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A Compact Reconfigurable Dual Band-notched Ultra-wideband Antenna using Varactor Diodes

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Abstract

In this paper, a reconfigurable dual band-notched ultra-wideband (UWB) antenna is presented. The antenna design consists of a circular shape with two pairs of the L-resonator. To realize the notch characteristics in WLAN at 5.2 GHz and 5.8 GHz bands, the half wavelength of the L-resonator is introduced in the design. The T-shaped notch is etched in the ground to enhance the bandwidth which covers the UWB operating frequency range from 3.219–10.863 GHz. The proposed reconfigurable dual band-notched UWB antenna shows good impedance matching for the simulated in the physical layout. Furthermore, the proposed antenna has a compact size of 37.6x28 mm^2. This proposed reconfigurable design can provide an alternative solution for the wireless system in the designing of a band-notched antenna with a good tuning capability.

Keywords: *ultra-wideband (UWB), varactor diode, i-resonator, band-notched*

1. Introduction

"Ultra-Wideband" is referred to as an ultra-operating range of frequencies in microwave engineering range from 3.1 to 10.6 GHz, and its related technique was initially applied for wireless communication system in the past few decades. In 2002, the Federal Communication Commission (FCC) has authorized the unlicensed usage of ultra-wideband (UWB) spectrum has been progressively released globally for commercial use especially in short-range wireless communications. It stimulates much interest in the exploration of various wideband or UWB techniques for commercial applications [1-3]. At present, many researchers have proposed several different techniques to design reconfigurable band-notched antennas [4-12]. Different designs have been proposed to realize the reconfigurable band-notched characteristic of UWB antenna structure [13-17]. Research shows that a compact UWB antenna was presented to vary the band notched response through the tunable element. This contribution has demonstrated a method to tune the capacitance value of the varactor diode through the input voltage from the simulation. This UWB antenna has a tuning range of 5.8 GHz to 4.4 GHz, which at 27.45% just by varying from 0.2 pF to 0.6 pF only [18].

The structure studied by [19] is composed of two U-shaped structures on the UWB antenna design. An equivalent to the transmission line resonator is used for each slot to find the optimum length and the effect of those slots for and UWB notched for WiMAX/WLAN band. However, by using slots, the patch radiates the signal, which interrupts the flow of the EM wave. Another researcher was proposed a printed reconfigurable slot antenna with band-notched with smaller size and better bandwidth enhancement for UWB antenna [20]. This design used slotted modified patch with PIN diode to produce a single notch or dual-notch by supply voltage on it. This structure was designed at operating frequency of 3.12–12.51 GHz with two notched responses of 3.12–3.84 GHz (WiMAX) and 4.9–6.06 GHz (WLAN) when both diodes are 'ON'. The UWB fractional bandwidth is over 120%, but the bandwidth of the band notched is large with a value of 760 MHz and 1.160 GHz for WiMAX and WLAN respectively. However, the researchers claim there are dual notch in the response, but only a single notch response appears on the simulation and measurement for WLAN response only. In this paper, a new approach to design a reconfigurable UWB antenna with dual band-notched is proposed. The antenna has two reconfigurable notched bands operating in a WLAN band at 5.2 GHz and

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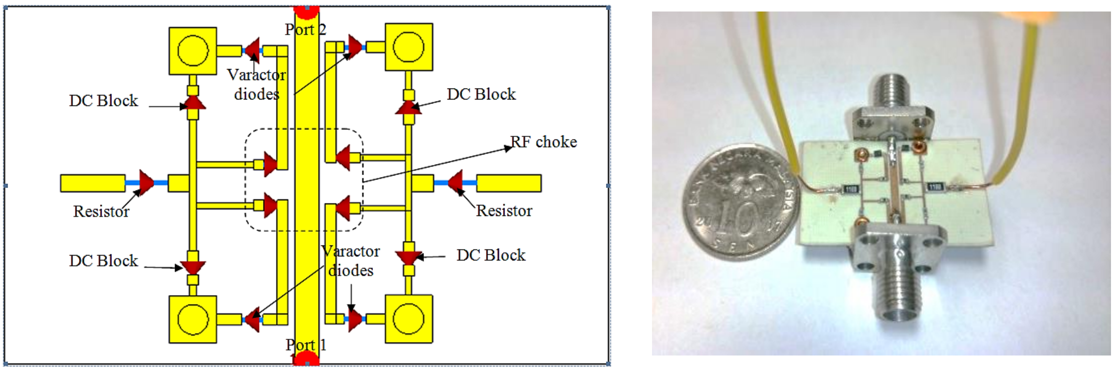
5.8 GHz with an ideal state and simulated physical layout. Additionally, the T-shape slot is etched on the partial ground plane in order to increase the UWB range, which covers the band from 3.1–10.6 GHz for wireless communication applications. The analysis focuses on the frequency response based on S-parameter, and electromagnetic (EM) simulation, frequency response is based on S-parameter and bandwidth.

