band. Also, it can be seen from Figure 3 that increasing the capacitor value from 0.02 pF to 0.1 pF shifts the notch band from 4 to 3.2 GHz. Compared to [9] the tuning shift is very large and can be tuned to a wide range of frequency band. It is also advantageous that we can shift the rejection band to 2-3 GHz just by increasing the capacitor value to 0.5 pF as shown in Figures 8 and 9.

The VSWR plot of the proposed antenna at different values of the capacitors is also shown in Figure 4. It validates that the antenna has the capability of rejecting fixed WLAN frequency band and continuously tunable rejection band within the frequency range of 3–4 GHz just by changing the capacitor value from 0.02 pF to 0.1 pF.

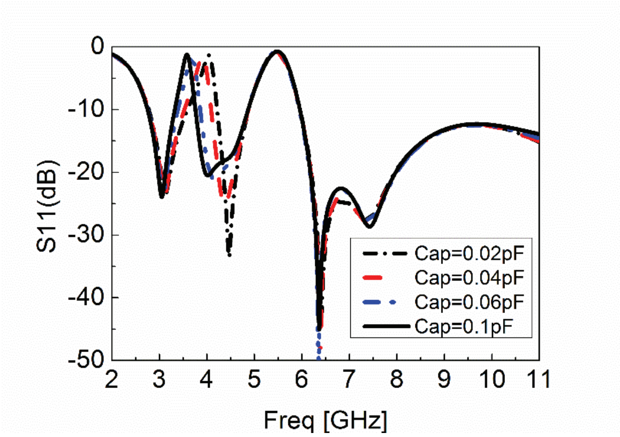

Figure 3. Simulated frequency response of the proposed antenna at different capacitor values.

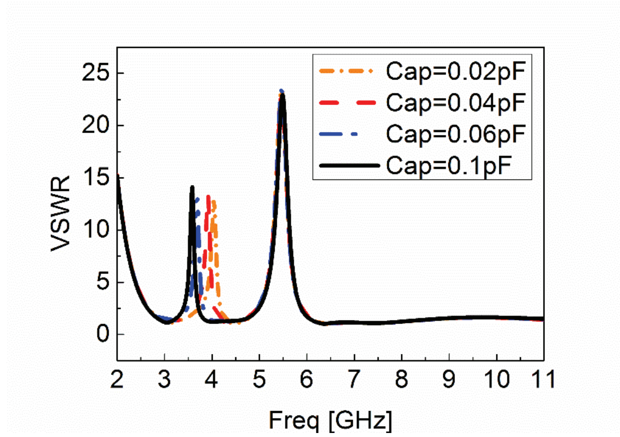

Figure 4. Simulated VSWR of the proposed antenna at different capacitor values.

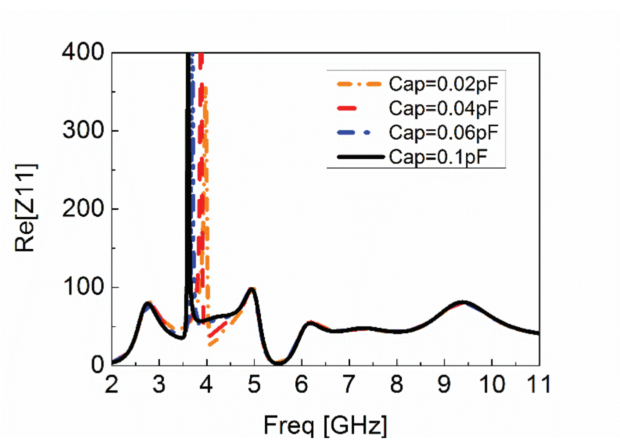

Figure 5. Simulated Impedance Response Re[Z11] of the proposed antenna at different values of capacitors.

