Dual Band-Notched Small Monopole Antenna with Bandwidth Enhancement by Means of Defected Ground Structure (DGS) for UWB Application

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Abstract **─** In this study, a small and compact dual band-notched microstrip-fed printed monopole antenna for ultra-wideband applications has been presented. This antenna consists of a square patch as radiator and a defected ground structure (DGS). In order to generate dual band-notched function, we use four slots in the ground plane. A parametric study of the proposed antenna is provided to achieve the dual band-notched by adjusting the lengths of the rectangular-shaped slots. The proposed antenna can easily adjust its stop-band functions by half-wavelength. Mainly, desired stop-bands are obtained without any variation on the patch. Using of this structure on the ground plane, the impedance bandwidth is effectively improved at the higher band, which results in a wide usable fractional bandwidth of more than 134% (2.7-13.7 GHz), defined by VSWR<2, with two notched bands, covering all the 5.2/5.8-GHz WLAN, 3.5/5.5-GHz WiMAX, and 4-GHz C-bands. The constructed antenna is small (15×15 mm^2) when compared with previously proposed single- and double-filtering monopole antennas with DGS in terms of slots on the ground only. The antenna has a desirable voltage standing wave ratio (VSWR) level and acceptable antenna gain for ultra-wideband frequency band range.

Index Terms **─** Defective ground structure, frequency band notched function, monopole antenna, ultra-wideband (UWB) antenna.

I. INTRODUCTION

There is a tremendous increase in the applications that use the ultra-wideband (UWB) technology. After the allocation of the frequency band between 3.1–10.6 GHz by the Federal Communication Commission (FCC) in 2002, the ultra-wideband (UWB) technology has become one of the most promising technologies for future high-data-rate wireless communication and imaging systems. One of the key elements in successful UWB system is the design of a compact UWB antenna with compact dimensions and proper characteristics providing wideband characteristic over the whole operating band. Different methods such as the truncated slot on the antenna patch have been proposed for increasing impedance bandwidth [1]. Since there are several existing systems operating within the UWB frequency spectrum, such as the IEEE802.11a WLAN (5.15-5.825 GHz) and the IEEE802.16 WiMAX (3.3-3.6 GHz), and C-band system (3.7-4.2 GHz), the UWB antenna is required to have the capability to notch those bands and thus to cancel any interference between those systems and the UWB system [2]. A number of printed microstrip antennas by combination of different types of slots in both patch and ground to generate more resonant modes for a wider impedance bandwidth have been introduced [3-12]. Many reports have appeared about the development of the band-notched characteristics which includes the capacitively-loaded loop (CLL) resonators [13], an open loop notch band resonator [14], a modified H-shaped resonator [15], a complementary split-ring resonator (CSRR) [16], and M-shaped parasitic element [17]. In [18], band-notch functions are obtained by T-shaped strip inside the slotted radiator and a pair of mirror inverted L-shaped slots at the two sides of the radiator. Moreover, band-

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rejection characteristics are generated by using a resonator at the center of a fork-shaped antenna [19] and with employing a U-slot defected ground structure in the ground plane on the back side and etching a split ring slot in the radiation patch on the front side [20]. In [21], by slitting an open-ended quarter-wavelength split slot on the back of the feed and a short-ended half-wavelength split-ring slot near the stepped slot, a second-order notched band is achieved. To obtain dual band-notched function, defected ground structure (DGS) has been used based on without any slots in radiating patch in this study. The ground plane is located at the bottom layer that is slotted with four rectangular-shaped slots. Dual band-notched of proposed antenna is achieved by adjusting the dimensions of the slots. Regarding defective ground structure (DGS), the creating slot in the ground plane provides an additional current path which it changes the inductance and capacitance of the input impedance, resulting in a change in the bandwidth. As a result, additional resonance is excited and bandwidth is improved, which obtains a fractional bandwidth of more than 134% (2.7-13.7 GHz). Compared with other reported antennas with DGS, this design has relatively small size which it is suitable to be integrated in portable devices. Good agreement between the measurement and simulation is obtained. Radiation patterns of the antenna are approximately omnidirectional. Detail of the antenna design and comparison between the measurement and simulation results are presented.

