Progress In Electromagnetics Research C, Vol. 79, 79–88, 2017

Recon UWB Antenna for Cognitive Radio

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Abstract—This paper talks about a simple printed reconfigurable antenna for cognitive radio. This antenna can be switched between ultra-wideband (UWB) and two other narrow bands. To achieve frequency reconfigurability, horizontal slots are inserted in the partial ground plane, and their lengths are varied by using ideal switches. These switches are incorporated so that they can be turned ON/OFF independently. The proposed antenna is suitable for cognitive radio as it is capable of sensing whole UWB from 3.1 GHz to 10.6 GHz (7.5 GHz bandwidth) and switching between two different narrow bands viz. 3.1 GHz and 8.23 GHz, and the corresponding observed gain and radiation pattern are also as per the requirement.

1. INTRODUCTION

Cognitive radio (CR), unlike conventional radio communication systems, can change its parameters such as carrier frequency, modulation or transmit power when interacts with environment which detects unused spectrum holes and provides reliable communication [1]. It helps to maintain the efficient utilization of scarce radio spectrum. Cognitive radio requires a UWB antenna with omnidirectional radiation pattern for spectrum sensing and narrow-band antenna for operation. Both of these requirements can be fulfilled by a single antenna, if it is made reconfigurable. An antenna is called reconfigurable if it can vary parameters such as frequency band, polarization and radiation pattern in accordance with the environmental conditions. This change is achieved by many techniques that redistribute the antenna currents and thus alter the EM fields of the antenna's effective aperture [2]. Reconfigurable Antennas (RAs) can be used to simplify the RF front end design of the cognitive radio system. As UWB technology is less expensive, capable of handling higher data rates and requires less power, it has attracted attention from both industry and academia. Signals with large relative bandwidth or absolute bandwidth are usually known as UWB signals. The operation of UWB spectrum from 3.1 GHz to 10.6 GHz was approved by the Federal Communications Commission (FCC) in 2002 [3]. A radio transmission technology covering a wider bandwidth (minimum 500 MHz) or having at least 20% of center frequency is known as UWB technique. As per FCC rules, UWB communication devices can be operated at low power, i.e., with an EIRP of −41.38 dBm/MHz in UWB spectrum [4]. To avoid unwanted interference to licensed users, these UWB devices have been restricted with low emission limits.

There are several ways to implement RA in CR systems. In order to communicate among multiple pre-defined frequency bands, one way is using single antenna to sense and communicate by reconfiguring the UWB antenna to multiple narrow-bands. Various designs of reconfigurable UWB antennas have been successfully implemented. For reconfiguration of UWB antennas to multiband, in literature major work has been done with ideal switches [5] and active switches comprising PIN diodes [6, 7] and FET switches [8].

Received 3 July 2017, Accepted 9 October 2017, Scheduled 25 October 2017
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The proposed antenna uses a circular patch as a radiator because it is easier to design and simple to manufacture. Also, when designed as a monopole radiator, it provides larger bandwidth than various other shaped monopoles [9]. The ideal switches are used for length variation of the horizontal slots incorporated in ground plane to achieve frequency reconfigurability. Current distribution changes, as the length of the slots changes, which further leads to change in the operating frequency. The antenna is simple, compact, and most importantly, radiation patterns remain almost unchanged while switching from UWB mode to the reconfigurable mode.

Rest of the paper is structured as follows. Section 2 contains the UWB antenna design with effect of different parameters on its performance and design of proposed recon UWB antenna. In Section 3, the antenna performance is investigated by comparing the results obtained from simulation and measurement.

2. ANTENNA DESIGN AND PERFORMANCE

Prior to designing a frequency reconfigurable UWB antenna, a simple UWB antenna is designed, and effect of important parameters on the antenna performance is studied. Figure 1 shows a simple UWB antenna geometry. A circular shaped patch (disc) of radius R and a $50\,\Omega$ microstrip feed line of width W_f is etched on top side of the dielectric substrate. The low cost FR4 substrate with thickness of 1.52 mm, relative permittivity $\epsilon_r = 4.4$ and loss tangent of 0.019 is used in this study. A partial ground plane of length L_g is printed on bottom side of the substrate. The length of feedline is $L_g + g$, where 'g' is the length of gap between the circular patch and the ground plane. A slot of dimension $L \times W$ is incorporated in the ground plane just below the feedline in order to achieve good antenna performance at higher frequency. Table 1 displays the dimensions of a simple UWB antenna.

