Multi-Resonance Monopole Antenna with Variable Band-Notch Performance for UWB Applications

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Abstract **─** In this paper, a novel multi-resonance monopole antenna with frequency band-notched function is presented. By cutting a pair of rotated Ω-shaped slots in the ground, the bandwidth is improved, that achieves a fractional bandwidth with multi resonance performance of more than 160 %. In order to achieve single band-rejected function an S-shaped parasitic structure was inserted in the ground plane and a frequency notched band of 5.03 GHz – 5.98 GHz has been received. The measured results reveal that bandwidth of proposed antenna is from 2.75 GHz to 18.73 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 **─** Band-notched performance, square monopole antenna, S-shaped parasitic structure, and ultra-wideband systems.

I. INTRODUCTION

In UWB communication systems, one of the key issues is the design of a compact antenna while providing wideband characteristic over the whole operating band. Consequently, a number of planar monopoles with different geometries have been experimentally characterized [1-2]. Moreover, other strategies to improve the impedance bandwidth have been investigated [3-7].

The federal communication commission (FCC)'s allocation of the frequency range 3.1 GHz – 10.6 GHz for UWB systems, which will cause interference to the existing wireless communication systems, such as, the wireless local area network (WLAN) for operating in 5.15 GHz – 5.35 GHz and 5.725 GHz – 5.825 GHz bands. Thus, the UWB antenna with a single band-stop performance is required. Lately to generate the frequency band-notch function, several modified planar antennas with band-notch characteristic have been reported [8-11]. In [8-10], different shapes of the slits (i.e., square ring, W-shaped, and folded trapezoid) are used to obtain the desired band notched characteristics. Single and multiple half-wavelength U-shaped slits are embedded in the radiation patch to generate the single and multiple band-notched functions, respectively [11].

In this paper, a new multi-resonance small square monopole antenna with a frequency-notch function is presented. In the proposed structure, by inserting two rotated Ω-shaped slots in the ground plane, multi-resonance characteristic can be achieved where the proposed antenna can operate from 2.75 GHz to 18.73 GHz. In order to generate a single notch function we insert an S-shaped parasitic structure in the ground plane. The designed antenna has a small size of 12×18 mm^2. Good VSWR and radiation pattern characteristics are obtained in the frequency band of interest.

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II. ANTENNA DESIGN

Figure 1 shows the geometry of the proposed planar monopole antenna that fed by a microstrip line, which is printed on an FR4 substrate of thickness 1.6 mm, permittivity 4.4, and loss tangent 0.018. As shown in Fig. 1, the presented antenna consists of a square radiating patch and modified ground plane with a pair of rotated Ω-shaped slots and an S-shaped parasitic structure. 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 $L_f + L_{gnd}$. 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 50 Ω SMA connector for signal transmission.

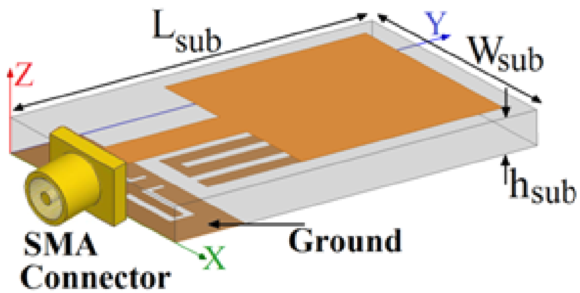
In this design, to achieve a multi-resonance function and provide a bandwidth enhancement performance, two rotated Ω-shaped slots are inserted in the ground plane. By adding an S-shaped parasitic structure in the ground plane, frequency band notch function (5.03 GHz -5.98 GHz WLAN) is generated. Regarding 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 in 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 slots [10]. Therefore, by cutting two rotated Ω-shaped slots at the ground plane and carefully adjusting its parameters, much enhanced impedance bandwidth may be achieved. As illustrated in Fig. 1, the S-shaped conductor-backed plane is placed under the radiating patch. The conductor-backed plane perturbs the resonant response and also acts as a parasitic half-wave resonant structure electrically coupled to the square monopole [9]. At the notch frequency, the current flows are more dominant around the parasitic element, 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 (W_S and L_S) for the S-shaped conductor-backed plane. In this structure, the length W_S, is the critical parameter to control the filter bandwidth. On the other hand, the center frequency of the notched band is insensitive to the change of W_S. The resonant frequency of the notched band is determined by L_S.