2. Design of Reconfigurable Notch Filter

The reconfigurable notch filter is designed on a Roger Duroid 4350B substrate of a 0.508 mm thickness with a dielectric constant of 3.48 and loss tangent of 0.0031. The component design of the reconfigurable L-resonator notch filter using varactor diode (model NXP BB202) with biasing circuit is shown in Figure 1. The frequency response of each L-resonator coupled to the main transmission line for coupling spacing Ga, is set for 0.3 mm (due to the minimum requirement for in-house fabrication) as shown in Figure 1 (a) with the length of λ/4 and then simulated using a CST Studio Suite software [21-22].

The biasing line is important in this design in order to supply the specific amount of input voltage into this notch filter design [23]. A varactor diode can be used in a shunt configuration to form an RF biasing circuit. The DC block (capacitor) should have a relatively low impedance at the RF operating frequency which to block current flow, while the RF choke (inductor) should have a relatively high impedance which to block RF signal. In some designs, a high impedance quarter-wavelength lines can be used in place of the chokes, to block RF signal [24-26]. All these values can be further tuned and optimization during the simulation in order to obtain the desired response.

The reconfigurable L-shaped notch filter is manufactured using a standard PCB process with a 0.508 mm thick Roger Duroid 4350B, dielectric constant εr = 3.48, loss tangent, tan δ=0.0031 and copper cladding=0.035 mm. Figure 1 (b) shows that the manufactured reconfigurable L-resonator while Figure 2 shows the comparison between the simulated and measured response.



(a) (b)

Figure 1. Reconfigurable L-resonator (a) simulated (b) prototype

The simulated results show the notch filter rejects two notches at the centre frequency bands of 5.124 GHz and 5.726 GHz with peak notch of 1.166 dB and 1.863 dB, bandwidth around of 196.33 MHz and 249.52 MHz and with a tuning range of 630 MHz and 406 MHz respectively. In the measured result, the notch filter successfully rejects two notches at the centre frequency bands of 4.130 GHz and 4.48 GHz with peak notch of 5.18 dB and 5.08 dB at 6.0 V and with tuning range of 330 MHz and 200 MHz respectively.

However, the measured two notches resonant frequency are shifted to lower frequency compared with the simulated results which is due to the variation of permittivity in the substrate, i.e. 3.48±0.05 (≈ up to 1.44%) and the inconsistencies of dielectric thickness and manufacturing tolerance as well. The losses which occurred, particularly in the band-notched are due to the losses at the transitions from microstrip to the transmission line, the amount of the solder wires, active component characteristics and also through SMA connectors.

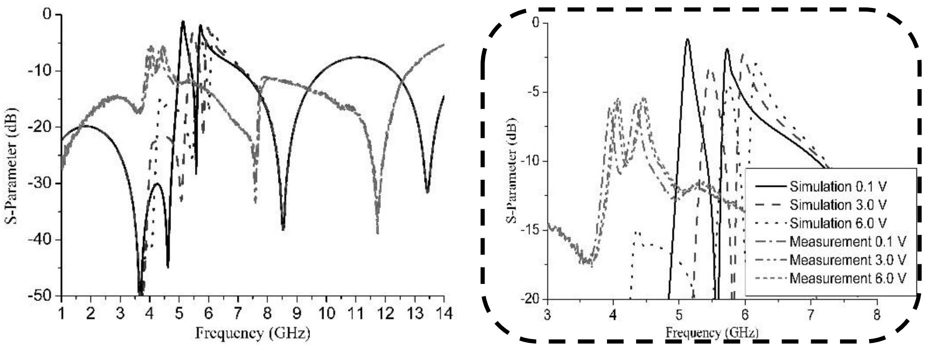


Figure 2. Comparison between the simulated and measured response (with zoom section)

