Omni-Directional/Multi-Resonance CPW-Fed Small Slot Antenna for UWB Applications

A. Kamalvand [1], Ch. Ghobadi [2], J. Nourinia [3], M. Ojaroudi [4], and N. Ojaroudi [5]

[1] Sciences and Researches
Urmia Branch, Islamic Azad University, Urmia, Iran
asmakamalvand@hotmail.com

[2, 3] Department of Electrical Engineering
Urmia University, Urmia, Iran
ch.ghobadi@urmia.ac.ir, j.nourinia@urmia.ac.ir

[4] Young Researchers Club
Ardabil Branch, Islamic Azad University, Ardabil, Iran
m.ojaroudi@iauardabil.ac.ir

[5] Department of Electrical Engineering
Germi Branch, Islamic Azad University, Germi, Iran
n.ojaroudi@iaugermi.ac.ir

Abstract **─** In this paper, a novel multi-resonance small slot antenna with CPW feed-line and square radiating stub, for UWB applications is proposed. The proposed antenna consists of a square radiating stub with an inverted T-shaped slot and a ground plane with a T-shaped slit, which provides a wide usable fractional bandwidth of more than 145 % (1.89 GHz – 12.43 GHz). By cutting a T-shaped slit with variable dimensions on the ground plane, and an inverted T-shaped slot in the square radiating stub additional resonances are excited and hence much wider impedance bandwidth can be produced, especially at the lower and upper bands. The proposed antenna displays a good omni-directional radiation pattern even at higher frequencies. The designed antenna has a small size of 30×30 mm^2. Simulated and experimental results obtained for this antenna show that it exhibits good radiation behavior within the UWB frequency range.

Index Terms **-** CPW-fed microstrip slot antenna, multi-resonance performance, and ultra wideband application.

I. INTRODUCTION

Commercial UWB systems require small low-cost antennas with omni-directional radiation patterns and large bandwidth [1]. It is a well-known fact that printed microstrip antennas present really appealing physical features, such as simple structure, small size, and low cost. Due to all these interesting characteristics, printed microstrip antennas are extremely attractive to be used in emerging UWB applications, and growing research activity is being focused on them.

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, number of microstrip antenna with different geometries have been experimentally characterized [2-4] and automatic design methods have been developed to achieve the optimum planar shape [5, 6]. Moreover, other strategies to improve the impedance bandwidth, which do not involve a modification of the geometry of the planar antenna have been investigated [7, 8].

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In this paper, we propose a novel modified CPW-fed slot antenna with multi-resonance performance and increased impedance bandwidth, for UWB applications. In this design, the proposed antenna can operate from 1.89 GHz to 12.43 GHz and unlike other antennas reported in the literature to date, the proposed antenna displays a good omni-directional radiation pattern even at higher frequencies [6]. The modified inverted T-shaped slot acts as an impedance matching element to control the impedance bandwidth of the proposed antenna, also the inverted T-shaped slot in the ground plane can create additional surface current paths in the antenna therefore additional resonances are excited and hence much wider impedance bandwidth can be produced, especially at the lower and upper bands. Simulated and measured results are presented to validate the usefulness of the proposed antenna structure for UWB applications. The designed antenna has a small size of 30×30 mm^2. Good return loss and radiation pattern characteristics are obtained in the frequency band of interest.

II. ANTENNA DESIGN

The proposed slot antenna fed by a 50-Ohm co-planar waveguide (CPW) feed-line is shown in Fig. 1, which is printed on an FR4 substrate of thickness 1.6 mm and permittivity 4.4. The basic antenna structure consists of a square radiating stub with an inverted T-shaped slot, a CPW feed-line, and a ground plane with a T-shaped slit. The proposed antenna is connected to a 50 Ω SMA connector for signal transmission.

