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Design and implementation of quad-port MIMO antenna with high isolation for UWB applications

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Abstract

In this paper, a novel heart-shaped UWB antenna with quintuple band-notched characteristics is proposed and demonstrated. The proposed antenna has a small size of 26 mm by 34 mm and it consists of a heart-shaped radiating element, a microstrip feed-line and ground planes with round corners. The measured results show that the proposed antenna has an ultrawideband(UWB) frequency range from 2.23 to 10.75 GHz with VSWR (voltage wave standing ratio) less than 2, except in the frequency bands of 2.31 to 2.62 GHz, 3.35 to 3.79 GHz, 5.14 to 5.9 GHz, 7.12 to 7.76 GHz and 8 to 8.43 GHz for filtering some existing narrowband communication systems such as WLAN (wireless local area networks), WiMAX (worldwide interoperability for microwave access), downlink of X-band satellite communication and ITU (International Telecommunication Union) 8-GHz band, respectively. The simulated and measured results of proposed antenna are in good correlation. It also has good omnidirectional radiation patterns and gain characteristics in the required frequency bands.

Keywords: *UWB antenna, quintuple band notched, heart-shaped.*

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INTRODUCTION

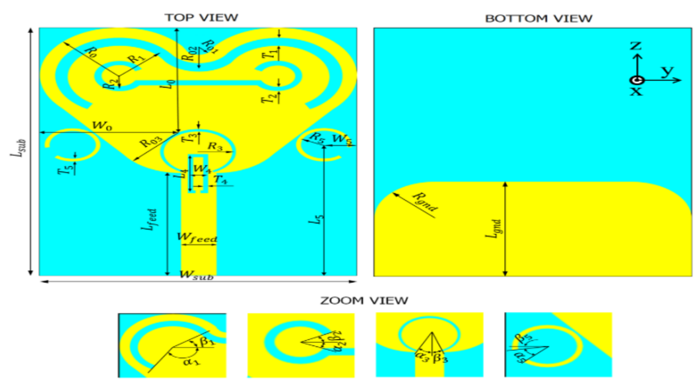
Since the FCC (Federal Communication Commission) authorized the frequency band from 3.1 to 10.6 GHz for commerical UWB systems, the UWB antenna is being investigated increasingly in recent years [1]. However, UWB communication systems may cause interference to existing narrowband communication systems within the band, such as the wireless local area networks (WLANs) operating at the bands of 2.45 GHz (2.4-2.484), 5.25 GHz (5.15-5.35) and 5.75 GHz (5.725-5.825), the worldwide interoperability for microwave access (WiMAX) systems operating at the bands of 2.35 GHz (2.3-2.4), 2.55 GHz (2.5-2.59), 3.55 GHz (3.3-3.8) and 5.8 GHz (5.725-5.85), downlink of X-band satellite communication system operating at the band of 7.5 GHz (7.25-7.75) and International Telecommunication Union (ITU) operating at the band of 8.2 GHz (8.025-8.4), respectively. Thus, it arises as a pressing issue to design UWB antennas with single or multiple band notch characteristics to remove mutual interferences from these frequency bands. In recent literatures, to overcome these problems caused by interference, many designs of single or multiple band-notched UWB antennas have been proposed [2–30]. Digging into these documents shows that there are two ways widely used to achieve band-notched characteristics. The first method is cutting several shaped slots such as U-shaped [2-7], C-shaped [8-11], H-shaped [12-14], T-shaped [15, 16], E-shaped [17, 18], F-shaped [19], W-shaped [20], L-shaped [21] and SRR-shaped [22-24] slot. Another method is adding several parasitic elements such as T-shaped [25, 26], S-shaped [27] and SRR shaped [28-30] elements. In this paper, the proposed antenna has a compact size of 26 mm × 34 mm × 1.6 mm and has designed on an inexpensive FR4 substrate. The required notched band can be independently controlled by adjusting the radii and lengths of the corresponding slots and strip, respectively. The proposed quintuple band-notched UWB antenna was successfully manufactured and measured, and the measured results were in very good agreement with the simulated results. A comparative analysis between simulation and measurement results was performed for the VSWR (voltage standing wave ratio). The directivity patterns, surface current distributions and realized gain patterns of the proposed antenna are also presented. This paper is organized as following 5 sections. In Section 2, the structure and design process of the proposed antenna is shown first. In Section 3, parametric analysis is investigated. In Section 4, the simulated and measured results are compared. In Section 5, a conclusion will be drawn.

