A Compact UWB Slot Antenna with Reconfigurable Band-Notched Function for Multimode Applications

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***Abstract*─** A novel design of printed slot antenna with multi-resonance and switchable band-notched performances is presented whose frequency characteristics can be reconfigured electronically to have both a single- or dual-band notch function. The presented antenna is reconfigurable to suppress unwanted interfering signals by using PIN diodes integrated within the antenna configuration. The presented antenna consists of square radiating stub with a pair of rotated Ω-shaped slits, feed-line with an inverted U-shaped slot, and a slotted ground plane. By cutting an inverted U-shaped slot at the feed-line we can gave a new resonance at the higher frequencies that with this structure, an UWB frequency range can be achieved. In the presented antenna, we use two PIN diodes across the Ω-shaped structures that by changing the ON/OFF conditions of the PIN diodes, the antenna can be used for multimode applications. In the proposed structure, when D_1&D_2=OFF, the UWB antenna with a single band-notched characteristic can be achieved. By changing the condition of integrated diodes to D_1&D_2=ON, the pair of rotated Ω-shaped slits at radiating stub have been converted to four L-shaped slits that with this design the antenna can be used to generate a dual band-notched function to isolate and block any interference in the UWB frequency range.

***Index Terms* ─** Band-notched function, multimode wireless communications, reconfigurable slot antenna, UWB systems.

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. Consequently, a number of microstrip antennas with different geometries have been experimentally characterized. Moreover, other strategies to improve the impedance bandwidth which do not involve a modification of the geometry of the planar antenna have been investigated [1-3].

The frequency range for UWB systems between 3.1-10.6 GHz will cause interference to the existing wireless communication systems; for example 7.25-7.75 GHz for downlink of X-band satellite communication, so the UWB antenna with a band-notched function is required. Lately, to generate the frequency band-notched function, several modified planar antennas with band-notched characteristic have been reported [4-5].

In this paper, a compact reconfigurable antenna with single and/or dual band-stop and multi resonance performances is presented. In the proposed structure, multimode operation is provided by changing the ON/OFF conditions of the PIN diodes that the antenna can be used to generate either a single or dual notch band to isolate and block any interference in UWB frequency range. [6-8]. Good VSWR and radiation pattern characteristics are obtained in the frequency band of interest. Simulated and measured results are presented to validate the usefulness of the proposed antenna structure for UWB applications.

II. ANTENNA DESIGN

The presented small slot antenna fed by a microstrip line is shown in Fig. 1, which is printed on FR4 substrate of thickness 0.8 mm, permittivity 4.4, and loss tangent 0.018. The basic slot antenna structure consists of a square radiating stub, a feed line, and a slotted ground plane. The square radiating stub has a width of W. The radiating stub is connected to a feed line with width of W_f and length L_f. The width of the microstrip feed line is fixed at 1.5 mm, as shown in Fig. 1. On the other side of the substrate, a conducting ground plane is placed.

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The proposed antenna is connected to a 50-SMA connector for signal transmission.

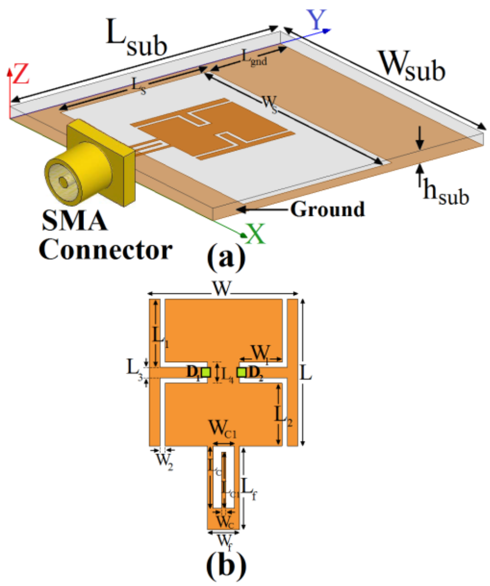

Fig. 1. (a) Side view of the proposed slot antenna, and (b) top view of modified square radiating stub.