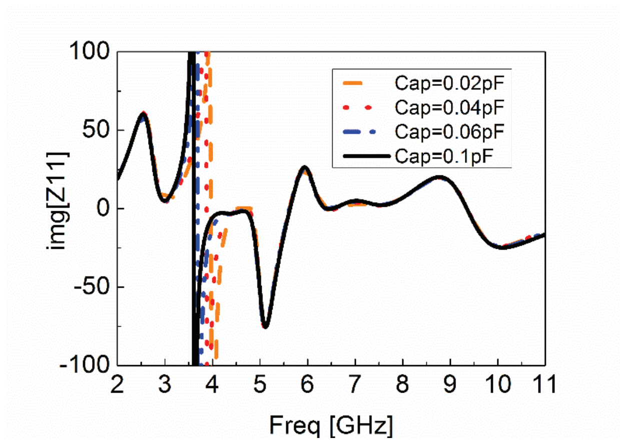

Figure 6. Simulated Impedance Response IMG[Z11] of the proposed antenna at different values of capacitors.

The Real and Imaginary [Z11] vs. frequency plots are also shown in Figure 5 and Figure 6, respectively. It has been seen that the antenna input impedance at the filtering bands becomes maximum while its input reactance almost vanishes. By changing the capacitor values from 0.02 pF to 0.1 pF the notched band at WiMAX range is shifted to lower frequencies while the WLAN notched bands is fixed at all values. These properties also confirm the continuous tuning of WiMAX notched bands in the UWB frequency range.

The antenna WiMAX tuning can be furthermore visualized from the antenna gain vs. frequency plot as shown in Figure 7. The gain plot reveals that antenna gain suppression is shifted from 4 to 3 GHz as the value of the capacitor is increased. It also shows that when capacitor value further increases up to 0.5 pF, the suppression effect is shifted to 2–3 GHz frequency range. The reason for the suppression is that at these frequencies the destructive interference takes place, thus validating the filtering effect.

The radiation patterns of the proposed antenna at different frequencies including 3.2, 4.1, 7.2 and 9.5 GHz are shown in Figure 8. These frequencies almost cover the lower, middle and higher frequency ranges of the UWB band. Because of symmetry and flatness, clean radiation patterns are obtained for the four different frequency bands that display a monopole type of radiation at selected frequencies.

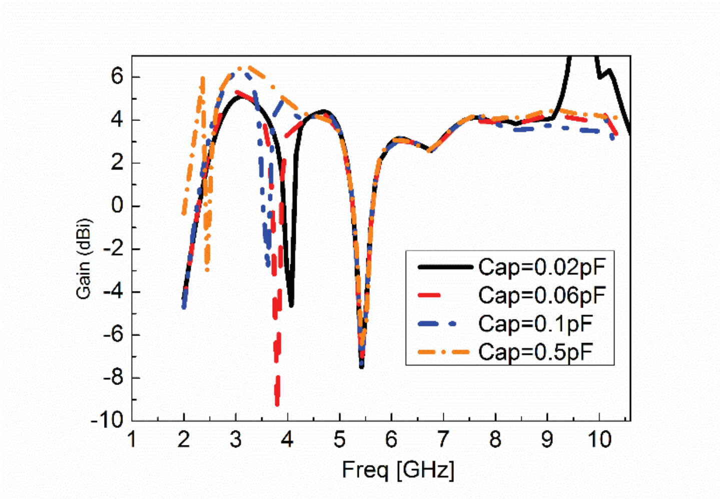

Figure 7. Gain of the proposed antenna at different values of capacitors.