STRUCTURE AND DESIGN PROCESS OF PROPOSED ANTENNA

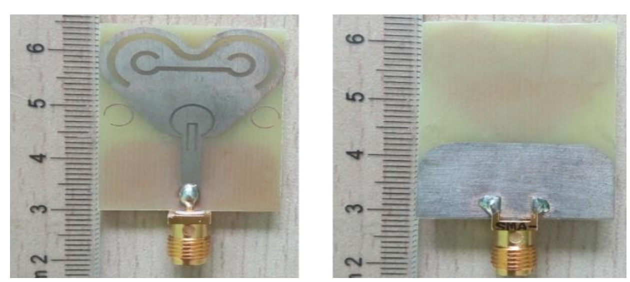
To achieved the desired characteristics, we have started to study UWB monopole antennas and have been further investigated for band-notched antennas. The novelty and innovation of proposed design are on the creation of quintuple band-notched characteristics on an antenna with a compact size.

Structure

The antenna is fabricated on an inexpensive FR-4 substrate with a compact size of 26 mm × 34 mm, thickness of 1.6 mm and relative permittivity of ε_r =4.3. The antenna includes an extended microstrip feed-line with a width of 3.05 mm and ground planes with round corners printed on the back surface of the substrate. The quintuple band-notched characteristics are achieved by utilizing five resonators labeled as slot1, slot2, slot3, slot4 and strip5 to create the band-notches at the center frequencies of 2.4, 3.63, 5.5, 7.55 and 8.16 GHz to reject the interference from the existing communication systems such as WLAN (wireless local area networks), WiMAX (worldwide interoperability for microwave access), downlink of X-band satellite communication and ITU (International Telecommunication Union) 8-GHz band, respectively. In proposed design, the total length of the chosen resonator is mainly decided to be nearly half/one-wavelength to achieve the desired notched band. The structure of the proposed antenna is shown in Fig. 1*a*. And the photograph of the manufactured antenna is shown in Fig. 1*b*.



a

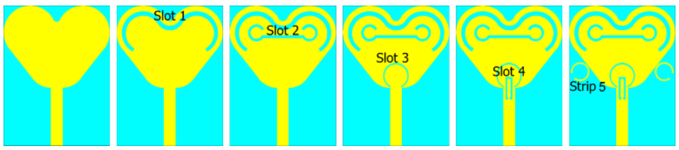


b

Fig. 1: *Geometry of the Proposed Antenna*
(a): Structure of the Proposed Antenna
(b): Photograph of the Proposed Antenna

Design process

For the first time, we design a novel heart-shaped antenna with good UWB characteristics. And the various band-notched resonators are located. The step-by-step implementation of the quintuple band-notched UWB antenna is presented in Fig. 2 and Fig. 3.



a *b* *c* *d* *e* *f*

Fig. 2: *Step-by-step implementation of structure (a): UWB antenna, (b): Single band-notched antenna, (c): Dual band-notched antenna, (d): Triple band-notched antenna, (e): Quadruple band-notched antenna, (f): Quintuple band-notched antenna*

