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

Nasser Ojaroudi¹, Mohammad Ojaroudi², and Noradin Ghadimi²

¹Department of Electrical Engineering
Germi Branch, Islamic Azad University, Germi, Iran
n.ojaroudi@yahoo.com

²Young Researchers Club
Ardabil Branch, Islamic Azad University, Ardabil, Iran
m.ojaroudi@iauardabil.ac.ir, noradin.ghadimi@gmail.com

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 mm².

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 mm². Good VSWR and radiation pattern characteristics are obtained in the frequency band of interest.
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 \( \Omega \)-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 \( \Omega \) SMA connector for signal transmission.

In this design, to achieve a multi-resonance function and provide a bandwidth enhancement performance, two rotated \( \Omega \)-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 \( \Omega \)-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 \((W_S, \lambda_S)\) 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 \( W_{sub} \times L_{sub} = 12 \text{ mm} \times 18 \text{ mm} \) or about \( 0.15 \lambda \times 0.25 \lambda \) 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 \( \lambda_{lower} \) is the lower bandwidth frequency wavelength. \( \lambda_{lower} \) 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 \( 0.25 \lambda_S \), where \( L_{resonance 3} = 2(L_X - L_1) + W_{X1} + W_{X2} \), and \( L_{resonance 4} = L_{X1} + W_S \). \( \lambda_g \) 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\( \lambda_S \), where \( L_{notch} = L_{X1} + W_S + 2W_{S1} \). \( \lambda_g \) 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: \( W_{sub} = 12 \text{ mm} \), \( L_{sub} = 18 \text{ mm} \), \( h_{sub} = 1.6 \text{ mm} \), \( W_f = 2 \text{ mm} \), \( L_f = 3.5 \text{ mm} \), \( W = 10 \text{ mm} \), \( W_S = 1.25 \text{ mm} \), \( L_s = 14 \text{ mm} \), \( W_{S1} = 0.25 \text{ mm} \), \( L_{S1} = 13.5 \text{ mm} \), \( W_{S2} = 0.5 \text{ mm} \), \( W_X = 4.5 \text{ mm} \), \( L_X = 2 \text{ mm} \), \( W_{X1} = 4 \text{ mm} \), \( L_{X1} = 1.25 \text{ mm} \), \( W_{X2} = 0.25 \text{ mm} \), \( L_{X2} = 0.25 \text{ mm} \), and \( L_{gnd} = 3.5 \text{ mm} \).

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].

![Figure 1](image1.png)

**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 \( \Omega \)-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 \( \Omega \)-shaped slots in the ground plane and the notch frequency, which is sensitive to the S-shaped parasitic structure.

![Figure 2](image2.png)

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

![Figure 3](image3.png)

**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 \( \Omega \)-shaped slots at 11.2 GHz and 17.1 GHz 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 \( \Omega \)-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.](image)

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.](image)

**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 \( \Omega \)-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\( \times \)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).

ACKNOWLEDGMENT
The authors are thankful to the Microwave Technology (MWT) Company staff for their beneficial and professional help (www.microwave-technology.com).

REFERENCES
Nasser Ojaroudi was born on 1986 in Germi, Iran. He received his B.Sc. degree in Electrical Engineering from Azad University, Ardabil Branch. From 2011, he is working toward the M.Sc. degree in Telecommunication Engineering at Shahid Rajaee Teacher Training University. Since March 2008, he has been a Research Fellow in the Microwave Technology Company (MWT), Tehran, Iran. His research interests include monopole antenna, slot antennas, microstrip antennas for radar systems, ultra-wideband (UWB) and wireless communications, microwave passive devices and circuits, and microwave/millimeter systems.

Mohammad Ojaroudi was born on 1984 in Germi, Iran. He received his B.Sc. degree in Electrical Engineering from Azad University, Ardabil Branch and M.Sc. degree in Telecommunication Engineering from Urmia University. From 2010, he is working toward the Ph.D. degree at Shahid Beheshti University. From 2007 until now, he is a Teaching Assistant with the Department of Electrical Engineering, Islamic Azad University, Ardabil Branch, Iran. Since March 2008, he has been a Research Fellow (Chief Executive Officer) in the Microwave Technology Company (MWT), Tehran, Iran. His research interests include analysis and design of microstrip antennas, design and modeling of microwave structures, radar systems, and electromagnetic theory. He is author and coauthor of more than 100 journal and international conference papers.

Noradin Ghadimi was born in Ardabil-Iran in 1985, and received the B.Sc. degree in Electrical Engineering from the Islamic Azad University, Ardabil Branch, Ardabil, Iran, in 2009 and the M.Sc. degree in Electrical Engineering from the Islamic Azad University Ahar Branch, Ahar, Iran, in 2011. His research interests include Power System Protection, modeling and analysis of distributed generations, renewable energy, and communications systems.