Based on electromagnetic coupling theory (ECT), by cutting a modified T-shaped slit of suitable dimensions at the ground plane, a new configuration can be constructed. In this structure, modified T-shaped slit of suitable dimensions at the ground plane is playing an important role in the broadband characteristics of this antenna, because it can adjust the electromagnetic coupling effects between the radiating stub and the ground plane, and improves its impedance bandwidth without any cost of size or expense. This phenomenon occurs because, with the use of a modified T-shaped slit structure, additional coupling is introduced between the upper edge of the square radiating stub patch and the ground plane [6]. The truncated ground plane is playing an important role in the broadband characteristics of this antenna, because it helps matching of the patch in a wide range of frequencies. Additionally, the modified inverted T-shaped slot acts as an impedance matching element to control the impedance bandwidth of the proposed antenna, because it can create additional surface current paths in the antenna therefore additional resonances are excited and hence much wider impedance bandwidth can be produced, especially at the lower and upper bands. This structure has a novel feeding configuration that consists of a splitting network connected to two symmetrical ports on its base. Using the theory of characteristic modes, it has been demonstrated that the insertion of two symmetric feed ports prevents the excitation of horizontal currents and assures that only the dominant vertical current mode is present in the structure [8]. As a result, an improvement in the polarization properties and impedance bandwidth of the rectangular monopole is achieved. This kind of excitation has recently been proposed for UWB application [8].

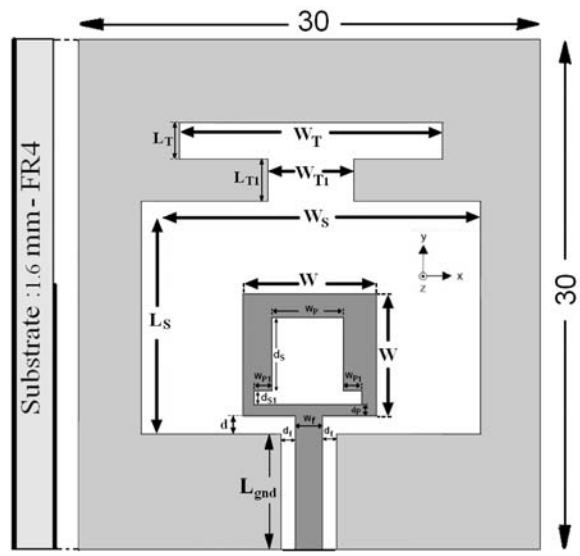


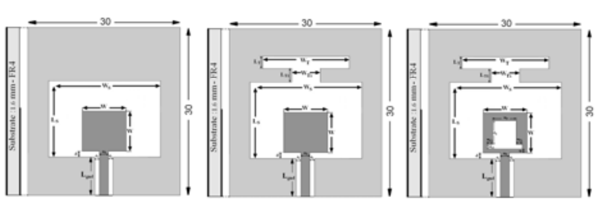
Fig. 1. Geometry of the proposed CPW-fed slot antenna.

The optimal dimensions of the designed antenna are as follows: W_S = 24 mm, L_S = 14 mm, d = 1 mm, W = 1.86 mm, d_f = 0.135 mm, W_f = 2 mm, W_T = 16 mm, L_T = 2 mm, W_{T1} = 4 mm, L_{T1} = 2 mm, W_P = 4 mm, d_P = 1 mm, W_{P1} = 1 mm, d_S = 4 mm, d_{S1} = 1 mm, and L_{gnd} = 7 mm.

III. RESULTS AND DISCUSSIONS

In this section, the CPW-fed slot 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 parameters of this proposed antenna are studied by changing one parameter at a time and fixing the others. The simulated results are obtained using the Ansoft simulation software high-frequency structure simulator (HFSS) [9].

Figure 2 shows the structure of the various antennas used for multi-resonance performance simulation studies. Return loss characteristics for ordinary CPW-fed ordinary slot antenna (Fig. 2 (a)), with a T-shaped slit in the ground plane (Fig. 2 (b)), and the proposed antenna structure (Fig. 2 (c)) are compared in Fig. 3. As shown in Fig. 3, it is observed that by using these matching elements including a coupled T-shaped slit, and an inverted T-shaped slot, additional third and fourth resonances are excited, respectively, and hence the bandwidth is increased. As shown in Fig. 3, in the proposed antenna configuration, the ordinary slot can provide the fundamental and next higher resonant radiation band at 2.4 GHz and 4.8 GHz, respectively, in the absence of these matching elements. To design a novel antenna, also in order improve the lower frequency bandwidth, a coupled T-shaped slit is cut in the ground plane as displayed in Fig. 2 (b). The upper frequency bandwidth is significantly affected by using the inverted T-shaped slot.