In this work, we start by choosing the dimensions of the designed antenna. These parameters, including the substrate, is $W_{Sub} \times L_{Sub}$ = 12 mm × 18 mm or about 0.15 λ × 0.25 λ at 4.2 GHz (the first resonance frequency). We have a lot of flexibility in choosing the width of the radiating patch. This parameter mostly affects the antenna bandwidth. As W_X decreases, so does the antenna bandwidth, and vice versa. Next step, we have to determine the length of the radiating patch L_X. This parameter is approximately $\lambda_{lower}/4$, where λ_{lower} is the lower bandwidth frequency wavelength. λ_{lower} depends on a number of parameters such as the radiating patch width as well as the thickness and dielectric constant of the substrate on which the antenna is fabricated [12]. The important step in the design is to choose $L_{resonance}$ (the length of the resonators), L_{notch} (the length of the filter). $L_{resonance}$ is set to resonate at $0.25\lambda_g$, where $L_{resonance3} = 2(L_X\text{-}L_{X1}) + W_{X1} + W_{X2}$, and $L_{resonance4} = L_{X1} + W_X$, λ_g corresponds to the resonance frequencies wavelength (11.2 GHz is the third resonance frequency and 17.1 GHz is the fourth resonance frequency). L_{notch} is set to band-stop resonate at $0.5\lambda_g$, where $L_{notch} = L_{S1} + W_S + 2W_{S1}$, λ_g corresponds to notched band frequency wavelength (5.5 GHz is the notched frequency).

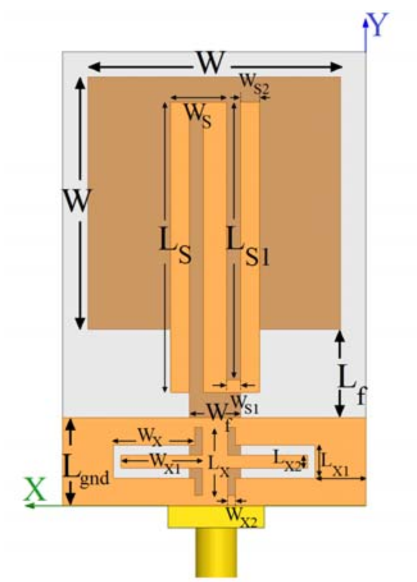
The optimized values of the proposed antenna design parameters are as follows: W_{sub} = 12 mm, L_{sub} = 18 mm, h_{sub} = 1.6 mm, W_f = 2 mm, L_f = 3.5 mm, W = 10 mm, W_S = 1.25 mm, L_s = 14 mm, W_{S1} = 0.25 mm, L_{S1} = 13.5 mm, W_{S2} = 0.5 mm, W_X = 4.5 mm, L_X = 2 mm, W_{X1} = 4 mm, L_{X1} = 1.25 mm, W_{X2} = 0.25 mm, L_{X2} = 0.25 mm, and L_{gnd} = 3.5 mm.

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 [13].



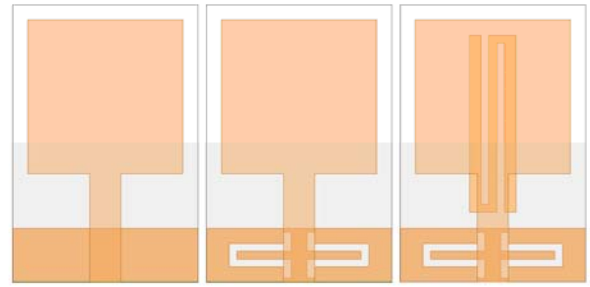
(a)



(b)

Fig. 1. Geometry of the proposed square monopole antenna; (a) bottom view and (b) side view.

The configuration of the various antennas structures were shown in Fig. 2. VSWR characteristics for ordinary square patch antenna, square antenna with two rotated Ω-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 a pair of rotated Ω-shaped slots in the ground plane and the notch frequency, which is sensitive to the S-shaped parasitic structure.



(a) (b) (c)

Fig. 2. (a) The ordinary square monopole antenna, (b) antenna with a pair of rotated Ω-shaped slots in the ground plane, and (c) the proposed square monopole antenna.

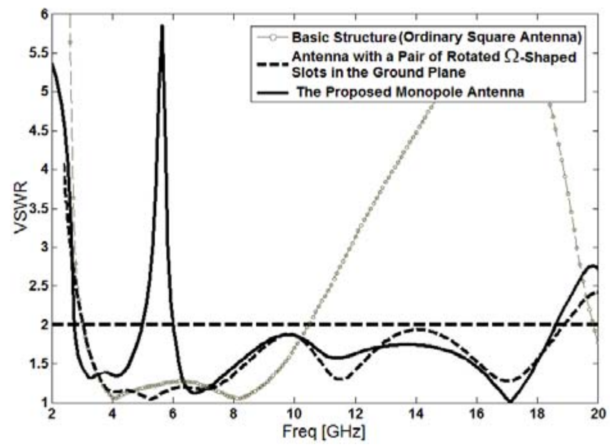


Fig. 3. Simulated VSWR characteristics for the various square monopole antenna structures shown in Fig. 2.