The optimized values of proposed antenna design parameters are as follows: $W_{sub} = 20$ mm, $L_{sub} = 20$ mm, $h_{sub} = 0.8$ mm, $W_f = 1.5$ mm, $L_f = 4$ mm, $W = 7$ mm, $L = 7$ mm, $W_s = 18$ mm, $L_s = 11$ mm, $W_1 = 2$ mm, $L_1 = 3.25$ mm, $W_2 = 0.25$ mm, $L_2 = 3$ mm, $L_3 = 0.5$ mm, $W_C = 0.2$ mm, $L_C = 3.3$ mm, $W_{C1} = 1$ mm, $L_{C1} = 2.8$ mm, $W_D = 0.5$ mm, $L_D = 0.5$ mm, and $L_{gnd} = 3.5$ mm.

III. RESULTS AND DISCUSSIONS

Configuration of the presented reconfigurable slot antenna was shown in Fig. 1. The proposed microstrip antenna with various design parameters was constructed and the numerical and experimental results of the input impedance and radiation characteristics are presented and discussed. The proposed microstrip-fed antenna was fabricated and tested. 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 [9].

A. UWB antenna with single band-notched function (D_1&D_2=OFF)

Geometry for the ordinary slot antenna (Fig. 2 (a)), with an inverted U-shaped slot at feed-line (Fig. 2 (b)), and with a pair of rotated Ω-shaped slits (Fig. 2 (c)) are compared in Fig. 2.

Simulated VSWR characteristics for the structures that were shown in Fig. 2 are compared in Fig. 3. As shown in Fig. 3, it is observed that the upper frequency bandwidth is affected by using the inverted U-shaped slot and we can gave additional resonance at higher bands that provides an UWB frequency range. To generate a band-notched function, we use a pair of Ω-shaped slits in the square radiating stub.

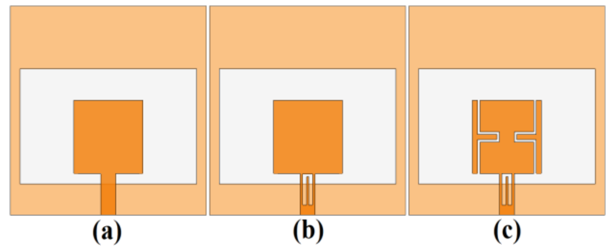

Fig. 2. (a) Basic structure (ordinary slot antenna), (b) the ordinary antenna with an inverted U-shaped slot at feed-line, and (c) the proposed slot antenna structure (D_1&D_2=OFF).

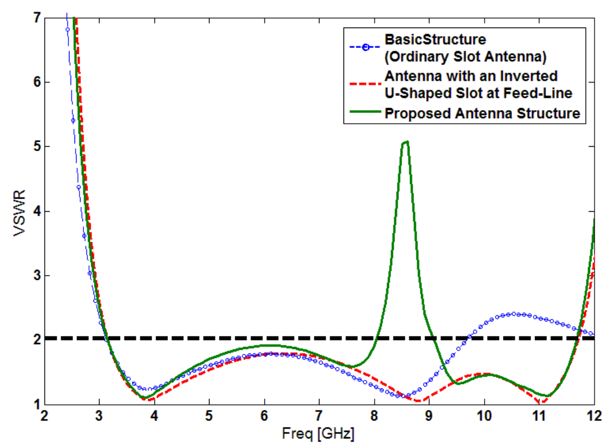

Fig. 3. Simulated VSWR characteristics for the various antenna structures shown in Fig. 2.

In order to know the phenomenon behind this multi-resonance and band-stop performance, the simulated current distributions for the proposed antenna at 11 GHz and 8.5 GHz are shown in Fig. 4. It can be observed in Fig. 4 (a) that, the current concentrated on the edges of the interior and exterior of the inverted U-shaped slot. Therefore, the antenna impedance changes at this frequency (11 GHz) due to the resonant properties of this structure [2].

