Enhanced Bandwidth Small Square Monopole Antenna with Band-Notched Functions for UWB Wireless Communications

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Abstract **─** A novel multi-resonance small square monopole antenna with frequency band-notched function is presented. By cutting two modified C-shaped slots in the ground plane bandwidth is increased that provides a wide usable fractional bandwidth of more than 145% (2.85- 17.83). In order to achieve band-rejected function a pair of C-shaped parasitic structures were inserted in the ground plane and a frequency notched band of 5.08–5.93 GHz has been received. The measured results reveal that the bandwidth of the proposed antenna is from 2.85 GHz to 17.83 GHz for VSWR<2. Simulated and experimental results obtained for this antenna show that it exhibits good radiation behavior within the UWB frequency range. The designed antenna has a small size of 12×18 mm^2.

Index Terms **─** Printed Monopole Antenna (PMA), C-shaped parasitic structure, modified ground plane, ultra-wideband (UWB).

I. INTRODUCTION

In UWB communication systems, one of key issues is the design of a compact antenna while providing wideband characteristic over the whole operating band [1]. Consequently, a number of printed microstrip antenna by the combination of different shapes of strips, feed lines and ground planes with different geometries to generate more resonant modes for a wider impedance bandwidth have been experimentally characterized [2-8]. In [2], two parasitic strips along the microstrip feed line are used to enhance the impedance bandwidth. Using T-shaped strips and L-shaped slots are the methods used in [3] and [4] to excite more resonances. Moreover, other strategies to improve the impedance bandwidth which do not involve a modification of the geometry of the planar antenna have been investigated [5]-[7].

The frequency range for UWB systems between 3.1 to 10.6 GHz will cause interference to the existing wireless communication systems, such as, the wireless local area network (WLAN) for IEEE 802.11a operating in 5.15–5.35 GHz and 5.725–5.825 GHz bands, so the UWB antenna with a band-stop performance is required. In order to generate the frequency band-notch function, modified planar monopoles have been recently proposed [8-11]. In [8] and [9], different shapes of the slits (i.e., W-shaped and folded trapezoid) are used to obtain the desired band-notch characteristics. Multiple half-wavelength U-shaped slits are embedded in the radiation patch to

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generate the single and multiple band-notch functions, respectively [11]. In [8]-[11], however the elements were developed on the same layer within the antenna radiator or on the backed side of the layer for generating single frequency band-notched antennas. Therefore, due to the space limitation, it is difficult to generate dual/multiple notches. On the other hand, in [8]-[10], the designs have complicated structures leading to increased fabrication costs, antenna size, and difficulty in the integration with microwave integrated circuits. In [12], band-notch function is achieved by using a T-shaped coupled-parasitic element in the ground plane. Two rod-shaped parasitic structures behind the radiating patch are used to generate a band-stop performance in [13].

In the proposed structure, based on Defected Ground Structure (DGS), by cutting two C-shaped slots on the ground plane, additional resonances are excited which leads to a bandwidth improvement that achieves a fractional bandwidth of more than 145% (2.85-17.83 GHz), with respect to the multi-resonance performance. Also, based on Electromagnetic Coupling Theory (ECT), band-notch function is provided by inserting two C-shaped parasitic structures. In the monopole antenna design, by reducing the antenna size, the impedance matching at lower frequencies becomes poor and the bandwidth is degraded. The distinctive point of the proposed antenna is that although it has small size respect to the antennas introduced in [6]-[12], it has wider impedance bandwidth in the frequency band of 2.85 to over 178.3 GHz with notched band, covering all the 5.2/5.8GHz WLAN band, and also the impedance matching at lower frequencies is very well obtained. Unlike other antennas reported in the literature up to date [8]-[12], the proposed antenna displays a good omni-directional with low cross-polarization level radiation pattern even at higher frequencies.