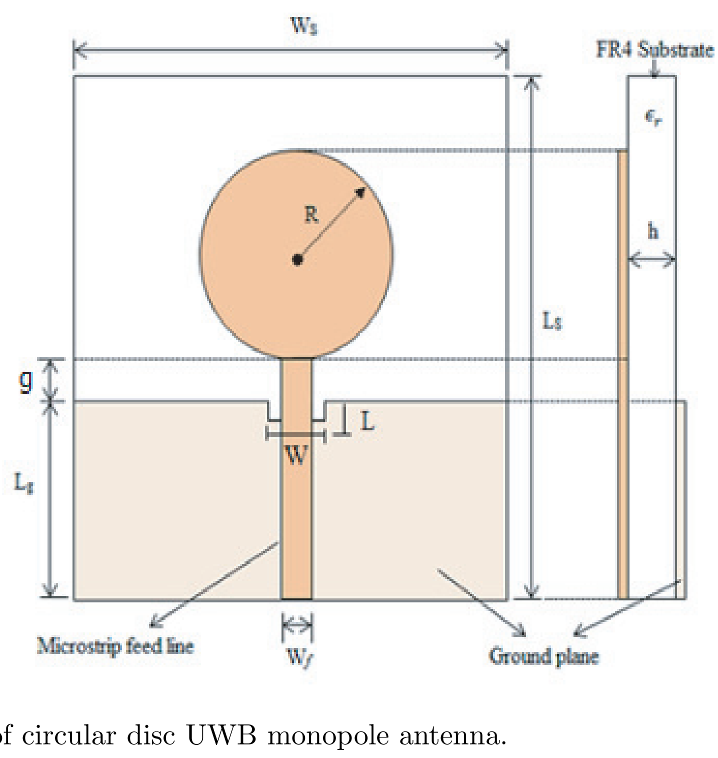


Figure 1. Geometry of circular disc UWB monopole antenna.

As circular patch is used as a radiator, there is only one degree of freedom to control the antenna performance which will keep the order of modes unchanged even with the varying radius, but can change the absolute value of the resonant frequency of each mode [10]. The circular patch supports closely spaced overlapping multiple resonant modes, with the higher order modes being the harmonics of a fundamental mode of the circular patch thus giving UWB characteristics.

Table 1. Dimensions of a simple UWB antenna.

Parameter	Values (mm)	Parameter	Values (mm)
L_S	50	W_f	2.6
W_S	42	L_g	20
R	10	$L \times W$	2×4

The simulated reflection coefficient curves for different values of feed gaps (g = 0.3, 0.6, 0.9 and 1 mm) and the other dimensions as mentioned in Table 1 are shown in Figure 2. It is observed that the −10 dB reflection coefficient bandwidth varies remarkably with the feed gap 'g' variation. At higher frequency, the impedance mismatch is observed when 'g' is greater than 0.6 mm leading to violation of UWB characteristics. Thus, the optimal gap where the operating bandwidth remains in the UWB range is found to be 0.3–0.6 mm.

To investigate the effect of ground plane on the antenna performance, its length (L_g) and width (W_g) are varied. Figure 3 shows curves of simulated reflection coefficient when length L_g (L_g = 18, 19, 20 and 21 mm) is varied. As L_g is reduced, the −10 dB reflection bandwidth is also decreased by small amount. The optimal value of length of ground plane (L_g), obtained for achieving ultra-wide bandwidth is 20 mm. The antenna performance is not significantly affected for values of L_g greater than 20 mm. Figure 4 illustrates the effect of W_g on antenna performance where the simulated reflection coefficient is plotted for various values of W_g (W_g = 10, 20, 30 and 40 mm). The −10 dB reflection bandwidth decreases as W_g is decreased from 42 mm. Hence variation of W_g is observed to have a dominating effect on reflection bandwidth whereas L_g does not affect severely after certain value.

The plot of reflection coefficient curves for different values of radius of circular patch (R = 8, 9, 10 and 12 mm) is shown in Figure 5. As R increases, the first resonant frequency decreases which reduces the lower cutoff frequency which in turn controls the bandwidth. In addition, it is observed that when the radius of circular patch is fixed at 10 mm, the first resonance always occurs at around 3 GHz irrespective of the feed gaps and the dimensions of the ground plane. This implies that the radius of circular patch mainly controls the first resonance while the ground plane, feed gap and feed location determine the impedance matching.

Figure 6 shows the geometry of the proposed frequency reconfigurable UWB monopole antenna. The optimized dimensions used to design this antenna are shown in Table 1. Additional horizontal slots

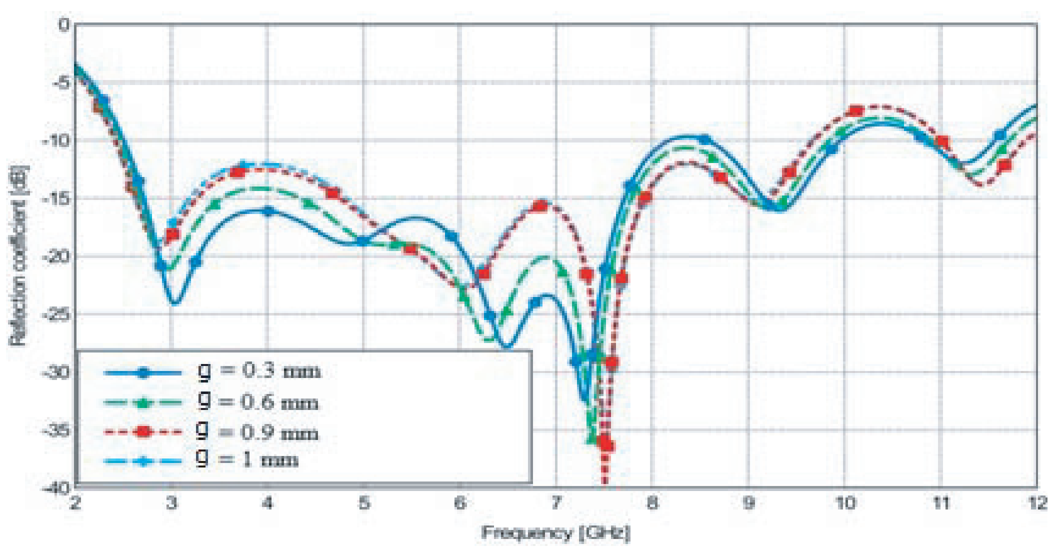


Figure 2. Simulated reflection coefficient curves for a simple UWB antenna for different values of feed gap.