3. Design of Reconfigurable Dual Band-Notched UWB Antenna

The material that is used in the UWB antenna design is similar with reconfigurable notch filter. The transmission line of the UWB antenna for this UWB design is λ/4. The UWB antenna has an overall size of 37.6 x 28 mm^2 as shown in Figure 3. A T-shaped notch is introduced on the ground plane to increase the frequency bandwidth of the UWB band, which can be adjusted by tuning the dimension of the T-shaped notch. Then, the reconfigurable notch filter is integrated with UWB antenna on the same planar to produce the notch on the UWB response. From the simulation, it is observed that the gap between the reconfigurable notch filter and the UWB circular antenna centre point, Gr needs to be optimized in order to achieve a good response. Figure 4 shows the variation distance of Gr, between the reconfigurable notch filter and the UWB circular antenna centre point, indicating the increase or decrease of the distance that will affect the attenuation level of the band-notched at fixed input voltage of 0.1 V. In this analysis, the attenuation level of the band-notched are 1.070 dB at 5.11 GHz and 1.709 dB at 5.600 GHz, while the value of Gr is 10.33 mm (1st); the attenuation levels of band-notched are 1.187 dB at 5.138 GHz and 3.113 dB at 5.614 GHz, whereas the value of Gr is 10.23 mm (2nd); and the attenuation levels of the band-notched are 1.283 dB at 5.124 GHz and 2.661 dB at 5.614 GHz, while the value of Gr is 10.13 mm (3rd). As the distance between the reconfigurable notch filter and UWB circular antenna decreases, the attenuation levels of the band-notched are slightly decreasing and the resonant frequencies are slightly shifted away from the origin of the resonant frequencies as well.

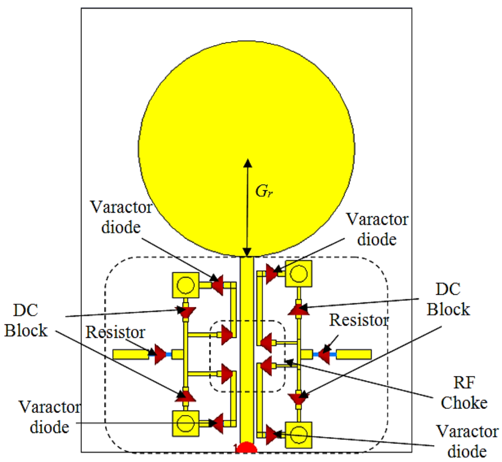


Figure 3. Reconfigurable dual band-notched UWB antenna

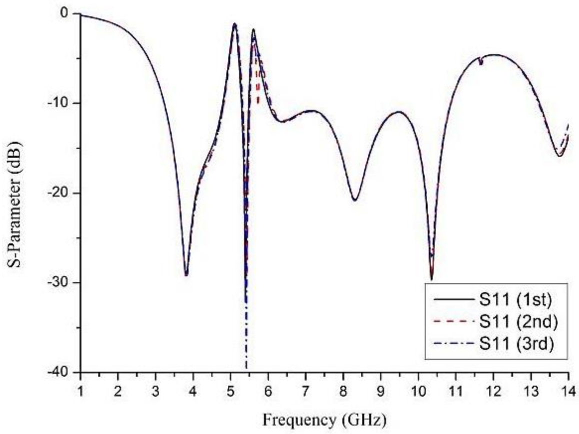


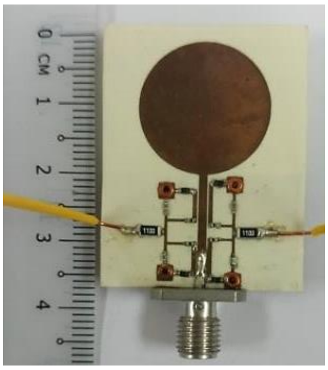
Figure 4. Effect G_r of reconfigurable design

Figure 5 (a) and Figure 5 (b) show the fabricated UWB antenna with notch filter with a final dimension of 37.60 mm and 28.00 mm while Figure 5 (c) shows the comparison between the simulated and measured S11 responses. The simulated results show the UWB antenna rejects two notches at the centre frequency bands of 5.411 GHz and 5.845 GHz with peak notch of 1.093 dB and 1.716 dB, bandwidth around of 495.89 MHz and 567.93 MHz and tuning range of 574 MHz and 434 MHz respectively. In the measured result, the reconfigurable UWB with notch filter successfully rejects two notches of 5.99 dB at 4.43 GHz and 7.96 dB at 4.92 GHz. Moreover, the band-notched bandwidth exhibit around 224.76 MHz and 89.90 MHz for the first and second notch within the UWB range of 3.387–12.372 GHz respectively.

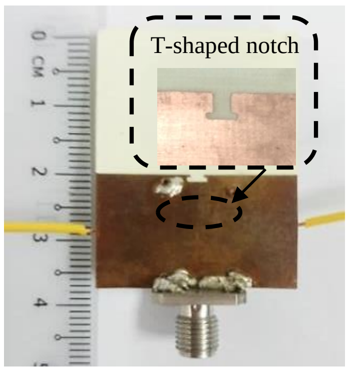
However, the measured two notches' frequency bandwidths are smaller compared to the simulated results for both notches, due to the tolerance of permittivity in the substrate, i.e. 3.48 ± 0.05 (≈ 1.44%), the inconsistencies of dielectric thickness, and manufacturing tolerance as well. The losses, especially in the band-notched, are due to the losses from the behaviour of the components, the amount of the solder wires and also through the SMA connector.