II. ANTENNA DESIGN

Figure 1 shows the geometry of the proposed planar monopole antenna fed by a microstrip line, which is printed on a FR4 substrate of thickness 1.6 mm, and loss tangent 0.018. As shown in Fig. 1, the presented antenna consists of a square radiating patch and modified ground plane with two C-shaped slots and parasitic structures. The basic antenna structure consists of a square patch, a feed line, and a ground plane. The square patch has a width *W*. The patch is connected to a feed line of width W_f and length L_f. On the other side of the substrate, a conducting ground plane of width W_{sub} and length L_{gnd} is placed. The proposed antenna is connected to a 50Ω SMA connector for signal transmission.

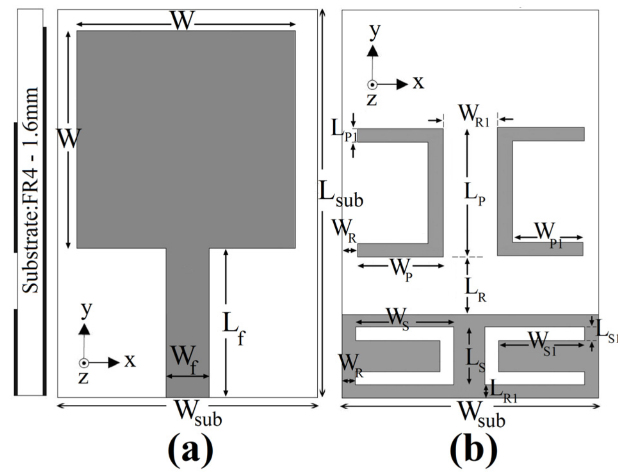

Fig. 1. Geometry of proposed square monopole antenna with modified ground plane.

In this design, to achieve a multi-resonance function and gave a bandwidth enhancement performance two C-shaped slots inserted in ground plane. By adding two C-shaped parasitic structures in the ground plane frequency band notch function (5.1-5.9GHz WLAN) is generated. Regarding Defected Ground Structures (DGS), the creating slots in the ground plane provide an additional current path. Moreover, this structure changes the inductance and capacitance of the input impedance, which in turn leads to change the bandwidth. The DGS applied to a microstrip line causes a resonant character of the structure transmission with a resonant frequency controllable by changing the shape and size of the slot [13]. Therefore, by cutting two C-shaped slots at the ground plane and carefully adjusting its parameters, much enhanced impedance bandwidth may be achieved. As illustrated in Fig. 1, the pair of C-shaped conductor-backed plane is placed under the radiating patch and is also symmetrical with respect to the longitudinal direction. The conductor-backed plane perturbs the resonant response and also acts as a parasitic half-wave resonant structure electrically coupled to the square monopole [14]. At the notch frequency, the current flows are more dominant around the parasitic elements, and they are oppositely directed between the parasitic element and the radiation patch. As a result, the desired high attenuation near the notch frequency can be produced. The variable band-notch characteristics can be achieved by carefully choosing the parameter (L_R and L_P) for the C-shaped conductor-backed plane. In this structure, the length L_R is the critical parameter to control the filter the coupling value between ground plane and parasitic element. On the other hand, the center frequency of the notched band is insensitive to the change of L_R . The resonant frequency of the notched band is determined by L_P . In this design, the optimized length is set to band-stop resonate at approximately, where and corresponds to band-notch frequency (5.5 GHz), and also is fixed at 8 mm.

In this design, the optimized length $L_{resonance}$ is set to resonate at $0.25\lambda_{resonance}$, where $L_{resonance3} = W_S + L_{S1} + 0.5W_{S1}$, and $L_{resonance4} = 0.5W_S + 0.5W_{S1} + L_{S1}$. $\lambda_{resonance3}$ and $\lambda_{resonance4}$ corresponds to new resonance frequency at 11.5 GHz and 14.5 GHz, respectively. Also the optimized length L_{notch} is set to band-stop resonate at $0.5\lambda_{notch}$, where $L_{notch} = L_P + 2W_P$. λ_{notch} corresponds to band-notch frequency (5.5 GHz).