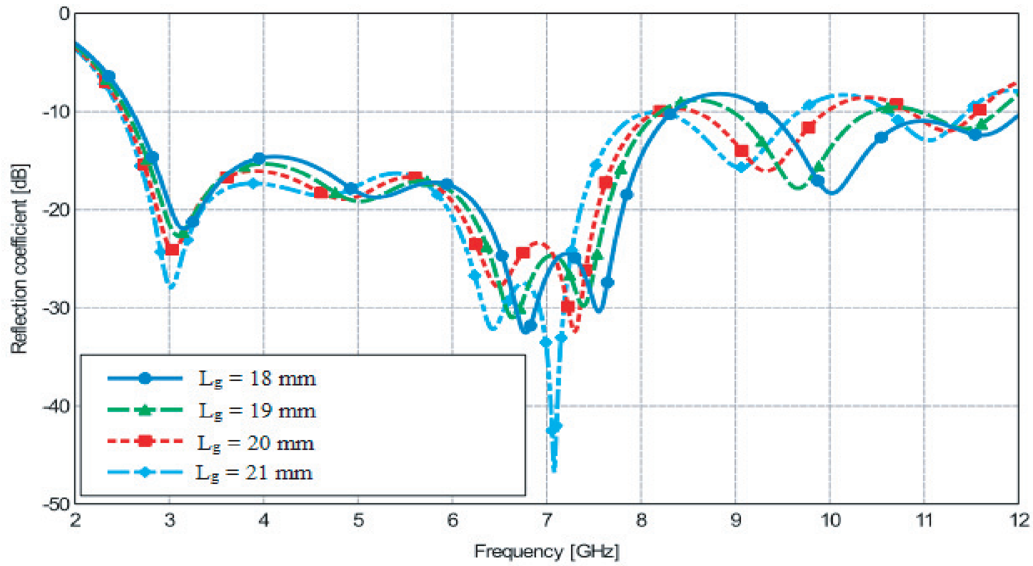


Figure 3. Simulated reflection coefficient curves for a simple UWB monopole for various values of L_g.

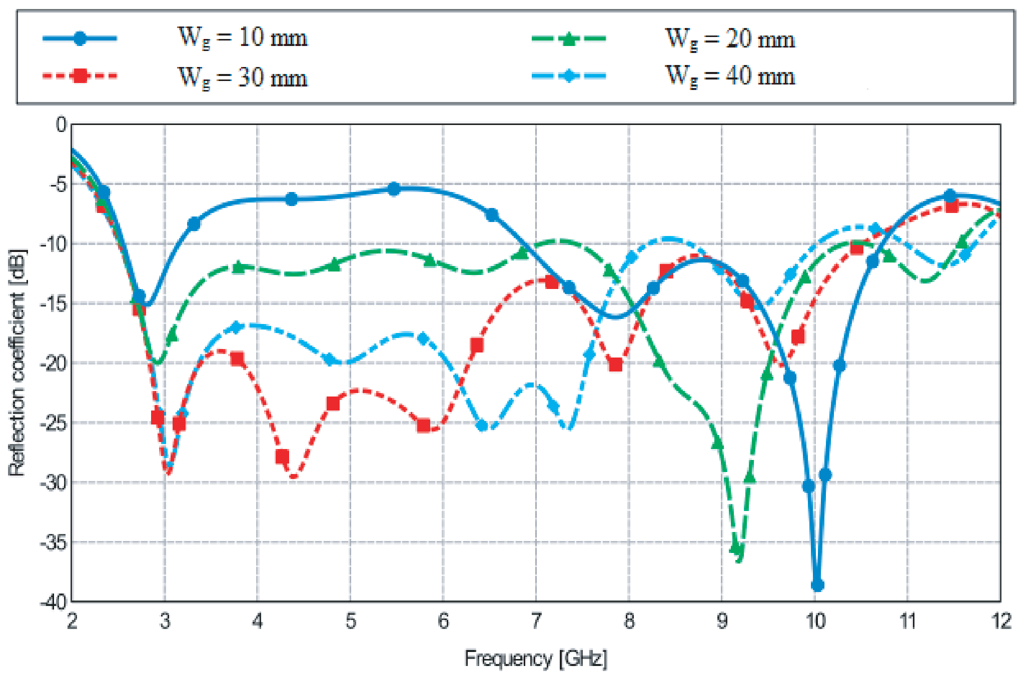


Figure 4. Reflection coefficient versus frequency curves for a simple UWB monopole for various values of W_g.

are inserted in ground plane with three ideal switches in order to achieve good UWB performance and two narrow bands. Three ideal switches S_1, S_2 and S_3 (metal pads with dimension of $2\,\text{mm} \times 1.5\,\text{mm}$) are used to change the length of the horizontal slot placed in ground plane. The frequency bands of interest are obtained by properly choosing the length of the horizontal slot by means of the position of switches. When switches are ON, the length of the slot decreases and vice versa.