Furthermore, most of the designs have unable to achieve the band-notched of WLAN with smaller bandwidth within the band, but this proposed reconfigurable UWB antenna has achieved the design requirement of the WLAN using two-pairs of the L-resonator.

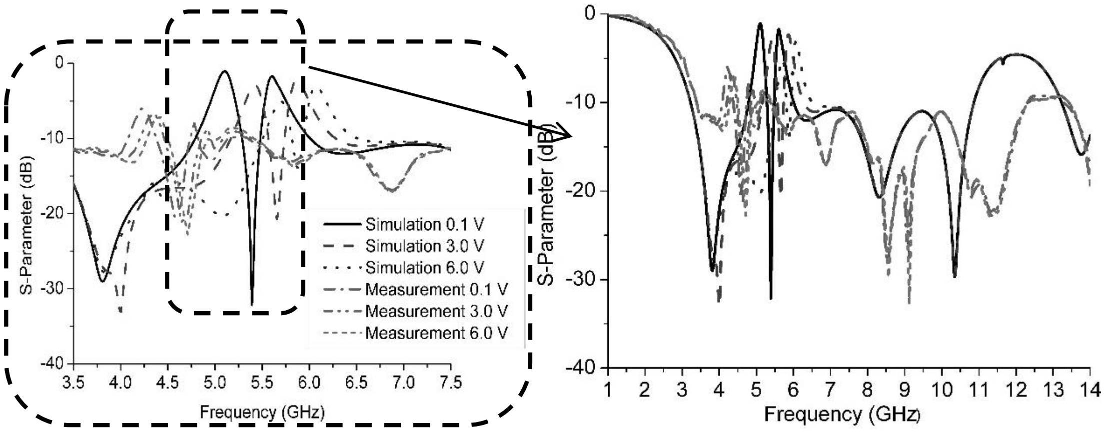
Paralleled to state-of-the-art notch response based, this technique is expected to exhibit a good response as well as to provide an alternative resolution for wireless architecture. The proposed design achieved a narrow band for the notch without any increment on the UWB antenna design. By adding tuning elements on the integrated UWB antenna with notch filter, the tuning range can be tuned up to 210 MHz. The comparison between the proposed design and other UWB antenna with notch filter structure with the same characteristics is summarized in Table 1.



(a)



(b)



(c)

Figure 5. Fabricated reconfigurable dual band-notched UWB antenna (a) top view (b) bottom view (c) comparison between the simulated and measured S11 response (with section zoom)

Table 1. Comparison Results with Previous Works

Ref.	[18] (S)	[19]	[20]	This work
Return loss	10.00	10.00	11.00	10.50
UWB range, GHz	3.100 – 8.000	2.900 – 8.200	3.12 – 12.51	3.387 – 12.372
BW_a, GHz	4.900	5.400	9.390	8.985
F_{n1st},GHz	3.200 – 3.700	3.100 – 3.600	3.120 – 3.820	4.220 – 4.430
Peak notch F_{n1st} , dB	2.000	2.500	2.000	5.990
TR for F_{n1st}, MHz	500.00	500.00	600.00	210.00
BW_m for F_{n1st} , MHz	400.00	950.00	760.00	224.76
F_{n2nd} , GHz	4.300 – 5.600	4.600 – 5.100	4.900 – 6.060	4.780-4.920
Peak notch F_{n2nd} (dB)	2.000	5.100	4.000	7.960
TR for F_{n2nd}, MHz	1400.00	500.00	1160.00	140.00
BW_m for F_{n2nd} , MHz	1000.00	600.00	1160.00	89.90
Size, mm^2	25.00 x 33.00	33.00 x 30.00	20.00 x 20.00	37.60 x 28.00

Note:** (S): Simulation only; BW_a: UWB antenna bandwidth; F_{n1st}: First notch centre frequency tuning range; TR: Tuning Range; BW_m: Maximum bandwidth; F_{n2nd}: Second notch centre frequency tuning range

4. Conclusion

A compact design of reconfigurable dual band-notched UWB antenna using varactor diode has been presented in this paper. It has been designed with two-pairs of the reconfigurable L-resonator to operate in a UWB band, with a T-shaped notch attached on the partial ground plane. The proposed antenna has a compact size of 37.60 mm x 28 mm. It has a UWB frequency bandwidth from 3.387 GHz–12.372 GHz. This antenna has smaller bandwidth for peak notch of 224.76 MHz and 89.90 MHz for both notches. This new structure of the reconfigurable dual band-notched UWB antenna is useful for RF/microwave front-end subsystems.

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