To understand the phenomenon behind this multi resonance performance, the simulated current distributions on the ground plane for the square antenna with two rotated Ω-shaped slots at 11.2 GHz and 17.1GHz are presented in Figs. 4 (a) and (b). It can be observed in Figs. 4 (a) and (b) that the current is concentrated on the edges of the interior and exterior of the two rotated Ω-shaped slots at 11.2 GHz and 17.1 GHz. Therefore, the antenna impedance changes at these frequencies due to the resonant properties of the rotated Ω-shaped slots. It is found that by using these slots, third and fourth resonances are generated at 11.2 GHz and 17.1 GHz, respectively [14]. Another important design parameter of this structure is the S-shaped parasitic structure used 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 S-shaped parasitic structure. As a result, the desired high attenuation near the notch frequency can be produced [11].

Fig. 4. Simulated surface current distributions on the ground plane for (a) the square antenna with a pair of Ω-shaped slots in the ground plane at a third resonance frequency (11.2 GHz), (b) at fourth resonance frequency (17.1 GHz), and (c)) for the proposed antenna at the notch frequency (5.5 GHz).

The simulated VSWR curves with different values of L_S are plotted in Fig. 5. As shown in Fig. 5, when the height of the L_S increases from 12.5 mm to 15 mm, the centre of the notch frequency decreases from 6.4 GHz to 4.9 GHz and from these results, we can conclude that the notch frequency is controllable by changing the interior height of the L_S. The simulated VSWR curves with different values of W_S are plotted in Fig. 6. As shown in Fig. 6, when the width of W_S increases from 0.75 mm to 2 mm, the filter bandwidth has a various size and with W_S = 1.25 mm, we provide a good bandwidth of the notch frequency.

The simulated input signal and impulse response for the proposed antenna is shown in Fig. 7. A first-order Rayleigh pulse is used as the source signal to drive the transmitter [8]. One of the characteristics of UWB signals is pulse distortion, which is inherently determined by their huge bandwidth. Good impedance matching over the operating frequency band is desired to minimize the reflection loss and to avoid pulse distortion [8]. Therefore, the signal distortions shown in Fig. 7 are mainly due to the bandwidth mismatch between the source pulse and the antenna. As a result, some frequency components of the pulse cannot be transmitted effectively by the monopole, leading to the distortions of the received signal.

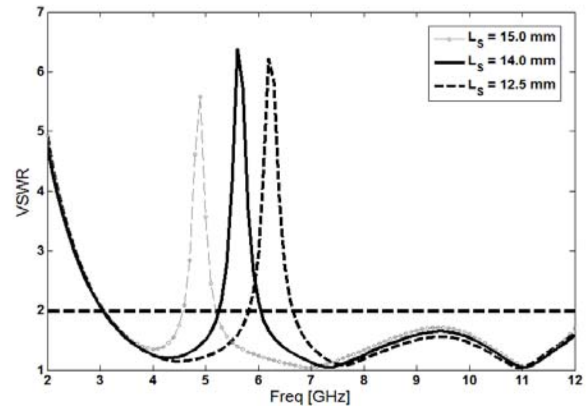


Fig. 5. Simulated VSWR characteristics for the proposed antenna with different values of L_S.

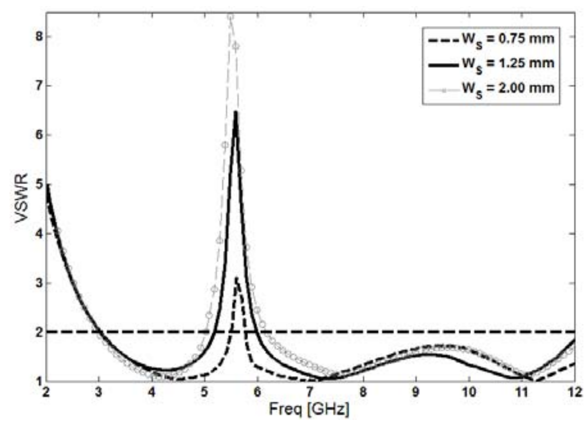


Fig. 6. Simulated VSWR characteristics for the proposed antenna with different values of W_S.