The proposed antenna prototype is fabricated in order to validate the antenna performance and shown in Figure 7. Although the proposed antenna uses ideal switches, it provides a good approximation

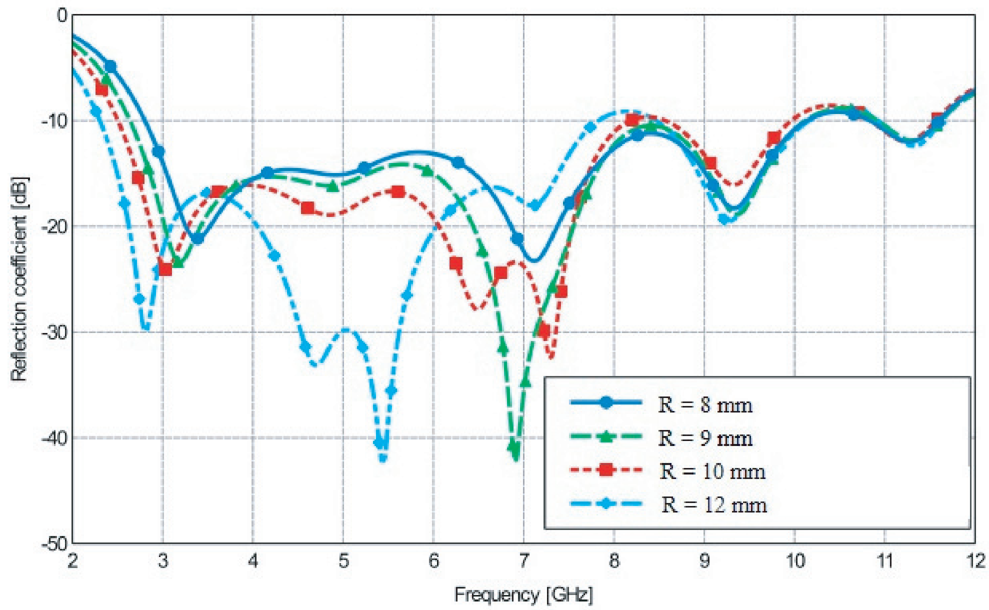


Figure 5. Reflection coefficient curves for various values of R.

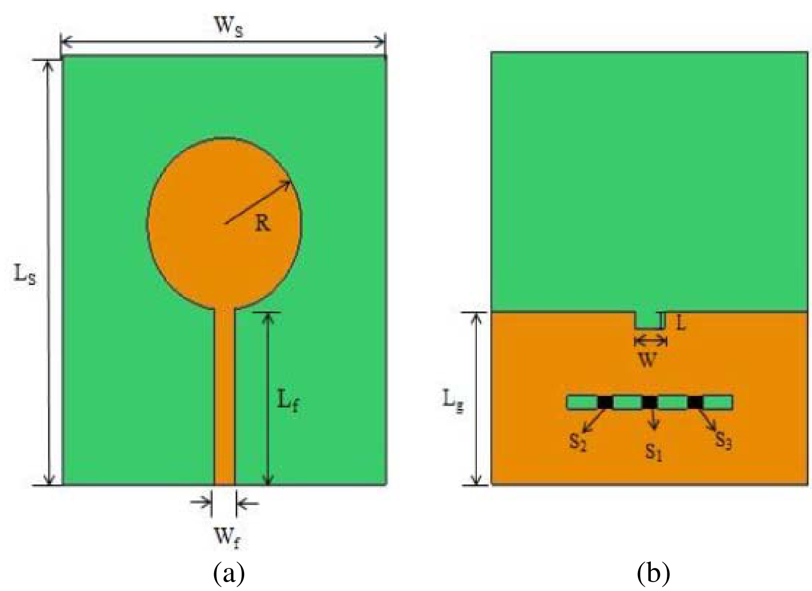


Figure 6. Geometry of proposed frequency recon UWB Antenna. (a) Top view. (b) Bottom view.

for the commercially used PIN diodes. Also, the GaAs FETs or MEMS technology can be used to realise RF switches. Using three ideal switches we have investigated one UWB (3.1 GHz–10.6 GHz) case and two reconfigurable cases viz. narrow band I (3.1 GHz) and narrow band II (8.23 GHz).

3. EXPERIMENTAL INVESTIGATION

The simulations and performance optimization of the proposed antenna are carried out in Altair's Computer Aided Design Package CADFEKO. Depending on the status of ideal switches, different cases of antenna operation are obtained viz. UWB operation, Reconfigurable Operation (3.1 GHz and 8.23 GHz).