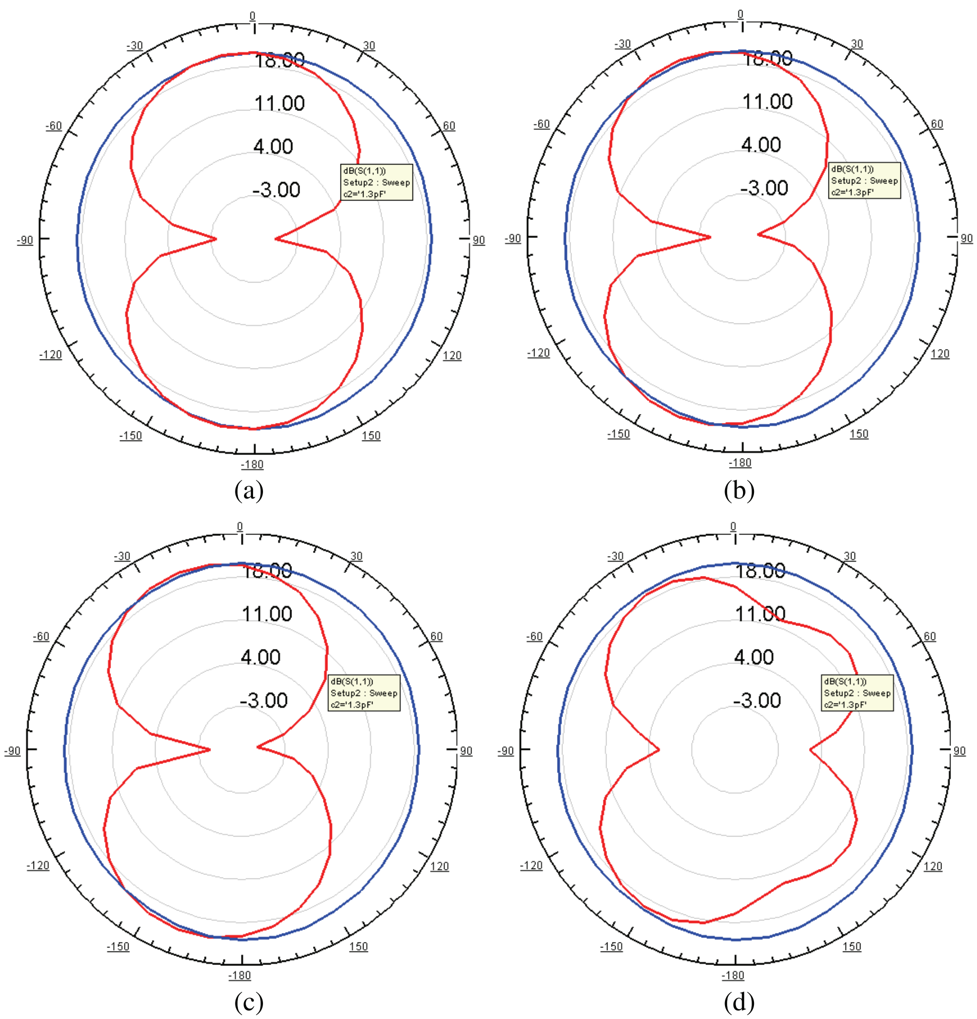

Figure 8. E-plane and H-plane of the proposed antenna (Red-Line) E-plane and (Blue-line) H-plane (a) 3.9 GHz (b) 4.8 GHz (c) 7.8 GHz (d) 8.7 GHz.

4. MEASUREMENTS

The simulations and measurement are accomplished by Ansoft^{TM} HFSS and Keysight^{TM} N5224A network analyzer, respectively. Figure 9 and Figure 10 show the measured vs. simulated frequency responses of the proposed antenna at 0.1 pF and 0.5 pF, respectively. The combined plot of the simulated and measured responses is shown in Figure 11, which indicates that we can shift the notched band from 2 to 4 GHz just by changing the capacitor value from 0.5 pF to 0.1 pF. As can be seen from the plot, at a higher value of the capacitor such as 0.5 pF the measurement response degrades because of parasitic effects. However, the proposed technique is widely valid for the continues tuning of the antenna within 3–4 GHz. The measurement at 0.5 pF is done to show that the notch band still exists, but shifted to lower frequencies. The aim of the proposed antenna is to continuously tune the reject band within 3–4 GHz frequency band.