(a) (b) (c)

Fig. 2. (a) ordinary slot antenna, (b) antenna with a T-shaped slit in the ground plane, and (c) antenna with a T-shaped slit in the ground plane and an inverted T-shaped slot in the radiating stub.

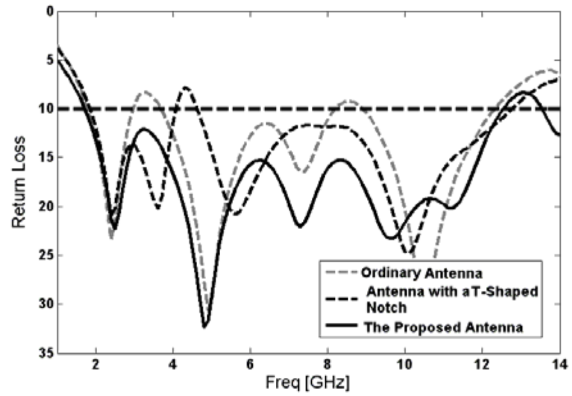


Fig. 3. Return loss characteristics for the various antenna structures shown in Fig. 2.

This behavior is mainly due to the change of surface current path by the dimensions of inverted T-shaped strip as shown in Fig. 4 (c) and (d). These figures show that the electrical current for the fourth (9.85 GHz) and fifth (11.35 GHz) resonance frequencies do change direction along the inverted T-shaped slot cut the square radiating stub. Therefore, the antenna impedance changes at these frequencies. In addition, by inserting matching elements the impedance bandwidth is effectively improved at the lower and upper frequencies [10].

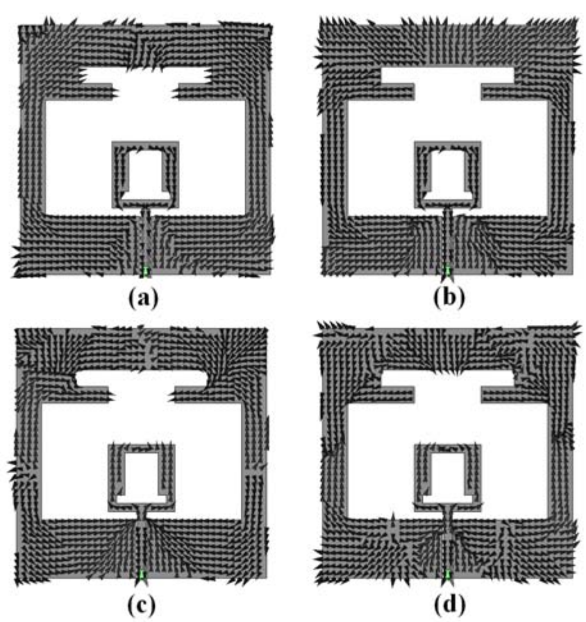


Fig. 4. Simulated surface current distributions for the proposed antenna at (a) 2.4 GHz, (b) 4.8 GHz, (c) 9.85 GHz, and (d) 11.35 GHz.

By properly tuning the dimensions of the inverted T-shaped slot, the antenna can actually radiates over a very wide frequency band. Figure 5 shows the effects of the W_{P1} on the impedance bandwidth. As illustrated in Fig. 5, the T-shaped slot is playing an important role in the broadband characteristics and in determining the sensitivity of impedance matching of this antenna [10, 11].

Another important parameter of this structure is the length L_{T1} of the T-shaped slit. By adjusting L_{T1}, the electromagnetic coupling between the top edge of the square stub and the ground plane can be properly controlled [10, 11]. Figure 6 shows the return loss characteristics simulated for different values of L_{T1}. It is seen that the upper-edge frequency of the impedance bandwidth is increased with increasing L_{T1}, but the matching became poor for larger values. Therefore the optimized L_{T1} is 2 mm.