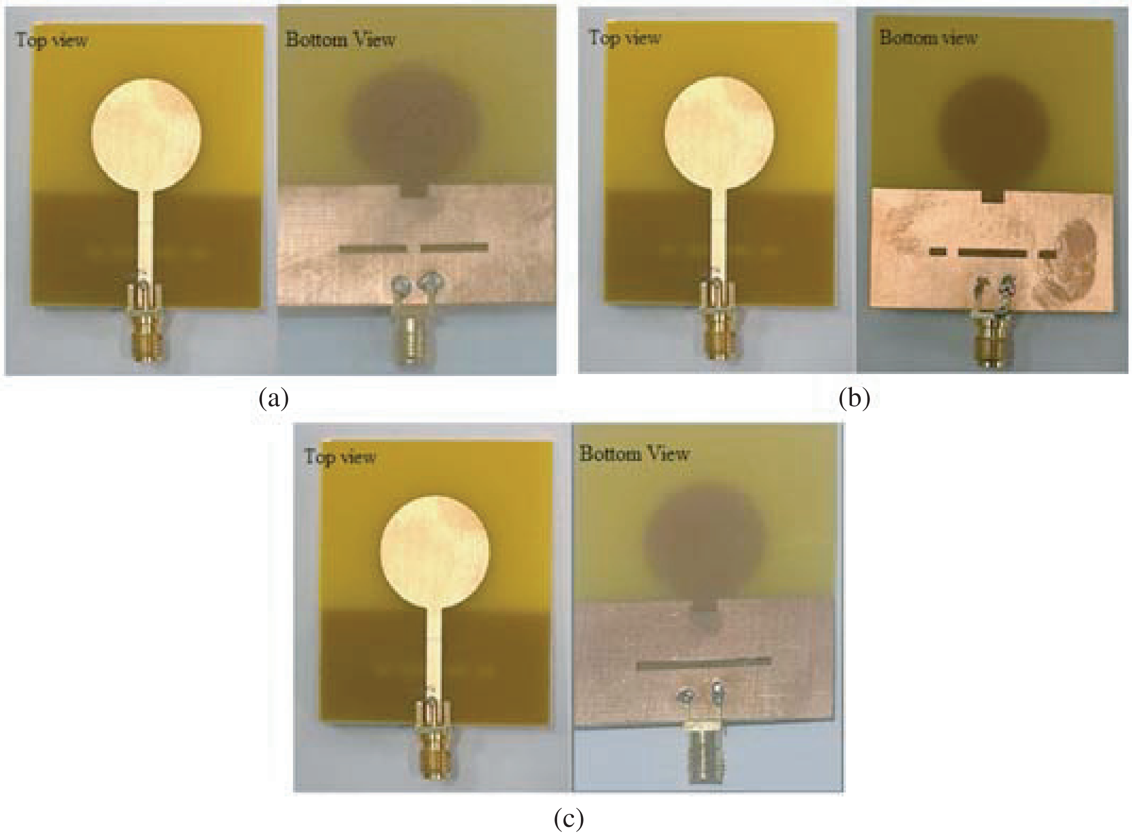


Figure 7. Fabricated prototype frequency reconfigurable UWB Antenna. (a) UWB. (b) Narrow Band I (3.1 GHz). (c) Narrow Band II (8.23 GHz).

3.1. UWB Operation

When switch S_1 is ON, and S_2 and S_3 are OFF, the proposed antenna functions as a UWB antenna operating over frequency range of 3.1 GHz–10.6 GHz which will be used for scanning the entire UWB spectrum in order to check the presence of spectrum holes. As S_1 is ON, and other two switches are OFF, the horizontal slot gets divided into two equal slots placed symmetrically along the centre of the antenna with each horizontal slot having a dimension of 10 mm × 1.5 mm giving UWB characteristics. Basically, the gain and efficiency of UWB antenna are important along with the impedance bandwidth. It is expected to have an omnidirectional pattern for UWB antenna.

The simulated and measured reflection coefficient curves for the UWB antenna are shown in Figure 8, given below. The simulated −10 dB reflection bandwidth of 9.10 GHz, i.e., from 2.55 GHz to 11.65 GHz, is obtained, while measured bandwidth is 8.8 GHz, i.e., from 2.62 GHz to 11.50 GHz. Maximum observed gain in this case is 2.48 dBi. The simulated and measured results are found in good agreement. A little deviation is observed because of fabrication error and SMA connector which acts as a scatter.

3.2. Frequency Reconfigurable Antenna Operation

In order to achieve reconfigurability, the length of the horizontal slots in the ground plane is varied by turning the ideal switches ON/OFF which in turn changes the current distribution and hence the frequency of operation. The idea behind making horizontal slots in ground plane is to use them as a filter which will allow frequency of interest and suppress remaining frequencies.