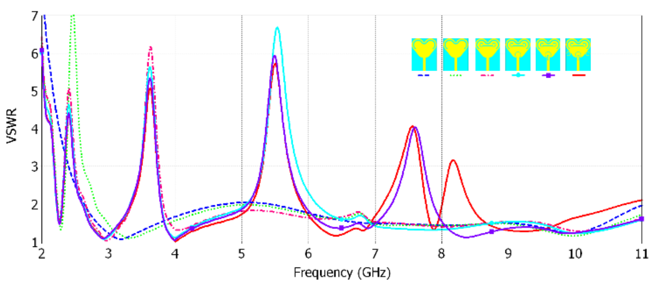
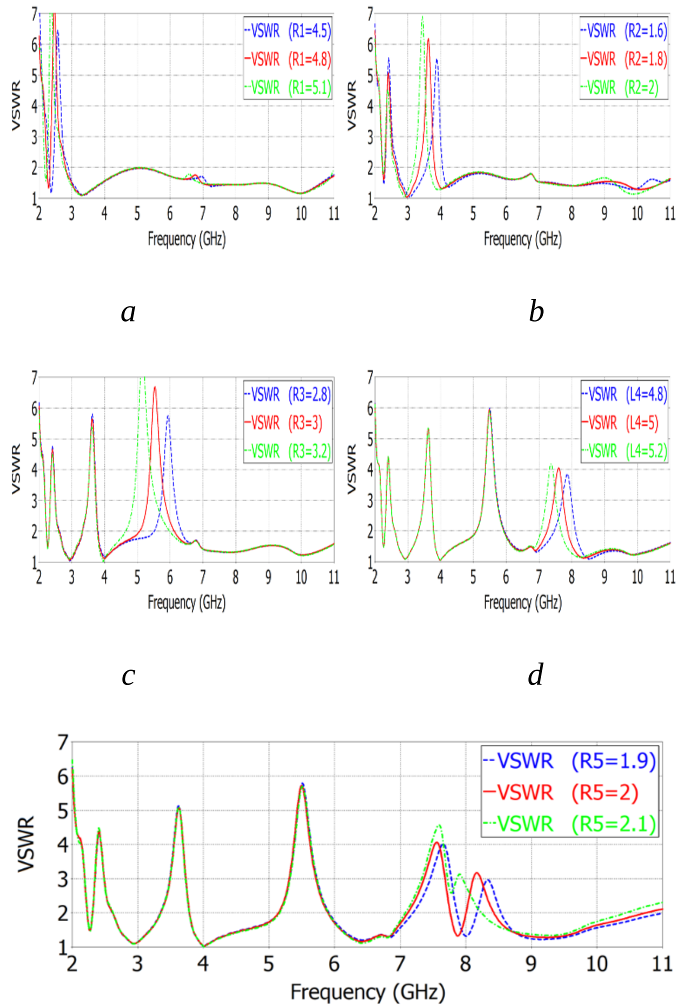


Fig. 3: *Step-by-step implementation of VSWR*

PARAMETRIC ANALYSIS

In order to control the band rejection function, a parametric analysis was carried out. The quintuple band-notched characteristics can be achieved by five resonators and each notched frequency depends on the dimensions of corresponding resonators, respectively. The stopbands at 2.3 to 2.6 GHz, 3.3 to 3.8 GHz, 5.15 to 5.85 GHz, 7.25 to 7.75 GHz and 8.025 to 8.4 GHz for filtering the WLANs, WiMAX systems, downlink of X-band satellite communication system and ITU can be achieved by parameters (R_1, R_2, R_3, L_4, R_5) of each elements, respectively. To obtain the optimized dimensions of the desired antenna, a parametric analysis was investigated using the commercial software CST. The notched band can be easily controlled by adjusting dimensions of each corresponding resonators. While the discussed parameter is varied, the other parameters are kept unvaried.



a *b* *c* *d* *e*

Fig. 4: *The Simulated VSWR of the Proposed Antenna with Different Values (a): R_1, (b): R_2, (c): R_3, (d): L_4, (e): R_5*

Controlling the first notched band

Fig. 4*a* shows the simulated VSWR while the parameter R_1 is being changed at the center frequency of the first notched band near 2.4 GHz. As shown in the figure, when the parameter R_1 increases from 4.5 mm to 5.1 mm, the center frequency of the first notched band decreases from

2.5 GHz to 2.3 GHz. On the other hand, the parameter R_1 little affects the other notched bands. Therefore, the center frequency of the first notched band can be controlled by changing the parameter R_1. The best result was obtained with a radius of 4.8 mm.