It is also observed that the notched band happens at the band rejection between 2 and 3 GHz frequency range at 0.5 pF, which validates that a shift in the frequency tuning of the lower notch band is maximum as compared to other state of the art designs in the literature [7–11]. The empirical formula for the notched bands can thus be calculated by Equation (3):

$$f_{notch} = \frac{1}{2\pi\sqrt{L_{eff} \cdot C_{eff}}} \tag{3}$$

As can be seen, increasing the length of the slot resonator shifts the notch bands towards the lower frequency, so as the capacitor value. Because when the value of the capacitor increases it in turn increases the effective permittivity which in turn shifts the notched bands towards the lower frequency range.

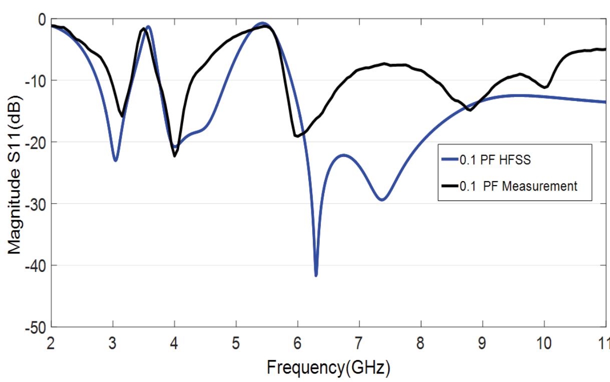

Figure 9. Simulated vs. Measured Response of the proposed antenna at capacitor value = 0.1 pF.

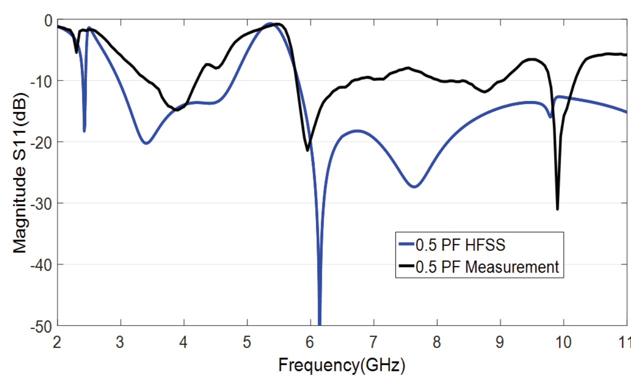

Figure 10. Simulated vs. Measured Response of the proposed antenna at capacitor value = 0.5 pF.

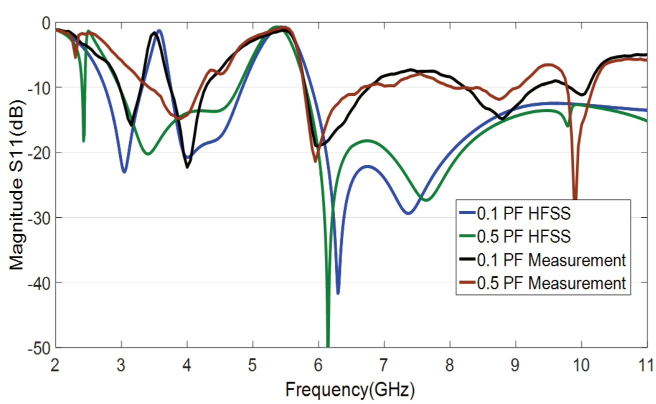

Figure 11. Simulated vs. Measured Response of the proposed antenna at 0.1 and 0.5 pF.

5. CONCLUSION

A CPW-fed UWB antenna having fixed WLAN rejection band and continuously tunable WiMAX notched band has been presented. The continuous tuning of the notched band is achieved with the help of a novel miniaturized resonator and capacitors placed at the ground plane. The notched band successfully resonates between the 3–4 GHz frequency band and can be used location and application wise. This antenna will pave the way to be used for UWB wireless communication applications irrespective of location and without any jamming effect.