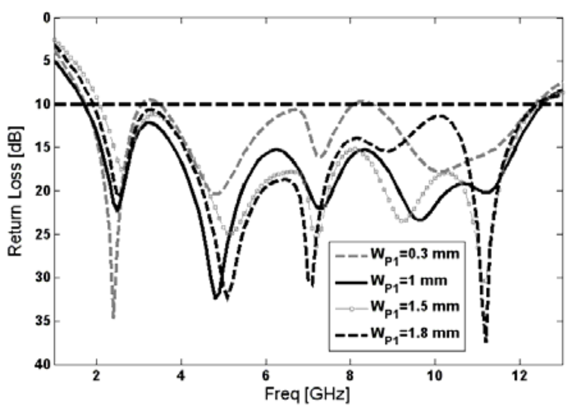


Fig. 5. Simulated return loss characteristics for the proposed antenna with different values of W_{P1}.

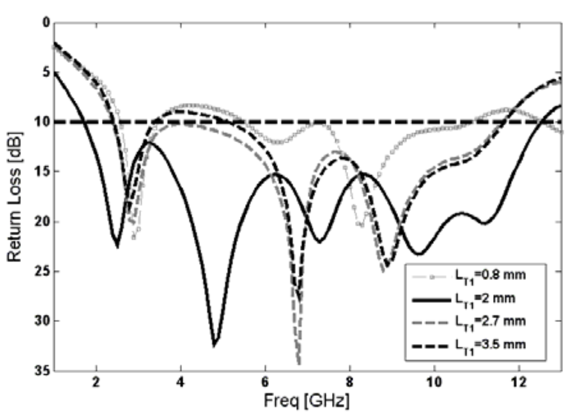


Fig. 6. Simulated return loss characteristics for the proposed antenna with different values of L_{T1}.

The proposed antenna with optimal design, as shown in Fig. 7, was built and tested. Figure 8 shows the measured and simulated return loss characteristics of the proposed antenna. The fabricated antenna has the frequency band of 1.89 GHz to over 12.43 GHz. As shown in Fig. 8, there exists a discrepancy between measured data and the simulated results this could be due to the effect of the SMA port, and also the accuracy of the simulation due to the wide range of simulation frequencies. In order to confirm the accurate return loss characteristics for the designed antenna, it is recommended that the manufacturing and measurement process need to be performed carefully.

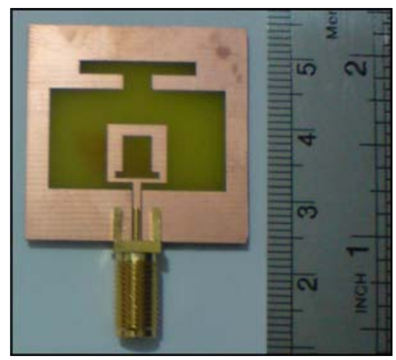


Fig. 7. Photograph of the realized printed CPW-fed slot antenna.

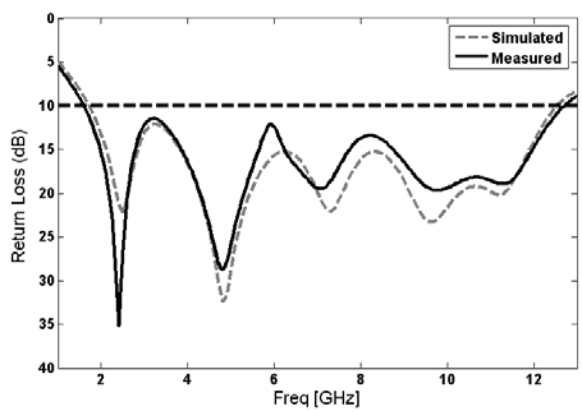


Fig. 8. Measured and simulated return loss characteristics for the proposed antenna.