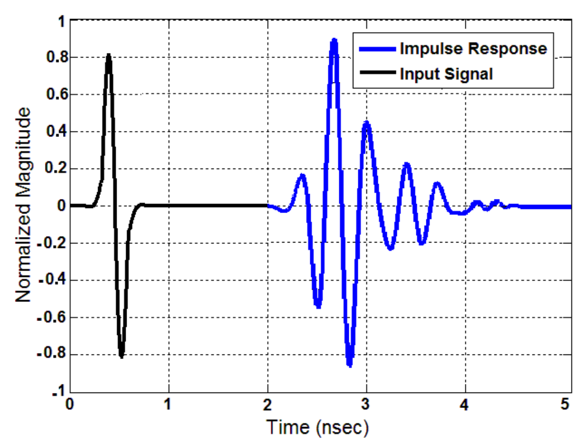


Fig. 7. Simulated time-domain analysis (input signal and impulse response).

A prototype of the proposed monopole antenna was fabricated and tested in the antenna laboratory at the Microwave Technology Company (MWT), and the VSWR were measured using an HP 8720ES network analyzer in an anechoic chamber. The measured and simulated VSWR characteristics of the proposed antenna are shown on Fig. 8. The fabricated antenna has a frequency band of 2.75 GHz to over 18.73 GHz with notched-band function around 5.03-5.98. As shown in Fig. 8, there exists a discrepancy between measured data and simulated results.

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. Figure 9 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 the x-z plane are nearly omnidirectional for three frequencies.

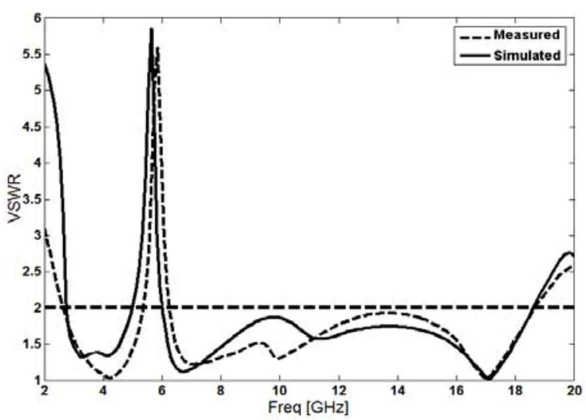


Fig. 8. Measured and simulated VSWR for the proposed antenna.

Figure 10 shows the effects of the rotated Ω-shaped slots and the S-shaped parasitic structure in the ground plane on the maximum gain in comparison to the ordinary slot antenna without them. A 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). As shown in Fig. 10, the ordinary antenna has a gain that is low at 3 GHz and increases with frequency. It is found that the gain of the ordinary monopole antenna is decreased with the use of the rotated Ω-shaped slots and the S-shaped parasitic structure in the ground plane. It can be observed in Fig. 10 that by using these structures, a sharp decrease of maximum gain in the notched frequency band at 5.5 GHz are shown. For other frequencies outside the notched frequencies band, the antenna gain with the filter is similar to those without it.

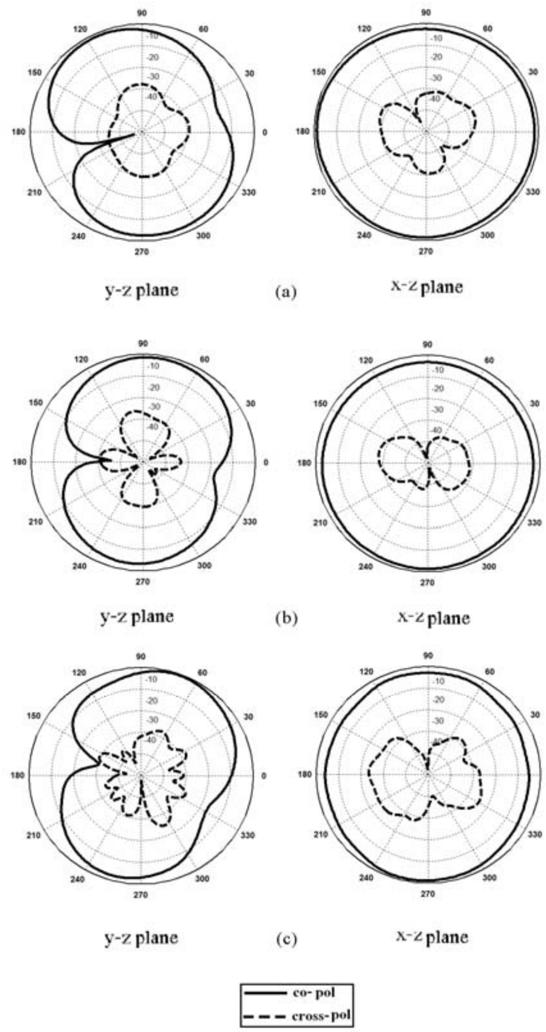


Fig. 9. Measured radiation patterns of the proposed antenna at (a) 4 GHz, (b) 7 GHz, and (c) 10 GHz.