Controlling the second notched band

Fig. 4*b* shows the simulated VSWR while the parameter R_2 is being changed at the center frequency of the second notched band near 3.6 GHz. As shown in the figure, when the parameter R_2 increases from 1.6 mm to 2 mm, the center frequency of the first notched band decreases from 3.9 GHz to 3.4 GHz. On the other hand, the parameter R_2 little affects the other notched bands. Therefore, the center frequency of the second notched band can be controlled by changing the parameter R_2. The best result was obtained with a radius of 1.8 mm.

Controlling the third notched band

Fig. 4*c* shows the simulated VSWR while the parameter R_3 is being changed at the center frequency of the third notched band near 5.5 GHz. As shown in the figure, when the parameter R_3 increases from 2.8 mm to 3.2 mm, the center frequency of the first notched band decreases from 5.9 GHz to 5.1 GHz. On the other hand, the parameter R_3 little affects the other notched bands. Therefore, the center frequency of the third notched band can be controlled by changing the parameter R_3. The best result was obtained with a radius of 3 mm.

Controlling the fourth notched band

Fig. 4*d* shows the simulated VSWR while the parameter L_4 is being changed at the center frequency of the fourth notched band near 7.5 GHz. As shown in the figure, when the parameter L_4 increases from 4.8 mm to 5.2 mm, the center frequency of the first notched band decreases from 7.8 GHz to 7.3 GHz. On the other hand, the parameter L_4 little affects the other notched bands. Therefore, the center frequency of the fourth notched band can be controlled by changing the parameter L_4. The best result was obtained with a length of 5 mm.

Controlling the fifth notched band

Fig. 4*e* shows the simulated VSWR while the parameter R_5 is being changed at the center frequency of the fifth notched band near 8.2 GHz. As shown in the figure, when the parameter R_5 increases from 1.9 mm to 2.1 mm, the center frequency of the first notched band decreases from 8.3 GHz to 7.9 GHz. On the other hand, the parameter R_5 little affects the other notched bands. Therefore, the center frequency of the fifth notched band can be controlled by changing the parameter R_5. The best results was obtained with a radius of 2 mm. From the results above, by changing the radii and length of resonators, we can independently adjust the band-notched frequencies. To synthesize and systematize, increasing the dimension of the resonator has the effect of decreasing the centre notched frequency. The optimized parameters of the proposed antenna geometry are obtained and listed in Table 1.

Table 1: *The Optimized Parameters of the Proposed Antenna.*

Parameters	**Values (mm)**	**Parameters**	**Values (mm)**	**Parameters**	**Values (mm)**	**Parameters**	**Values (°)**
L_{sub}	34	R_2	1.8	L_5	18	α_1	120
W_{sub}	26	R_3	3	W_0	11.5	α_2	30
L_{feed}	14	R_5	2	W_4	1.2	α_3	25
W_{feed}	3	R_{01}	1.25	W_5	2.7	α_5	40
L_{gnd}	13	R_{02}	2.85	T_1	1	β_1	30
R_{gnd}	5	R_{03}	4.9	T_2	0.7	β_2	30

R_0	6.5	L_0	15	T_3	0.4	β_3	25
R_1	4.8	L_4	5	T_4, T_5	0.3	β_5	10

RESULT AND ANALYSIS

The proposed quintuple band-notched antenna was successfully manufactured and measured. The measurement was taken with an Agilent FieldFox N9918A vector network analyzer.

VSWR

Fig. 5 shows the simulated and measured VSWR of the proposed antenna. We can know that the simulated and measured results of proposed antenna are in good correlation and the proposed antenna is effective to reject the interference from other narrowband systems.