II. ANTENNA DESIGN

The schematic configuration of the proposed microstrip-fed planar monopole antenna for band-notched function is shown in Fig. 1. The design of proposed antenna is based on a microstrip patch antenna that is low profile and simple but it has relatively large dimensions ($\sim\lambda_g/2$, λ_g is a guided wavelength at the center frequency of the UWB) and does not satisfy dual-notched bands. To design a small and compact antenna with desired performance with the following design procedure has been used. The dimensions of the patch antenna were significantly reduced and the four rectangular-shaped slots were made within the ground plane. The design of the four slots was based on the expectation that they can be on the other side of substrate when they provide the desired notched frequencies. For this purpose, the initial lengths of each part of the slots was selected in such a way that the total length are about a half of the guided wavelength at the desired notched frequency ($L_{slot\_1}+L_{slot\_2}\sim\lambda_g/2$) using the approximate effective permittivity approach. Based on the DGS, the proposed structure is designed to minimize the space utilized around patch. It is also expected that far-field radiation patterns of the antenna will be omnidirectional since the patch is electric small. In this design, the antenna is printed on FR4 substrate with permittivity of 4.4, thickness of (t_{sub}) of 1.6 mm, and loss tangent of 0.02. The impedance of 50-Ω is obtained by width of the feed-line microstrip (W_f). In order to show the impact of using the defected ground plane, the antenna's performance is simulated for different cases as indicated in Fig. 2. If the proposed antenna be used without slot_2 (Fig. 2 (a)) and without slot_3 (Fig. 2 (b)), the impedance matching will be poor at the frequency band over 5 GHz as shown in Fig. 3. However, this frequency band does not notched the desired frequency bands in particular at 5.2/5.8 GHz WLAN. As shown in Fig. 3 (Fig. 2 (c)), in order to generate single band-notched characteristics (5.2/5.8-GHz WLAN), we use slot_1 and slot_2. By adding slot_3 and slot_4, a dual band-notched function is obtained that covers all the 5.2/5.8-GHz WLAN, 3.5/5.5-GHz WiMAX, and 4-GHz C-bands. It is worth mentioning that the DGS structure improves the performance at the upper frequency band. Also, by DGS, additional resonances are excited, and hence the bandwidth is increased; especially at the frequency band over 10 GHz.

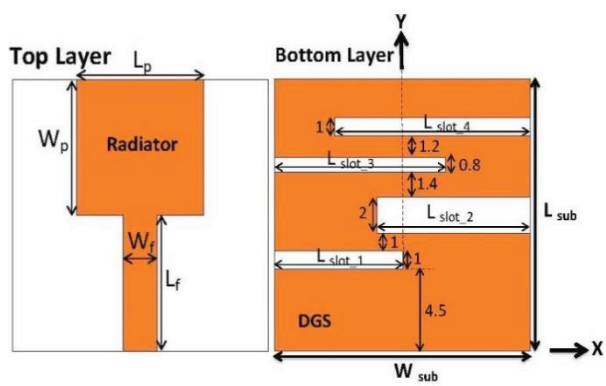

Fig. 1. Geometry of the proposed antenna with DGS structure. *(Units: mm)*

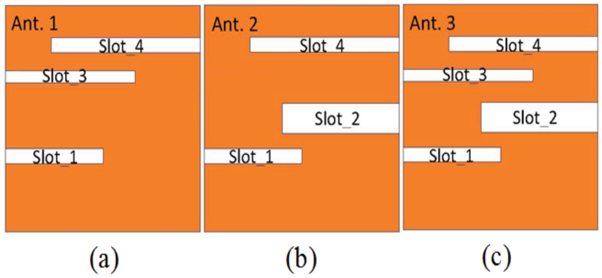

Fig. 2 Structure of various antennas used for simulation studies: (a) the antenna without slot_2, (b) the antenna without slot_3, and (c) the antenna with final design.