Other important design parameter of this structure is the pair of rotated Ω-shaped slits used in the square radiating stub. Figure 4 (b) presents the simulated current distributions at the notched frequency (8.5 GHz). As shown in Fig. 4 (b), in the notched frequency the current flows are more dominant around of the rotated Ω-shaped slits. As a result, the desired high attenuation near the notched frequency can be produced [5-6]. It can be observed that the directions of surface currents on the radiation stub of the antenna are reversed in compared with each other, which cause the antenna impedance changes at these frequencies to generate resonance and notch band characteristics.

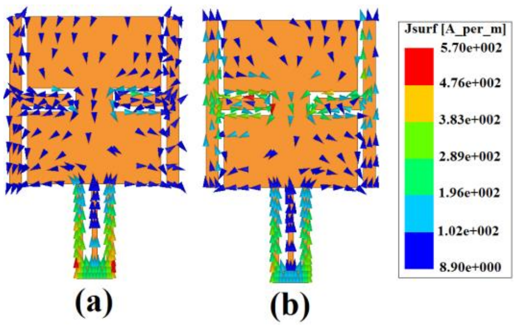

Fig. 4. Simulated surface current distributions on the radiating stub: (a) at 11 GHz, and (b) at 8.5 GHz.

B. UWB antenna with reconfigurable band-notched function (D_1&D_2=ON)

In the proposed antenna configuration, by changing the conditions of PIN diodes the desired double band notching characteristics can be achieved. Geometry for the presented antenna with single band-notched function (D_1&D_2=OFF) (Fig. 5 (a)), and with dual band-notched function (D_1D_2=ON) (Fig. 5 (b)) are compared in Fig. 5.

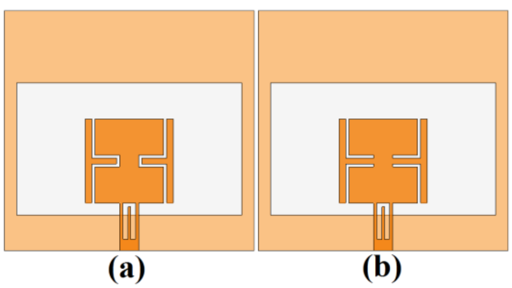

Fig. 5. Various structures for the proposed reconfigurable slot antenna: (a) D_1&D_2=OFF, and (b) D_1&D_2=ON.

To know the phenomenon behind this single or dual band-notched performance, the simulated current distributions for the proposed antenna on the radiating stub at 7.5 and 9.5 GHz (notched frequencies) are presented in Fig. 6. As shown in Figs. 6 (a) and 6 (b), the current flows are more dominant around of four L-shaped slits. Therefore, the antenna impedance changes at this frequency due to the resonant properties of the L-shaped structure. By changing the condition of integrated diodes to D_1&D_2=ON, the pair of rotated Ω-shaped slits at radiating stub have been converted to four L-shaped slits, that with this design the antenna can be used to generate a dual band-notched function to isolate and block any interference in the UWB frequency range. The first and second notches are affected from corners inserted L-shaped slits. Figure 6 (b) clearly shows at the second notched frequency, the inserted L-shaped slits act as half-wave resonant structures [8].

As seen in these figures, the current direction on the radiation stub is opposite to each other, so the far fields produced by the currents on the reject structures cancel out each other in the reject band.

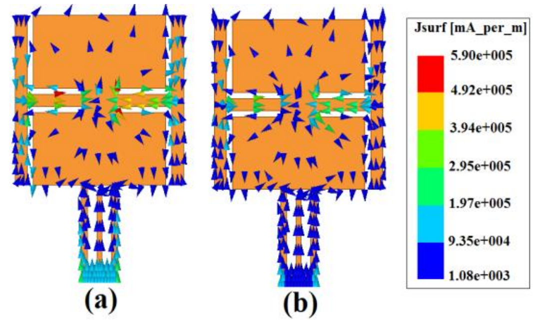

Fig. 6. Simulated surface current distributions for the proposed slot antenna at the notched frequencies: (a) at 7.5 GHz, and (b) at 9.5 GHz.