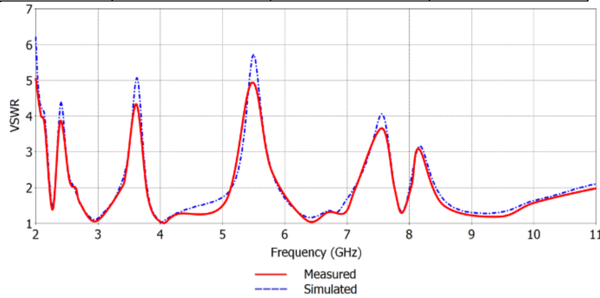


Fig. 5: *The Simulated and Measured VSWR*

From Table 2, it can be seen that the measured notched frequencies and the bandwidths for quintuple notched band are very suitable for rejecting the interference from WLANs, WiMAX systems, X-band downlink satellite communication system and ITU. There is a little discrepancy between the measured and simulated results and it may be due to the tolerance in manufacturing, and the interference of the connector and feeding cable in the measurement.

Table 2: *The Notched Bands Achieved with the Proposed Antenna*

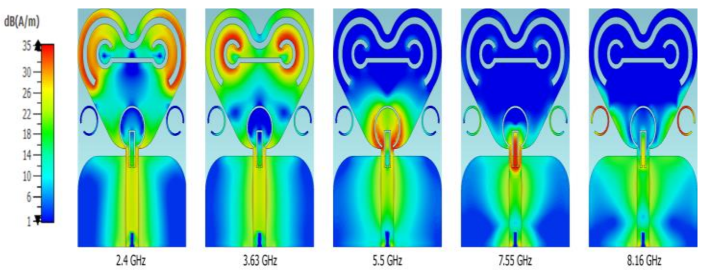
	Notched bands				
	1st Notched Band, GHz	**2nd Notched Band, GHz**	**3rd Notched Band, GHz**	**4th Notched Band, GHz**	**5th Notched Band, GHz**
Unwanted Interference Bands	2.3–2.6	3.3-3.8	5.15-5.85	7.25-7.75	8.025-8.4
Simulated Notched Bands	2.31–2.62	3.35-3.79	5.14-5.9	7.12-7.76	8-8.43
Measured Notched Bands	2.3-2.63	3.3-3.82	5.12-5.92	7.09-7.7	7.99-8.45

Surface Current Distribution

To better understand the principle of the proposed antenna, the surface current distributions at stopbands and passbands are shown in Fig 6*a* and Fig 6 *b*. As shown in Fig. 6*a*, the surface current at the stopband center frequencies of 2.4, 3.63, 5.5, 7.55 and 8.16 GHz mainly concentrated on the corresponding slots and strip of frequencies, respectively. It means that the radiation efficiency decreases at the stopbands because of a large amount of electromagnetic energy has been stored around the slots and strip. As a result, quintuple band-notched characteristics are successfully achieved. As shown in Fig. 6*b*, the surface current at the passband center frequencies of 2.27, 2.94, 4, 6.41, 7.88 and 9.24 GHz is slightly concentrated on the slots and strip.

Directivity

Figs. 7*a*~*d* show the radiation patterns of the *E*-plane(*xz*-plane) and *H*-plane(*xy*-plane) at the five stopband center frequencies of 2.4, 3.63, 5.5, 7.55 and 8.16 GHz and the passband center frequencies of 2.27, 2.94, 4, 6.41, 7.8 and 9.24 GHz, respectively. Figs 7*c* and d show that the radiation pattern in *E*-plane is bidirectional and the radiation pattern in *H*-plane is almost omnidirectional at the passband frequencies out of the stopbands. Thus, the proposed antenna can be a good candidate for the UWB communication systems.