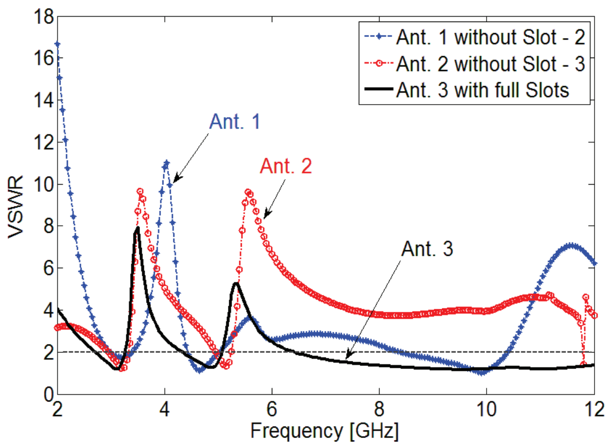

Fig. 3. Simulated VSWR characteristics for various antenna structures shown in Fig. 2.

For displaying the effect of the parameters slot_1, slot_2, slot_3, and slot_4, the simulated performance of the antenna is computed for various lengths of the proposed antenna. The length of slot_1 and slot_2 defines the upper notched band (5.07-6.4 GHz), whereas the length of slot_3 and slot_4 defines the lower notched band (3.27-4.4 GHz). The relation between the center of the notched bands (f_{c1} and f_{c2}) and length of notches is approximately by:

$$L_{slot_1} + L_{slot_2} = \frac{c}{2(f_{c1})\sqrt{\varepsilon_{eff}}}, \quad (1)$$

$$L_{slot_3} + L_{slot_4} = \frac{c}{2(f_{c2})\sqrt{\varepsilon_{eff}}}, \quad (2)$$

$$\varepsilon_{eff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2\sqrt{1 + \frac{12h}{W_f}}}, \quad (3)$$

where c, ε_{eff}, ε_r, h, and W_f are the speed of light in free space, effective dielectric constant, dielectric constant, thickness of substrate, and the width of the feed line, respectively. As a result, the values of the designed parameters L_{slot_1} and L_{slot_2} that are centered at the frequencies 5.5 and L_{slot_3} and L_{slot_4} at the 3.5 GHz can be calculated from (1) and (2). The effect of the value of the L_{slot_1} and L_{slot_2} on VSWR is shown in Fig. 4. It can be seen in Fig. 4 that the center of the band-notch for WLAN is determined by the length of the slot_1 and slot_2 indicated in Fig. 2 (c). The length of slot_1 and slot_2 is equal to half guided wavelength at the center of the rejected sub-band. The effect of the value of the L_{slot_3} and L_{slot_4} on VSWR is shown in Fig. 5. The increase in the values cause the lower rejected sub-band to shift down in the frequency without almost any impact on the upper rejected sub-band. It can be seen in Fig. 5 that the center of the band-notch for WiMAX is determined by the length of the slot_3 and slot_4 indicated in Fig. 2 (c). The length of slot_3 and slot_4 is equal to half guided wavelength at the center of the lower rejected sub-band.