The final values of presented slot antenna design parameters are as follows:

TABLE I: The final dimensions of the designed antenna

Param	mm	Param	mm	Param.	mm
W_{Sub}	12	L_{Sub}	18	h_{Sub}	1.6
L_f	7	W	10	W_f	2
W_P	4.5	L_P	7.5	W_{P1}	4
L_{P1}	0.5	W_S	5	L_S	2.5
W_{S1}	4.5	L_{S1}	0.5	W_R	0.5
L_R	2	W_{R1}	2	L_{R1}	0.5

III. RESULTS AND DISCUSSIONS

In this Section, the microstrip Monopole antenna with various design parameters were constructed, and the numerical and experimental results of the input impedance and radiation characteristics are presented and discussed. The proposed microstrip-fed monopole antenna was fabricated and tested to demonstrate the effect of the presented. The parameters of this proposed antenna are studied by changing one parameter at a time and fixing the others. Ansoft HFSS simulations are used to optimize the design and agreement between the simulation and measurement is obtained [15].

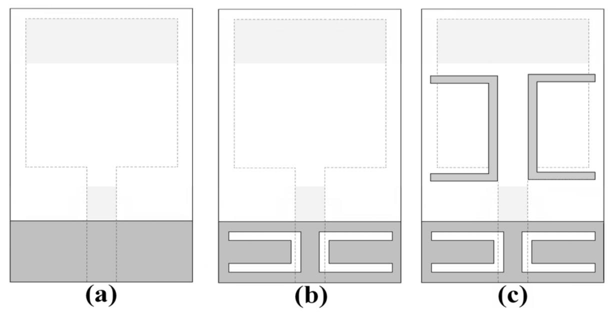

Fig. 2. (a) basic structure (ordinary monopole antenna), (b) antenna with a pair of C-shaped slots in the ground plane, (c) the proposed antenna.

The configuration of the various antennas structures are shown in Fig. 2. Return loss characteristics for ordinary square patch antenna, square antenna with two C-shaped slots in the ground plane and the proposed antenna structure are compared in Fig. 3. As shown in Fig. 3, it is observed that the upper frequency bandwidth is affected by using the C-shaped slots in the ground plane and the notch frequency bandwidth is sensitive to the C-shaped parasitic structures. Also the input impedance of the various monopole antenna structures that studied on Fig. 3, on a Smith Chart is shown in Fig. 4.

To understand the phenomenon behind this multi resonance performance, the simulated current distributions on the ground plane for the proposed antenna with two C-shaped slots at 11.5 GHz and 14.5GHz are presented in Fig. 4 (a) and 4 (b). It can be observed in Fig. 4 (a), (b) that the current concentrated on the edges of the interior and exterior of the two C-shaped slots at 11.5 GHz and 14.5 GHz. Therefore, the antenna impedance changes at these frequencies due to the resonant properties of the C-shaped slots. It is found that by using these slots, third and fourth resonances generated at 11.5 GHz and 14.5 GHz [3]. Other important design parameters of this structure are two C-shaped parasitic structures use in the ground plane. Figure 4 (c) presents the simulated current distributions on the modified ground plane at the notch frequency (5.5 GHz). As shown in Fig. 4 (c), at the notch frequency the current flows are more dominant around of the C-shaped parasitic structures. As a result, the desired high attenuation near the notch frequency can be produced [8].