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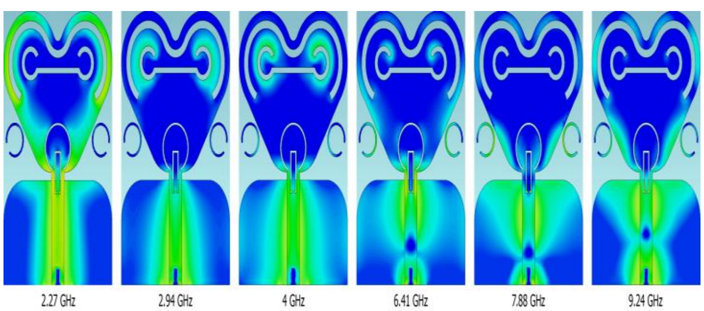
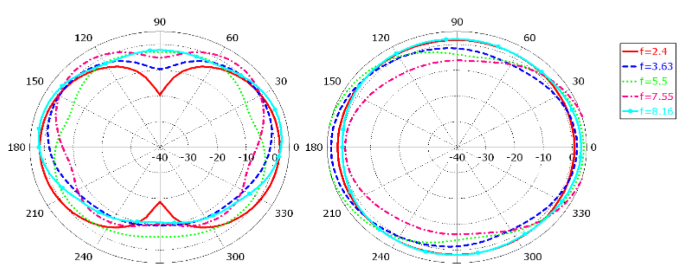


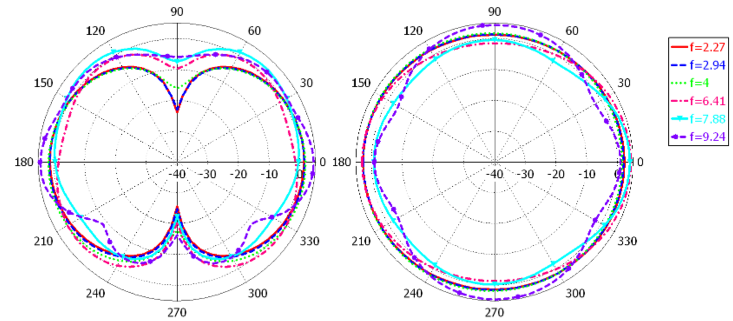
b

Fig. 6: *The Simulated Current Distribution of the Proposed Antenna*

(a): Stopbands, (b): Passbands



a *b*



c *d*

Fig. 7: *Radiation Patterns of the Quadruple Band-Notched UWB Antenna*

(a): E-Plane(x-z Plane) at the Stopband Frequencies, (b): H-Plane(x-y Plane) at the Stopband Frequencies

(c): E-Plane(x-z Plane) at the Passband Frequencies, (d): H-Plane(x-y Plane) at the Passband Frequencies

4.4 Realized gain

Fig. 8 shows the realized gains of the proposed antenna with and without the band-notches.

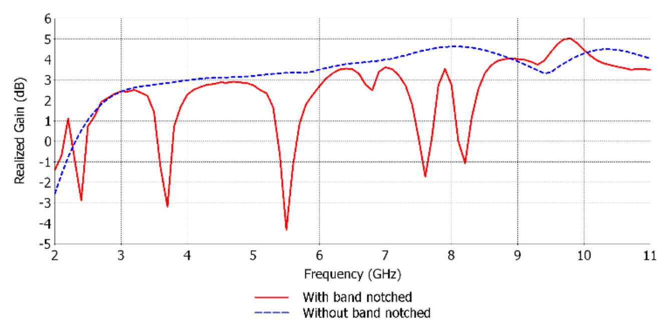


Fig. 8: *Realized Gain of the Proposed Antenna with and without Notched Band Structure*

As was expected, it can be seen that the antenna exhibits five sharp gain decreases at the center of the five notched bands. In other words, the radiation efficiency drops in the five notched frequency bands because of the energy in the five notched frequency bands is not radiated. The results indicate that the slots and strip work efficiently to ensure quintuple band-notched characteristics for the wireless communication systems.

Conclusion.

In this paper, a novel Heart-shaped UWB antenna with quintuple band-notched characteristics has been proposed and analyzed. And the design has a good agreement between measurement and simulation results. The proposed antenna has wide band characteristic from 2.23 to 10.75 GHz with VSWR less than 2 and also exhibits a good band-notched in the interference bands. Furthermore, the radiation pattern shows bi-directional properties in the *E*-plane, and omnidirectional properties in the *H*-plane over the operating frequency. As a result, the proposed quintuple band-notched UWB antenna is suitable for UWB devices and it can avoid the unwanted electromagnetic interference perfectly.

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