The optimization of the structure is obtained using the Ansoft simulator (HFSS) [22]. Optimal parameters for the proposed antenna are as follows: W_{sub} = 15 mm, L_{sub} = 15 mm, $W_{f=}$ 2 mm, L_f = 7.5 mm, W_p = 7.5 mm, L_p = 7.5 mm, L_{slot_1} = 7.5 mm, L_{slot_2} = 9 mm, L_{slot_3} = 10 mm, L_{slot_4} = 11.5 mm. For further examining of the whole designed antenna, the excited surface current distributions on the DGS approach are provided by the simulation tool HFSS. As shown in Fig. 6, current concentrates mainly in opposite directions around slot_1 and slot_2 at 5.5 GHz, whereas it concentrates in opposite directions around slot_3 and slot_4 at 3.5 GHz. Thus, the total effective radiation from the antenna becomes almost zero. Therefore, the antenna impedance changes at these frequencies due to the band-notched properties of the DGS structure. Figure 7 shows the simulated input impedance of the proposed antenna with defected ground structure. As observed, the impedance changes nearby the notched resonant frequencies. The real part of impedance is close to zero, resulting in the mismatch of the antenna at the first and second notched frequency bands.

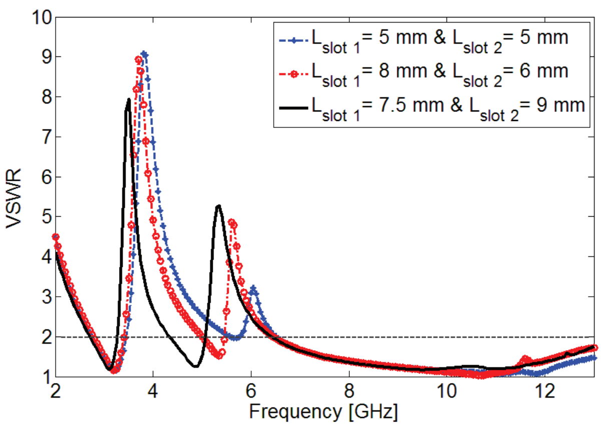

Fig. 4. Simulated VSWR of the antenna for various Lslot_1 and Lslot_2.

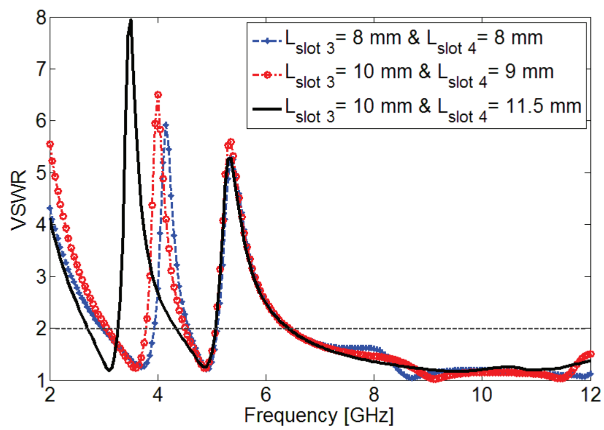

Fig. 5. Simulated VSWR of the antenna with various for Lslot_3 and Lslot_4.

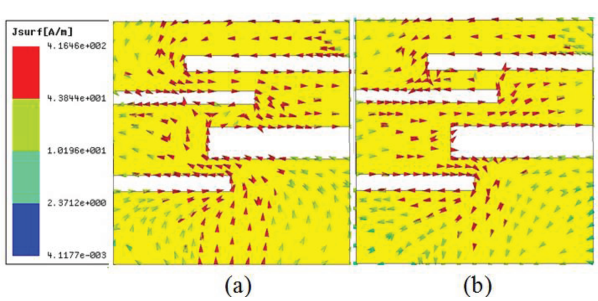

Fig. 6. Simulated current distribution of the dual-notched monopole antenna at: (a) 3.5 GHz and (b) 5.5 GHz.

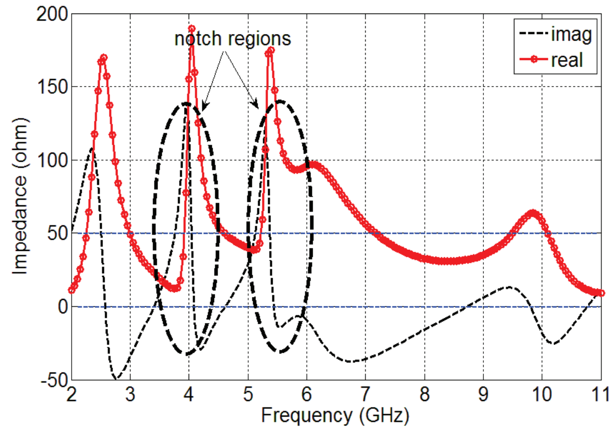

Fig. 7. Simulated real and imaginary part of impedance of the proposed antenna with notch regions.