IV. 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 2.75 GHz to 18.73 GHz with WLAN rejection band around 5.03 GHz – 5.98 GHz. In order to enhance the bandwidth we cut two rotated Ω-shaped slots in the ground plane, and also by inserting an S-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 application.

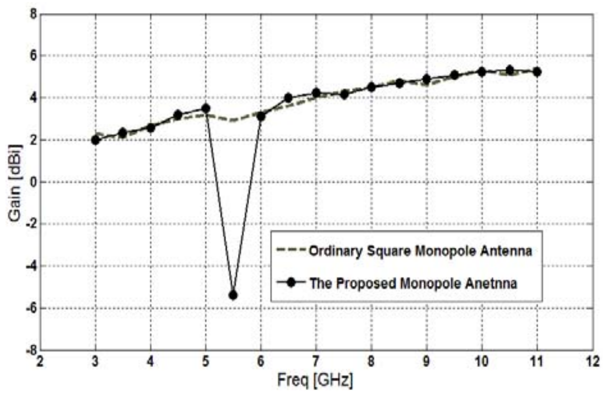


Fig. 10. Maximum gain comparisons for the ordinary monopole antenna (simulated), and the proposed antenna (measured) in the z-axis direction (x-z plane).

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REFERENCES

[1] M. Ojaroudi, Sh. Yzdanifard, N. Ojaroudi, and M. Nasser-Moghaddasi, "Small square monopole antenna with enhanced by using inverted T-shaped slot and conductor-backed plane," *IEEE Transactions on Antenna and Propagation*, vol. 59, no. 2, pp. 670-674, Feb. 2011.

[2] M. Ojaroudi, G. Kohneshahri, and Ja. Noory, "Small modified monopole antenna for UWB application," *IET Microw. Antennas Propag.*, vol. 3, no. 5, pp. 863-869, August 2009.

[3] M. Ojaroudi, Ch. Ghobadi, and J. Nourinia, "Small square monopole antenna with inverted T-shaped notch in the ground plane for UWB application," *IEEE Antennas and Wireless Propagation Letters*, vol. 8, no. 1, pp. 728-731, 2009.

[4] Y. Li, W. Li, and W. Yu, "A switchable UWB slot antenna using SIS-HSIR and SIS-SIR for multi-mode wireless communications applications," *Applied Computational Electromagnetics Society (ACES) Journal*, vol. 27, no. 4, pp. 340-351, April 2012.

[5] M. T. Partovi, N. Ojaroudi, and M. Ojaroudi, "Small slot antenna with enhanced bandwidth and band-notched performance for UWB applications," *Applied Computational Electromagnetics Society (ACES) Journal*, vol. 27, no. 9, pp. 772-778, Sep. 2012.

[6] J. William and R. Nakkeeran, "A new UWB slot antenna with rejection of WiMax and WLAN bands," *Applied Computational Electromagnetics Society (ACES) Journal,* vol. 25, no. 9, pp. 787-793, Sep. 2010.

[7] J. Jung, W. Choi, and J. Choi, "A compact broadband antenna with an L-shaped notch," *IEICE Trans. Commun.*, vol. E89-B, no. 6, pp. 1968–1971, June 2006.

[8] 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.

[9] Sh. Yazdanifard, R. A. Sadeghzadeh, and M. Ojaroudi, "Ultra-wideband small square small monopole antenna with variable frequency function," *Progress In Electromagnetics Research C*, vol. 15, pp. 133-144, 2010.

[10] M. Ojaroudi, "Printed monopole antenna with a novel band-notched folded trapezoid for ultra-wideband applications," *Journal of Electromagnetic Waves and Application (JEMWA)*, vol. 23, pp. 2513–2522, 2009.

[11] 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.

[12] M. Ojaroudi, N. Ojaroudi, and Y. Ebazadeh, "Dual band-notch small square monopole antenna with enhanced bandwidth characteristics for UWB applications," *Applied Computational Electromagnetics Society (ACES) Journal*, vol. 27, no. 5, pp. 420-426, May 2012.

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

[14] B. H. Siahkal-Mahalle, M. Ojaroudi, and N. Ojaroudi, "Enhanced bandwidth small square monopole antenna with band-notched functions for UWB wireless communications," *Applied Computational Electromagnetics Society (ACES) Journal*, vol. 27, no. 9, pp. 759-765, Sep. 2012.

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