After checking all dimensions and final adjustments, the proposed antenna with final design was fabricated. Measured and simulated VSWR characteristics for the structures that were shown in Fig. 5 are compared in Fig. 7. As shown in Fig. 7, it is observed that the single frequency band-notched function around of 8-9 GHz is affected by using a pair of Ω-shaped slits on the radiating stub and by changing the condition of integrated diodes to D_1&D_2=ON, the pair of rotated Ω-shaped slits at radiating stub have converted to four L-shaped slits and a dual band-notched performance in 7-8 GHz and 9-10 GHz can be generated. The presented antenna has the frequency band of 3.02 to over 12.43 GHz with a variable single or/and dual band-stop performance.

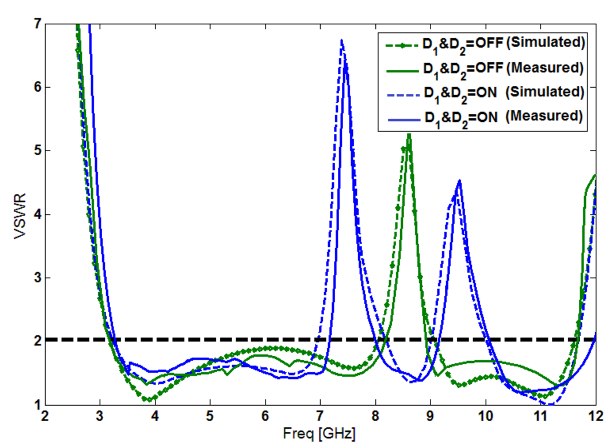

Fig. 7. Measured and simulated VSWR characteristics for the various structures shown in Fig. 5.

In a physical network analyzer measurement, the feeding mechanism of the proposed antenna is composed of a SMA connector and a microstrip line (the microstrip feed-line is excited by a SMA connector), whereas the simulated results are obtained using the Ansoft simulation software (HFSS), that in HFSS by default, the antenna is excited by a wave port that it is renormalized to a 50-Ohm full port impedance at all frequencies. In order to confirm the accurate return loss characteristics for the designed antenna, it is recommended that the manufacturing and measurement processes need to be performed carefully.

The VSWR characteristic of the antenna was measured using the HP 8720ES network analyzer in an anechoic chamber. The radiation patterns have been measured inside an anechoic chamber using a double-ridged horn antenna as a reference antenna placed at a distance of 2 m. Also, two-antenna technique using an Agilent E4440A spectrum analyzer and a double-ridged horn antenna as a reference antenna placed at a distance of 2 m is used to measure the radiation gain in the z axis direction (x-z plane). Measurement set-up of the proposed antenna for the VSWR, antenna gain and radiation pattern characteristics are shown in Fig. 8.

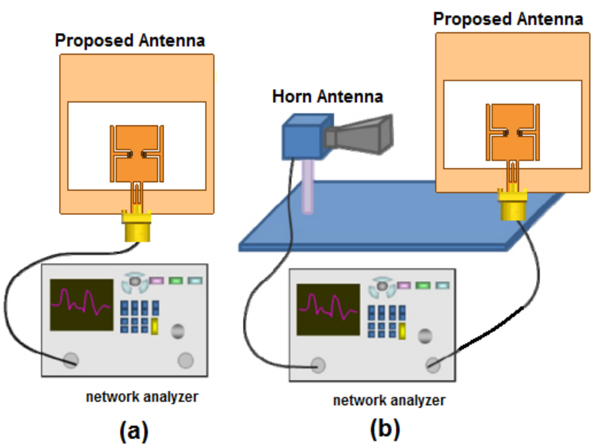

Fig. 8. Measurement set-up of the proposed antenna: (a) VSWR, and (b) antenna gain and radiation patterns.