III. RESULTS AND DISCUSSIONS

The designed antenna is fabricated (Fig. 8) and tested by using an Agilent 8722ES Vector Network Analyzer. The effect of the coaxial cable connecting the antenna with the VNA becomes a main problem in process of measurement. The cable distorts the far-field radiation pattern of the antenna. Several techniques were introduced to decouple the cable, such as using different types of baluns, ferrite beads or optic links [23-25]. In order to minimize the effect of the cable on the antenna, high impedance ferrite beads approach are applied along the measurement cable close to its connection with the antenna to reflect and/or absorb the induced power on the cable. The simulated and measured VSWR of the antenna with DGS method is shown in Fig. 8. The presented antenna can cover the frequency band between 2.7 GHz and 13.7 GHz with band-notch characteristics around 3.27-4.4 GHz and 5.07-6.4 GHz for specified criteria VSWR less than 2. There is generally good agreement between the simulation and measurement results. Figure 9 shows the simulated and measured maximum antenna gain of the proposed antenna which is used to propose notched bands. The values in Fig. 9 depict that the obtained dual band-notched antenna has relatively good gain. It also clearly shows that the gain values at notch band frequencies are significantly lower than at the whole frequency band. Figure 10 shows the simulated radiation efficiency of the proposed antenna. Results of the calculations show that the designed antenna features a good efficiency, being greater than 88% across the entire radiating band except in two notched bands. The simulated radiation efficiencies at 3.5 and 5.5 GHz are only about 40 and 50%, respectively. The radiation pattern of the antenna is also tested to confirm its omnidirectional performance as mainly required by the short range indoor UWB communication systems. Figure 11 shows the measured radiation pattern at 3, 4.5, 7.5 and 10 GHz, in the H-plane (xz-plane) and E-plane (yz-plane) knowing that the antenna is assumed to be located in the xy-plane. It can be seen that radiation patterns in the xz-plane are nearly omnidirectional for four frequencies.

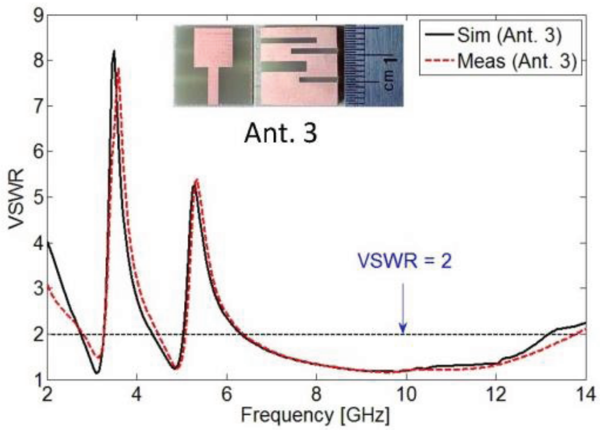

Fig. 8. Measured and simulated VSWR of the proposed dual band-notched monopole antenna (inset).

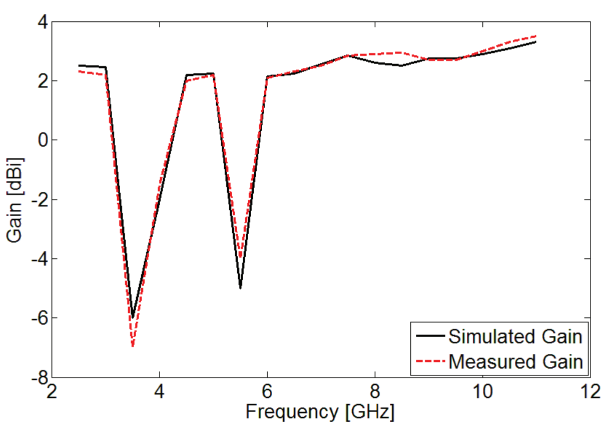

Fig. 9. Measured and simulated maximum gain of the proposed antenna.