1) *Narrow Band I (3.1 GHz):* To design a reconfigurable antenna to operate at 3.1 GHz, switch S_1 is OFF, and switches S_2 and S_3 are turned ON. As two switches are ON, three horizontal slots are

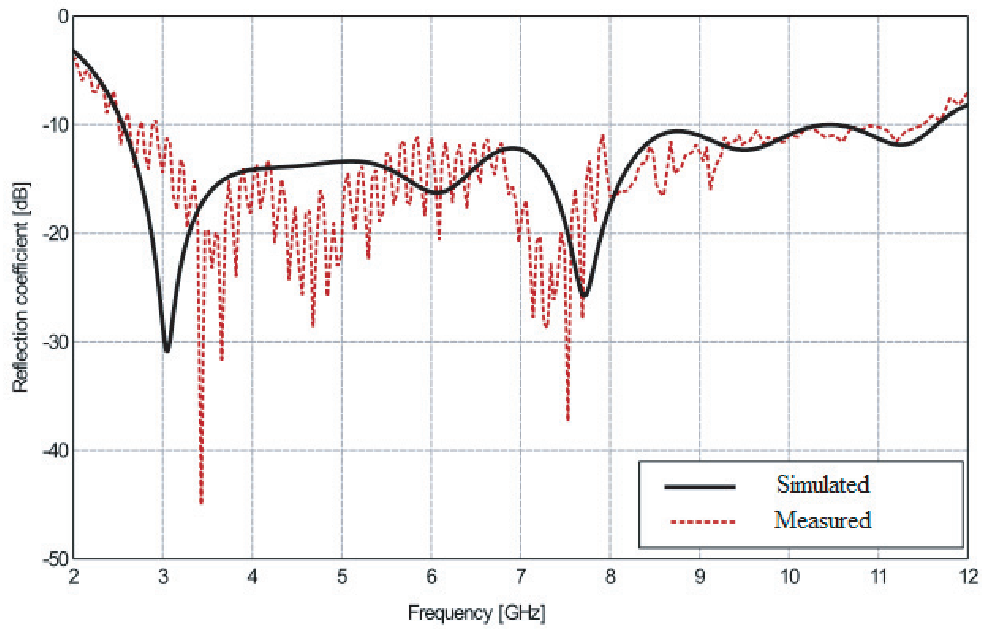


Figure 8. Reflection coefficient curves for frequency recon UWB antenna when operating as UWB.

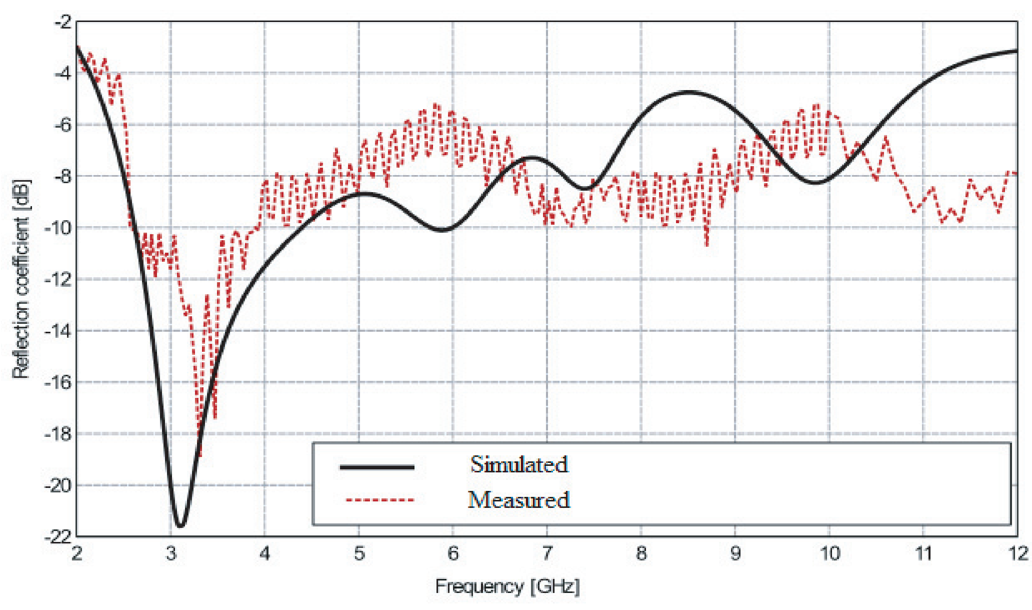


Figure 9. Reflection coefficient curves when antenna configured as narrow band antenna operating at 3.1 GHz (Narrow Band I).

created in the ground plane which leads to a narrow band operating at 3.1 GHz. The simulated and measured reflection coefficient curves of this RA are shown in Figure 9. The simulated −10 dB reflection bandwidth obtained is 1.78 GHz covering 2.61–4.39 GHz band, with the measured reflection bandwidth of 1.37 GHz covering 2.58–3.95 GHz band. Figure 11(a) shows the simulated surface current distribution of proposed antenna at resonant frequency 3.1 GHz for narrow band I. Most of the current is distributed along the patch edge, indicating that the circular patch dimension is associated with the first resonant frequency (f_r). On the ground plane, the current is majorly distributed on an upper edge parallel to horizontal slots, which indicates that the upper portion of the ground plane adjacent to patch acts as a part of the radiating structure.