REFERENCES

1. Anon, "FCC first report and order on ultra-wideband technology," FCC 802 Standards Notes, Feb. 2002.
2. Li, T., H. Zhai, L. Li, C. Liang, and Y. Han, "Compact UWB antenna with tunable band-notched characteristic based on microstrip open-loop resonator," *IEEE Antennas Wireless Propag. Lett.*, Vol. 11, 1584–1587, 2012.
3. Jeong, W.-S., S.-Y. Lee, W.-G. Lim, H. Lim, and J.-W. Yu, "Tunable band-notched ultra wideband (UWB) planar monopole antennas using varactor," *38th European, Microwave Conference, EuMC2008*, 2662268, Amsterdam, Holland, Oct. 27–31, 2008.
4. Antonino-Daviu, E., M. Cabedo-Fabres, M. Ferrando-Bataller, and A. Vila-Jimenez, "Active UWB antenna with tunable band-notched behaviour," *Electron. Lett.*, Vol. 43, No. 18, 959–960, Aug. 2007.
5. Hu, Z. H., P. S. Hall, J. R. Kelly, and P. Gardner, "UWB pyramidal monopole antenna with wide tunable band-notched behaviour," *Electron. Lett.*, Vol. 46, No. 24, 1588–1590, Nov. 2010.
6. Antonino-Daviu, E., M. Cabedo-Fabres, M. Ferrando-Bataller, and V. M. R. Penarrocha, "Modal analysis and design of band-notched UWB planar monopole antennas," *IEEE Transactions on Antennas and Propagation*, Vol. 58, No. 5, 1457–1467, May 2010.
7. Li, T., H. Zhai, L. Li, C. Liang, and Y. Han, "Compact UWB antenna with tunable band-notched characteristic based on microstrip open-loop resonator," *IEEE Antennas Wireless Propag. Lett.*, Vol. 11, 1584–1587, 2012.
8. Elfergani, I. T. E., R. A. Abd-Alhameed, C. H. See, S. M. R. Jones, and P. S. Excell, "A compact design of tunable band-notched ultrawideband antenna," *Microw. Opt. Technol. Lett.*, Vol. 54, No. 7, 1642–1644, Jul. 2012.
9. Loizeau, S. and A. Sibille, "Reconfigurable ultra-wide band monopole antenna with a continuously tunable band notch," *IET Microw., Antennas Propag.*, Vol. 8, No. 5, 346–350, Apr. 2014.
10. Nouri, M. and S. A. Aghdam, "Reconfigurable UWB antenna with electrically control for triple on-demand rejection bandwidth," *Microw. Opt. Technol. Lett.*, Vol. 57, No. 8, 1894–1897, Aug. 2015.
11. Tang, M. C., H. Wang, T. Deng, and R. W. Ziolkowski, "Compact planar ultrawideband antennas with continuously tunable, independent band-notched filters," *IEEE Transactions on Antennas and Propagation*, Vol. 64, No. 8, 3292–3301, 2016.
12. Yang, S., C. Zhang, H. Pan, A. Fathy, and V. Nair, "Frequency reconfigurable antennas for multiradio wireless platforms," *IEEE Microw. Mag.*, Vol. 10, No. 1, 66–83, Feb. 2009.
13. Sun, X. L., S. W. Cheung, and T. I. Yuk, "Dual-band monopole antenna with frequency-tunable feature for WiMAX applications," *IEEE Antennas and Wireless Propagation Letters*, Vol. 12, 100–103, 2013.
14. "Wideband-to-narrowband tunable monopole antenna with integrated bandpass filters for UWB/WLAN applications," *IEEE Antennas and Wireless Propagation Letters*, Vol. 16, 2734–2737, 2017.
15. Deng, J., S. Hou, L. Zhao, and L. Guo, "A reconfigurable filtering antenna with integrated bandpass filters for UWB/WLAN applications," *IEEE Transactions on Antennas and Propagation*, Vol. 66, No. 1, 401–404, 2018.