Figure 9 depicts the measured and simulated radiation patterns of the antenna 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 nearly omnidirectional radiation pattern can be observed on x-z plane over the whole UWB frequency range. The radiation patterns on the y-z plane are like a small electric dipole leading to bidirectional patterns in a very wide frequency band. The main purpose of the radiation patterns is to demonstrate that the antenna actually radiates over a wide frequency band. With the increase of frequency, the radiation patterns become worse because of the increasing effects of the cross-polarization [10].

The radiation intensity corresponding to the isotropic ally radiated power is equal to the power accepted by the antenna divided by 4π. This can be expressed as:

$$G = \frac{4\pi U(\varphi,\theta)}{P_{in}}. \quad (1)$$

It is assumed that the antenna is receiving a signal in the direction of maximum gain. It is also common for the gain to be expressed in decibels and referenced to an isotropic source (G = 1), as shown:

$$G(dBi) = 10\,Log\,(G/1). \quad (2)$$

Measured maximum gains of the proposed antenna for different conditions of active elements are shown in Fig. 10. As illustrated, sharp decreases of the maximum gain in the notched frequencies (7.5, 8.6 and 9.5 GHz) are shown. For other frequencies outside the notched frequency band, the antenna gains are almost constant. As seen, the proposed antenna has sufficient and acceptable gain level in the operation bands [11].

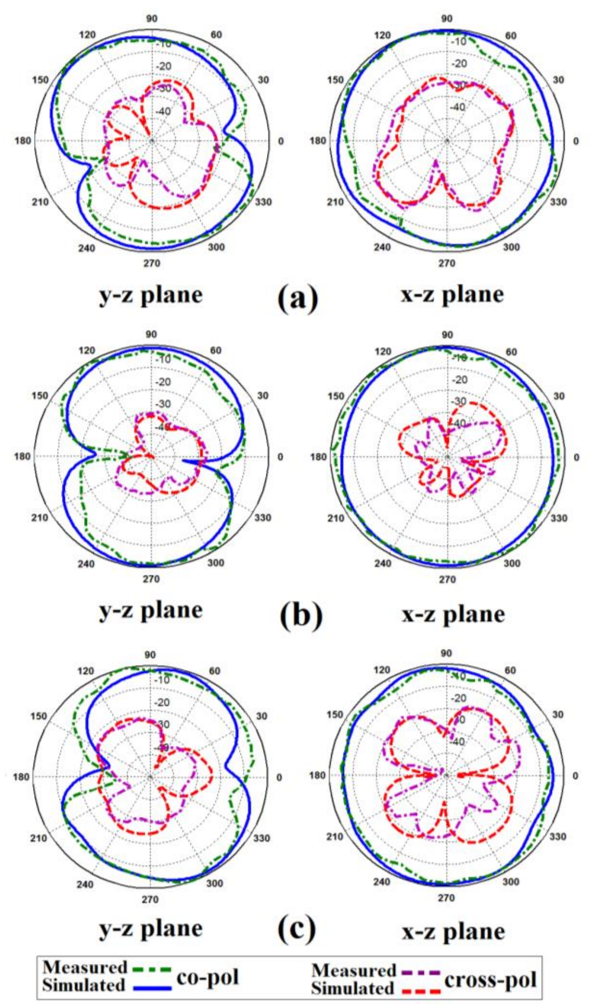

Fig. 9. Simulated and measured radiation patterns of the proposed antenna for D_1&D_2=ON: (a) 5 GHz, (b) 8.5 GHz, and (c) 11 GHz.