2) *Narrow Band II (8.23 GHz):* To design a RA to operate at 8.23 GHz, all the three switches are kept in OFF state. Thus, a horizontal slot of dimension 22 mm × 1.5 mm is created in the ground plane which leads to narrow band operating at 8.23 GHz. The simulated and measured reflection bandwidths are 1.96 GHz covering 7.77–9.73 GHz band and 2.05 GHz covering frequency range 7.75–9.8 GHz, respectively. The reflection coefficient curves obtained from simulation and measurement for the reconfigurable antenna operating at 8.23 GHz are illustrated in Figure 10. Figure 11(b) shows the current distribution at resonant frequency 8.23 GHz for narrow band II. There is decrease in the current distribution along the patch edge as well as along the upper edge of ground plane which is parallel to horizontal slots. Also, the current path is altered due to change in the length of horizontal slot which leads to higher resonating frequency.

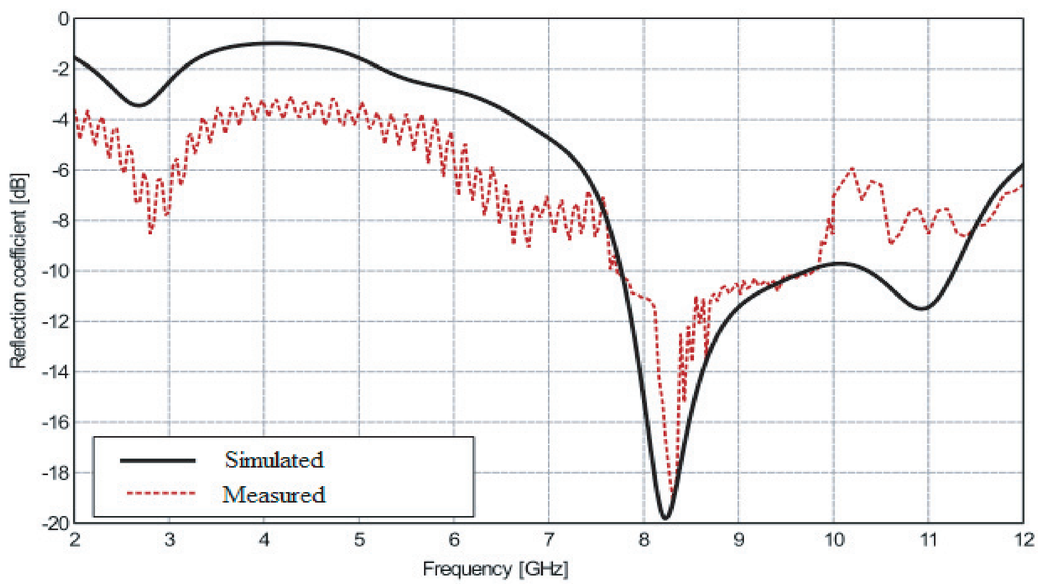


Figure 10. Reflection coefficient curves when antenna configured as narrow band antenna operating at 8.23 GHz (Narrow Band II).

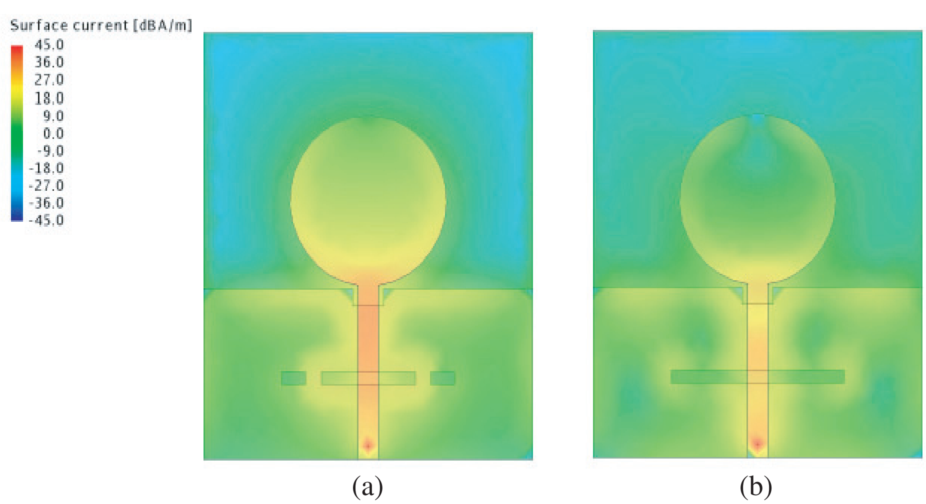
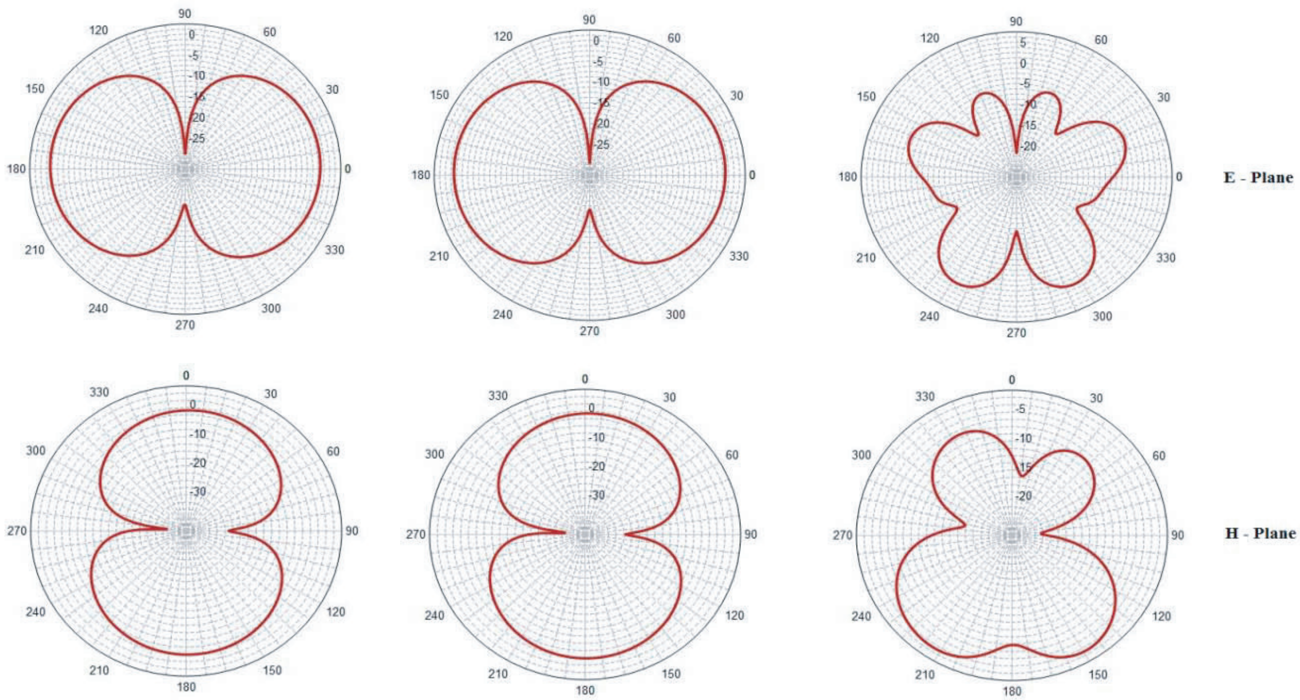