Figure 9 shows the measured and simulated radiation patterns including the co- and cross-polarization in the x-z, y-z, and x-y planes. It can be seen that the radiation patterns in the x-z plane are nearly omni-directional for the three frequencies. As shown in Fig. 9 (b) and (c), the differences between maximum and minimum co-polarized patterns are around 10 dB or more in the x-z plane at 7 GHz and 10 GHz, respectively. This discrepancy between measured and expected results is mostly due to the small ground plane effects and the change of excited surface current distributions on the system ground plane at high frequencies.

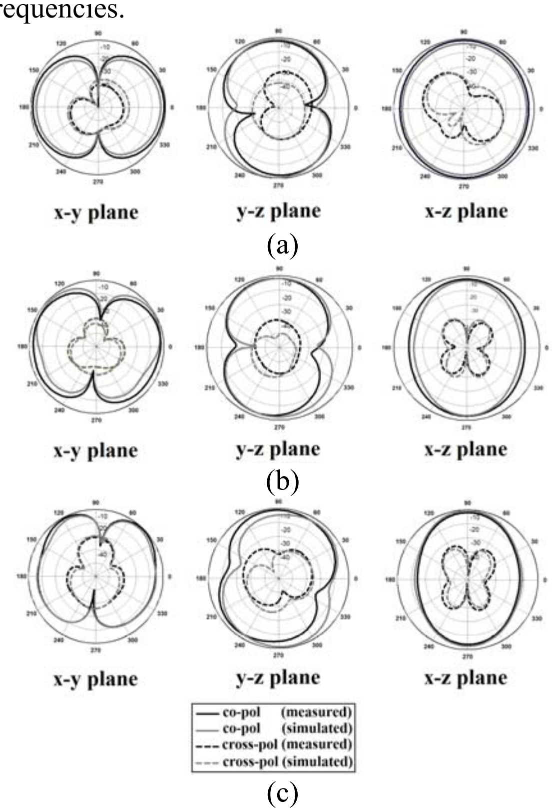


Fig. 9. Measured and simulated radiation patterns of the proposed antenna at (a) 4 GHz, (b) 7 GHz, and (c) 10 GHz.

Figure 10 shows the effects of the T-shaped slit in the ground plane and the inverted T-shaped slot in the radiating stub on the maximum gain in comparison to the same antenna without them. As shown in Fig. 10, the ordinary square antenna has a gain that is low at 3 GHz and increases with frequency. It is found that the gain of the square antenna is enhanced with the use of the inverted T-shaped slot in the radiating stub of the antenna. In addition, the ordinary square antenna with an inverted T-shaped slot has a flat gain. In this structure, inverted T-shaped slot in the radiating stub acts as a dual-fed structure, and it is created to enhance the gain of the square slot antenna at the lower and middle of the frequency band such that the gain of the proposed antenna over the complete bandwidth remains nearly constant. Another effective parameter on this structure gain is the T-shaped slit in the ground plane. It can be observed in Fig. 10 that by T-shaped slit in the ground plane, the gain of the square antenna is increased specially at the higher frequency.

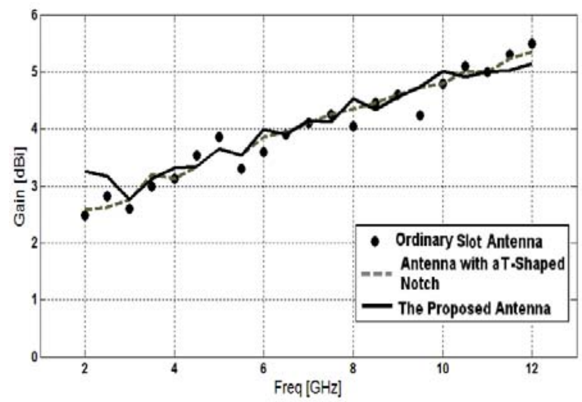


Fig. 10. Maximum gain comparisons for the ordinary square antenna (simulated), square antenna with a T-shaped slit in the ground plane (measured), and the proposed antenna (measured).