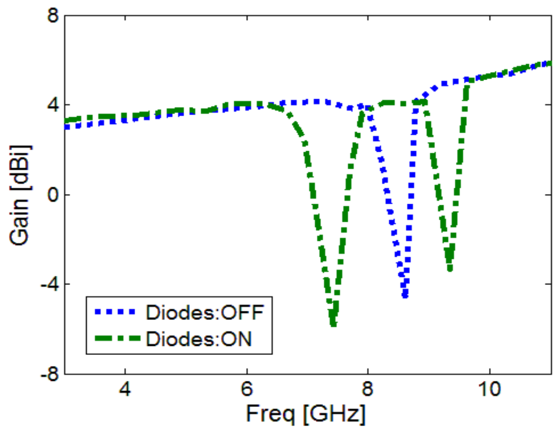

Fig. 10. Measured gain characteristics of the antenna for different conditions of active elements.

IV. CONCLUSION

A new reconfigurable slot antenna with multi-resonance and electrically switchable notch band functions for UWB applications is presented. The antenna is reconfigurable to suppress unwanted interfering signals by using PIN diodes integrated within the antenna configuration. By changing the ON/OFF conditions of the PIN diodes the antenna can be used to generate single or dual notch band in order to block any interference in the UWB frequency band. The designed antenna has a small size. Simulated and experimental results show that the proposed antenna could be a good candidate for UWB applications.

REFERENCES

[1] H. Schantz, *The Art and Science of Ultra Wideband Antennas*, Artech House, 2005.

[2] M. Ojaroudi, Sh. Yzdanifard, N. Ojaroudi, and M. Nasser-Moghaddasi, "Small square monopole antenna with enhanced bandwidth by using inverted T-shaped slot and conductor-backed plane," *IEEE Transactions on Antenna and Propagation*, vol. 59, pp. 670-674, 2011.

[3] A. Ghazi, M. N. Azarmanesh, and M. Ojaroudi, "Multi-resonance square monopole antenna for ultra-wideband applications," *Progress In Electromagnetics Research C*, vol. 14, pp. 103-113, 2010.

[4] M. Ojaroudi, Sh. Yzdanifard, N. Ojaroudi, and R. A. Sadeghzadeh, "Band-notched small square-ring antenna with a pair of T-shaped strips protruded inside the square ring for UWB applications," *IEEE Antennas and Wireless Propagation Letters*, vol. 10, pp. 227-230, 2011.

[5] M. Ojaroudi, Gh. Ghanbari, N. Ojaroudi, and Ch. Ghobadi, "Small square monopole antenna for UWB applications with variable frequency band-notch function," *IEEE Antennas and Wireless Propagation Letters*, vol. 8, pp. 1061-1064, 2009.

[6] D. Piazza, P. Mookiah, M. D'Amico, and K. R. Dandekar, "Experimental analysis of pattern and polarization reconfigurable circular patch antennas for MIMO systems," *IEEE Trans. Veh. Technol.*, vol. 59, pp. 2352-2362, 2010.

[7] S.-L. S. Yang, A. A. Kishk, and K.-F. Lee, "Frequency reconfigurable U-slot microstrip patch antenna," *IEEE Antennas Wirel. Propag. Lett.*, vol. 7, pp. 127-129, 2008

[8] S. Nikolaou, N. D. Kingsley, G. E. Ponchak, J. Papapolymerou, and M. M Tentzeris, "UWB elliptical monopoles with a reconfigurable band notch using MEMS switches actuated without bias lines," *IEEE Trans. Antennas Propag.*, vol. 57, pp. 2242-2251, 2009.

[9] Ansoft High Frequency Structure Simulation (HFSS), ver. 13, Ansoft Corporation, 2010.

[10] Y. S. Li, X. D. Yang, C. Y. Liu, and T. Jiang, "Analysis and investigation of a cantor set fractal UWB antenna with a notch-band characteristic," *Progress In Electromagnetics Research B*, vol. 33, pp. 99-114, 2011.

[11] Y. Zhang, W. Hong, C. Yu, Z. Q. Kuai, Y. D. Don, and J. Y. Zhou, "Planar ultrawideband antennas with multiple notched bands based on etched slots on the patch and/or split ring resonators on the feed line," *IEEE Transactions on Antennas and Propagation*, vol. 56, no. 9, pp. 3063-3068, 2008.