Figure 11. Simulated current distribution of frequency reconfigurable UWB antenna at (a) 3.1 GHz (Narrow Band I), (b) 8.23 GHz (Narrow Band II).



(a) (b) (c)

Figure 12. Normalised E-plane (x-y plane) and H-plane (y-z plane) radiation patterns of proposed antenna at (a) 3.1 GHz (Narrow Band I), (b) 3 GHz (UWB) and (c) 8.23 GHz (Narrow Band II).

Table 2. Different cases with status of switches.

Cases	Case 1 (UWB)		Case 2 (Reconfigurable)			
			Narrow Band I (3.1 GHz)		Narrow Band II (8.23 GHz)	
Switch Status	S_1-ON, S_2 & S_3-OFF		S_1-OFF, S_2 & S_3-ON		S_2-OFF, S_1 & S_3-ON	
	Simulation	Measured	Simulation	Measured	Simulation	Measured
Resonant Frequency (GHz)	-	-	3.1	3.31	8.23	8.3
Bandwidth (GHz)	9.101 GHz	8.88	1.78	1.37	1.96	2.05
Gain (dBi)	2.48	-	2.57	-	3.95	-

3.3. Radiation Pattern and Gain

Figure 12 shows the simulated E-plane and H-plane normalised radiation patterns at different frequencies. The E-plane (x-y plane) radiation pattern of proposed antenna is a donut shape, like a traditional monopole. However, when the frequency increases, the back lobes become smaller, and pattern becomes more directional.

Table 2 investigates the performance of the proposed frequency RA in terms of resonant frequency, bandwidth and gain for a UWB case and two narrowband cases, i.e., narrow band I (3.1 GHz) and narrow band II (8.23 GHz). The RA shows slight increase in the realized peak gain with respect to the UWB.

4. CONCLUSION

A simple compact planar frequency reconfigurable circular patch monopole antenna using ideal switches (metal pads) has been designed, optimized, fabricated and tested. Frequency reconfigurability is incorporated by means of the horizontal slots in the ground plane. The proposed antenna is versatile when various frequency reconfigurable bands are required. The simulated reflection coefficient and radiation patterns are well within the specified limits. The slots used in ground plane to reconfigure the antenna do not affect the original UWB radiation pattern. An antenna when operated in UWB mode provides ultra-wide bandwidth of 9.10 GHz covering frequency band of 2.55 GHz to 11.65 GHz with gain of 2.48 dBi, while in reconfigurable mode it provides bandwidth of 1.78 GHz for narrow band I with gain of 2.57 dBi and the bandwidth of 1.96 GHz for narrow band II with gain of 3.96 dBi.

As of now ideal switches are used to realize the proposed antenna, which can be replaced with practical switches such as PIN diodes or MEMS RF switches. The proposed reconfigurable antenna can be used in cognitive radio or other applications which require switching of frequency bands. Also, the antenna can be used in wireless communication systems like WiMAX and in fixed wireless systems if being used only as narrow band.

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