The time domain performance of UWB applications is important for pulsed based systems. In addition to radar and imaging applications, the standard has provided for their use in communications. While channel equalization is challenging for the propagation environment, the antenna features can be optimized to reduce their inherent pulse spreading effect. The group delay is defined as the negative derivative of the phase response with respect to frequency [3]. The group delay gives an indication of the time delay that the impulse signal suffers in proportion to various wavelength dimensions on the antenna. Group delays of the proposed antennas are shown in Fig. 11. The variation of the group delay of the proposed antenna is about 1 ns across the whole UWB frequency range.

IV. CONCLUSION

In this paper, a novel small slot antenna with wide bandwidth capability for UWB applications is proposed. In this design, the proposed antenna can operate from 1.89 GHz to 12.43 GHz with S_{11} < -10 dB and unlike other antennas reported in the literature to date, the proposed antenna displays a good omni-directional radiation pattern even at higher frequencies. The designed antenna has a small size. Good return loss and radiation pattern characteristics are obtained in the frequency band of interest. Simulated and experimental results show that the proposed antenna could be a good candidate for UWB application.

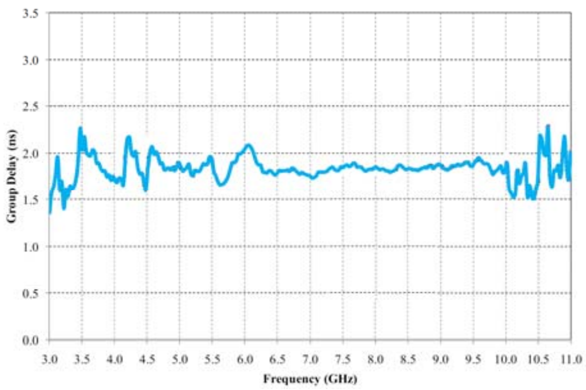


Fig. 11. Measured group delay characteristics for the proposed antenna.

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Asma Kamalvand was born in Khoramabad, Iran 1987. She received her B.Sc. in Electrical Engineering-Electronic from Azad University of Khoramabad, Iran, in 2009 and M.Sc. degrees in Electrical Engineering-Telecommunication from Sciences and Researches, Urmia Branch, Islamic Azad University, Urmia, Iran, in 2013. Her primary research interests are in printed microstrip antenna design.

Changiz Ghobadi was born in June, 1960 in Iran. He received his B.Sc. in Electrical Engineering-Electronic and M.Sc. degrees in Electrical Engineering-Telecommunication from Isfahan University of Technology, Isfahan, Iran and Ph.D. degree in Electrical-Telecommunication from University of Bath, Bath, UK in 1998. From 1998 he was an Assistant Professor and now he is an Associate Professor in the Department of Electrical Engineering of Urmia University, Urmia, Iran. His primary research interests are in antenna design, radar and adaptive filters.

Javad Nourinia received his B.Sc. in Electrical and Electronic Engineering from Shiraz University and M.Sc. degree in Electrical and Telecommunication Engineering from Iran University of Science and Technology, and Ph.D. degree in Electrical and Telecommunication from University of Science and Technology, Tehran Iran in 2000. From 2000 he was an Assistant Professor and now he is an Associate Professor in the Department of Electrical Engineering of Urmia University, Urmia, Iran. His primary research interests are in antenna design, numerical methods in electromagnetic, microwave circuits.

Mohammad Ojaroudi was born in 1984 in Germi, Iran. He received his B.Sc. degree in Power 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. Also from July 2013 he has been working, as a research visitor in University of Tennessee, Knoxville, USA. From 2007 until now, he is a Teaching Assistant with the Department of Electrical Engineering, Islamic Azad University, Ardabil Branch, Iran.

Since March 2009, he has been the chief executive officer in the Microwave Technology Company (MWT), Tehran, Iran. From 2012, Dr. Ojaroudi is a member of the IEEE Transaction on Antennas and Propagation (APS) reviewer group and the Applied Computational Electromagnetic Society. 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 120 journal and international conferences papers. His papers have more than 450 citations with 11 h-index.

Nasser Ojaroudi was born in 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 microstrip antennas for radar systems, ultra-wideband (UWB) and small antennas for wireless communications, microwave passive devices and circuits, and microwave/millimeter systems.