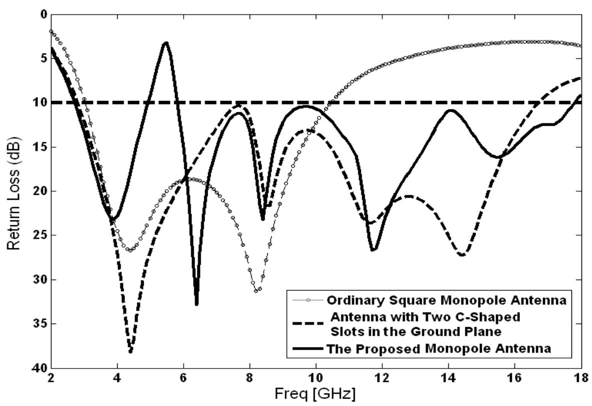

Fig. 3. Simulated return loss characteristics for the square monopole antenna without and with C-shaped slots and parasitic structures.

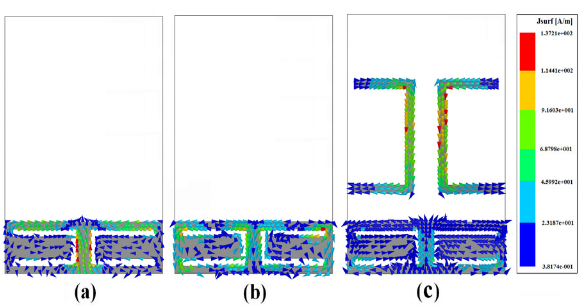

Fig. 4. Simulated surface current distributions on ground plane (a) at 11.5 GHz, (b) at 14.5 GHz, and (c) at 5.5 GHz.

The simulated VSWR curves with different values of W_{S1} are plotted in Fig. 5. As shown in Fig. 5, when the width of the W_{S1} increases from 3 to 4.75mm, the bandwidth of antenna has a various and with $W_{S1} = 4.5mm$, we gave a good bandwidth of square antenna with two C-shaped slots in the ground plane.

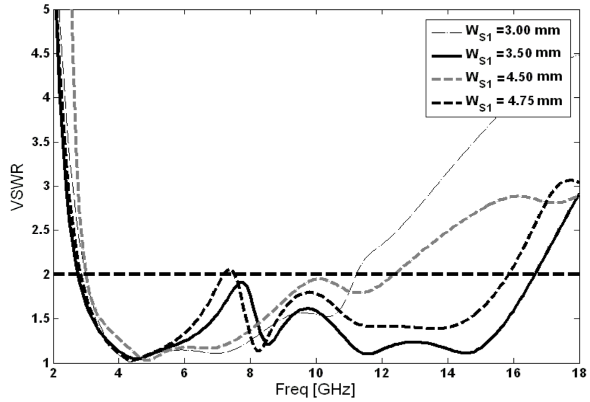

Fig. 5. Simulated VSWR characteristics for the proposed antenna without two C-shaped parasitic structures with different values of W_{S1}.

The simulated VSWR curves with different values of L_P are plotted in Fig. 6. As shown in Fig. 6, when the height of the L_P increases from 6 to 10 mm, the centre of notch frequency is decreases from 6.4 to 4.6 GHz and from these results, we can conclude that the notch frequency is controllable by changing the interior height of the L_P.

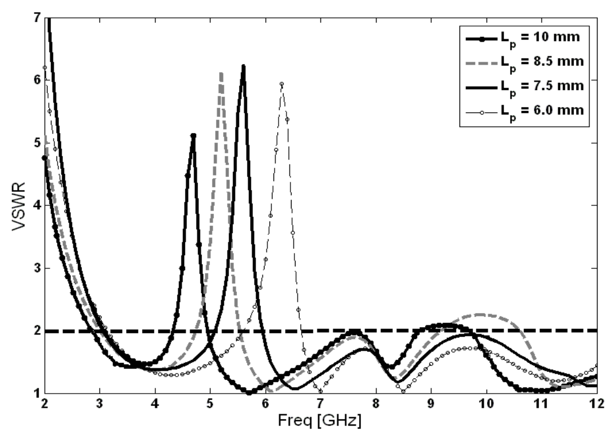

Fig. 6. Simulated VSWR characteristics for the proposed antenna with different values of L_P.