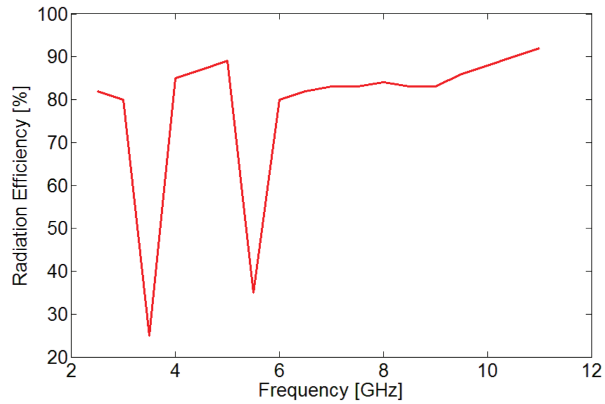

Fig. 10. Simulated radiation efficiency of the proposed antenna.

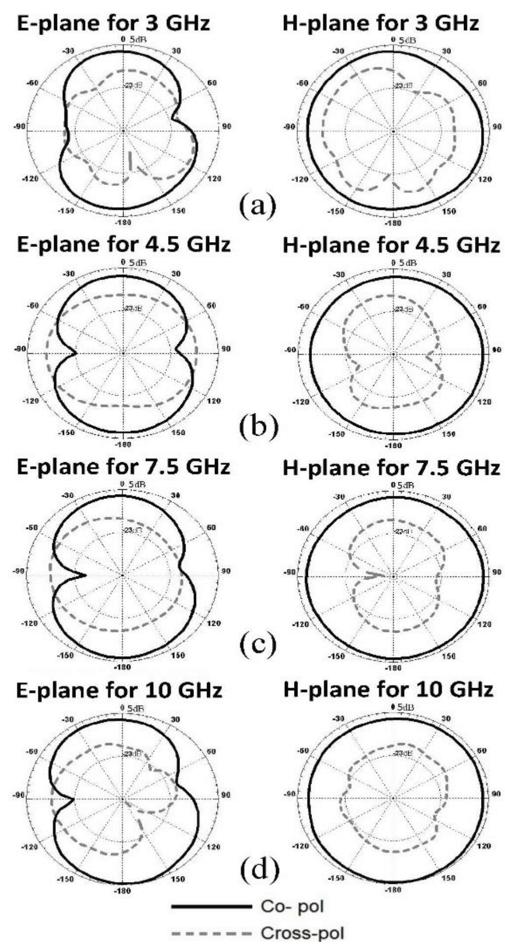

Fig. 11. The Measured radiation patterns of the proposed antenna at: (a) 3 GHz, (b) 4.5 GHz, (c) 7.5 GHz, and (d) 10 GHz.

IV. CONCLUSION

In this paper, a compact planar antenna with a new method to create dual band-notched characteristics and wide band-width capability for UWB applications has been presented. The antenna consists of a square patch as the main radiator and defected ground structure (DGS). Implementing the DGS, the dual band-notched characteristics are achieved by means of four rectangular-shaped slots at the ground plane. Also by introducing this structure, additional resonance is excited and the bandwidth is improved, resulting in a fractional bandwidth of more than 134%. Simulation and measured results are in good agreement and they show that the desired band-notch for WLAN/WiMAX/C-bands, gain and radiation pattern for UWB application can be obtained. The designed antenna can be a suitable choice for dual band-notched characteristics due to its small size, simple configuration, and omnidirectional radiation pattern.

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