The simulated VSWR curves with different values of L_R are plotted in Fig. 7. As shown in Fig. 7, when the height of the L_R increases from 1.5 to 3 mm, the filter bandwidth is varied from 0.5 to 1.8 GHz.

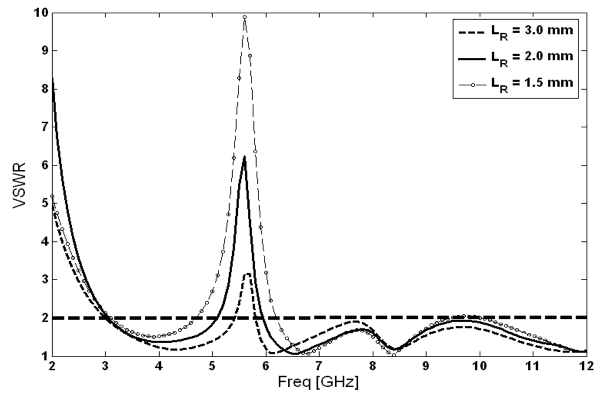

Fig. 7. Simulated VSWR characteristics for the proposed antenna with different values of L_R .

The proposed antenna with optimal design, as shown in Fig. 8, was built and tested. The measured and simulated VSWR characteristics of the proposed antenna are shown on Fig. 9. The fabricated antenna has the frequency band of 2.85 to over 17.83 GHz with notched-band function around 5.07-5.91.

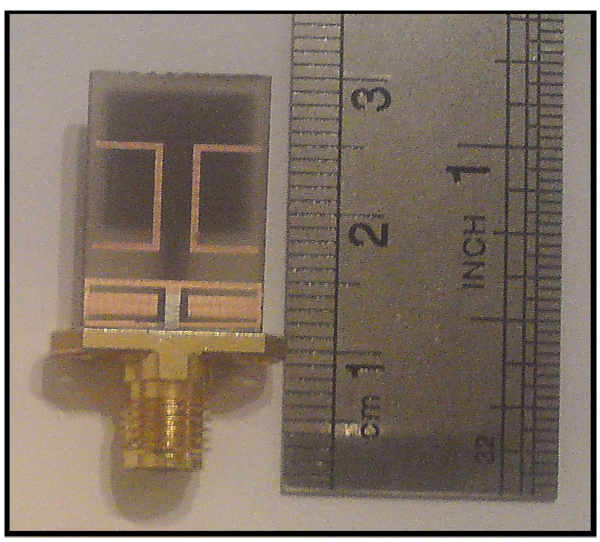

Fig. 8. Photograph of the realized printed monopole antenna.

Figure 10 illustrates the measured radiation patterns, including the Co-polarization and cross-polarization, in the H–plane (x-z plane) and E-plane (y-z plane). It can be seen that the radiation patterns in *x-z* plane are nearly omnidirectional for the three frequencies.

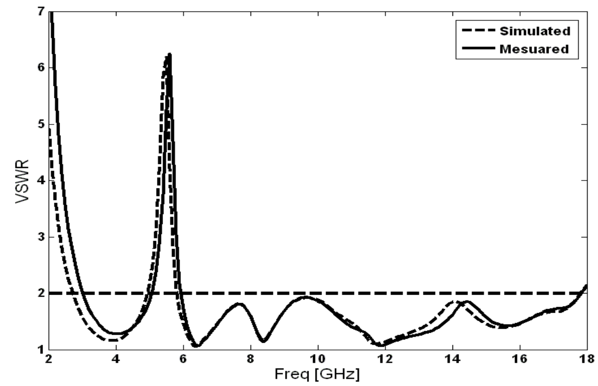

Fig. 9. Measured and simulated VSWR for the proposed antenna.

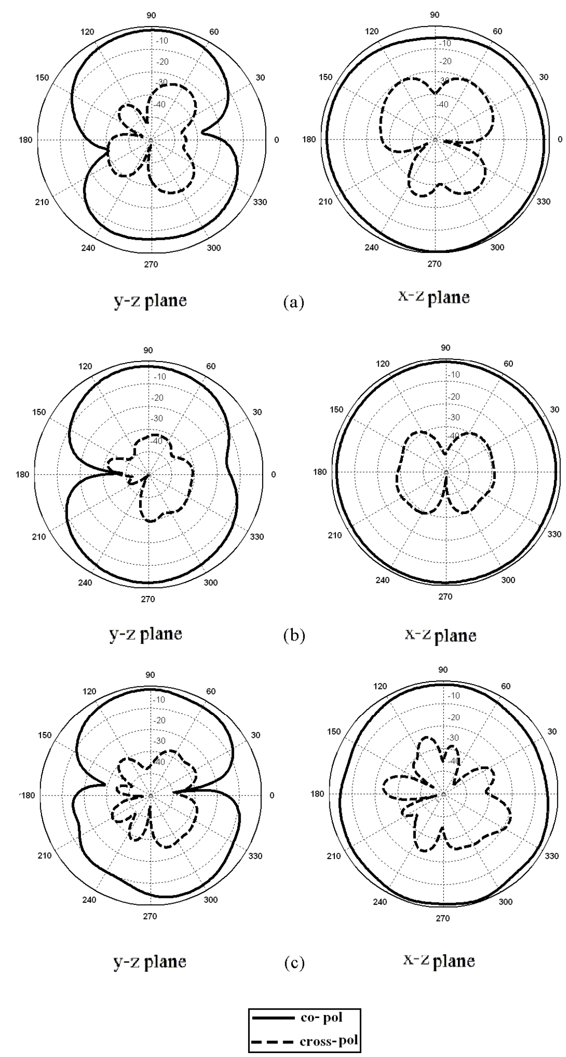

Fig. 10. Measured radiation patterns of the proposed antenna (a) 3 GHz, (b) 7 GHz, and (c) 10 GHz.

Figure 11 shows the effects of the C-shaped slots and the coupled C-shaped strips, on the maximum gain in comparison to the same antenna without them. As shown in Fig. 11, the ordinary square antenna has a gain that is low at 3 GHz and increases with frequency. It can be observed in Fig. 11 that by using a square radiating patch with a pair of C-shaped slots and parasitic structures, a sharp decrease of maximum gain in the notched frequency band at 5.5 GHz is shown. For other frequencies outside the notched frequency band, the antenna gain with the filter is similar to those without it.

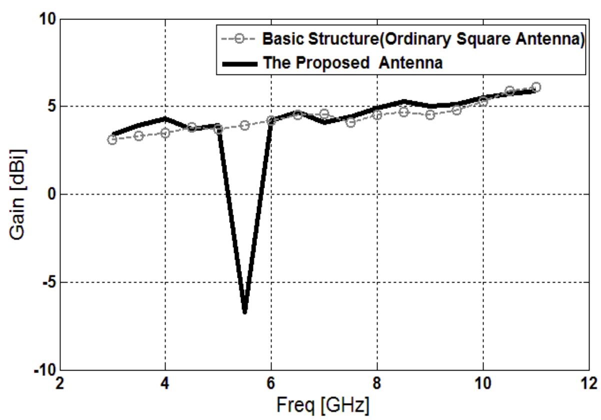

Fig. 11. Maximum gain comparisons for the ordinary square antenna (simulated), and the proposed antenna (measured).

V. CONCLUSION

In this paper, we present a novel multi-resonance microstrip-fed square monopole antenna for UWB applications with band-notch performance. The proposed antenna can operate from 2.85 to 17.83 GHz with WLAN rejection band around 5.1–5.97 GHz. In order to enhance bandwidth we insert two C-shaped slots in the ground plane, and also by adding two C-shaped parasitic structure a frequency band-notch function can be achieved. The designed antenna has a small size of 12×18 mm^2. Simulated and experimental results show that the proposed antenna could be a good candidate for UWB applications.

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