Progress In Electromagnetics Research, PIER 77, 137–148, 2007

A MODIFIED MICROSTRIP-FED TWO-STEP TAPERED MONOPOLE ANTENNA FOR UWB AND WLAN APPLICATIONS

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Abstract—This paper presents a novel modified Printed Tapered Monopole Antenna (PTMA) for ultra wideband (UWB) wireless communication applications. The proposed antenna consists of a truncated ground plane and two-tapered radiating patch separated by a slot (air gap) of different slopes, which provides a wideband behavior and relatively good matching. Moreover, the effects of a modified T-shaped slot inserted in the first tapered patch, on the impedance matching is investigated. The antenna has a small area of $23 \times 26.5\,\text{mm}^2$ and offers an impedance bandwidth as high as 100% at a centre frequency of 7.2 GHz for $S_{11} < -10\,\text{dB}$, which has an area reduction of 15% and a frequency bandwidth increment of 72% with respect to the previous similar antenna. The presented antenna covers the 5.2/5.8 GHz WLAN and 5.5 GHz WIMAX operating bands. Numerical analysis using Ansoft HFSS and measurement results is also presented in the paper.

1. INTRODUCTION

Wireless communications have been developed widely and rapidly in the modern world specially during the last decade. The future development of the personal communication devices will aim to provide image, speech and data communications at anytime, and anywhere around the world. This indicates that the future communication terminal antennas must meet the requirements of multi-band or wide-band to sufficiently cover the possible operating bands. However, the difficulty of antenna design increases when the number of operating frequency bands increases and cover an octave or more. In addition, for miniaturizing the wireless communication system, the antenna must also be small enough to be placed inside the system [1]. To achieve this, planar monopole antennas are good candidates for wide-band applications, as they exhibit wide impedance bandwidth, compact and simple structure, and ease of construction [1–8, 13]. Moreover, the omnidirectional radiation properties of monopole antenna make them very suitable for base-station and for indoor applications.

Recently, several microstrip slot antennas [11, 12] and planar monopole geometries such as circular, square, rectangular, elliptical, hexagonal and pentagonal, have been analyzed, providing wide impedance bandwidth. One of the best antennas in the last decade is the tap monopole antenna. The planar tap monopole antennas have been adopted and studied extensively for UWB communication systems because of their many appealing features such as simple structure, small size, wide impedance bandwidth and omnidirectional radiation patterns [1]. In [6, 7], two new small wideband planar monopole antennas with truncated ground plane using an L-shaped notch in the lower corner to achieve the maximum impedance bandwidth were proposed. In [1] a small printed tap monopole antenna (PTMA) for UWB wireless communication applications was designed and its numerical analysis was presented. In this design, a slit, tapered transition and two-step staircase notch are implemented to obtain the ultra wide bandwidth of the antenna. This antenna is a good candidate for hand-held UWB applications. In [5], a novel antenna topology was presented based on the PTMA. In this design, The antenna structure consists of a tapered radiating element fed by a microstrip line and a slot in the radiating element and in the ground plane, which yields a wideband behavior with a relatively good matching. The proposed antenna, with small size of $25.0 \times 28.5\,\mathrm{mm}^2$, was designed to operate over the frequency band between 3.11 and 7.30 GHz for $S_{11} < -10\,\mathrm{dB}$ (VSWR ≤ 2).

In this paper, a novel modified Printed Tapered Monopole Antenna (PTMA) for ultra wideband (UWB) applications is presented. Our new antenna, consists of a truncated ground plane and two-tapered radiating patch separated by a slot and with different slopes, which provide the maximum impedance bandwidth for UWB (3.1∼10.6 GHz) [10], WLAN (5.2/5.8 GHz) and WIMAX (5.5 GHz) applications. The proposed structure is designed based on the antenna presented in [5] but with a smaller size, lower cost and higher frequency bandwidth. In this paper, we investigate the effects of various slopes for the two-tapered patch and also insertion of a modified inverted T-shaped slot in the first tapered patch on the frequency bandwidth and impedance matching. The results of this paper are obtained from Ansoft HFSS simulations [9], which are based on the Finite Element Method (FEM).

2. ANTENNA DESIGN AND PARAMETERS

Figure 1 shows the structure and dimensions of the proposed antenna, whose conductor is fabricated on an inexpensive FR4 substrate with the dielectric constant of $\varepsilon_r = 4.4$ and the substrate thickness of $h = 1.6$ mm. The antenna shape and its dimensions were first designed based on the antenna presented in [5] and modified using the Ansoft High Frequency Structure Simulator (HFSS). Then the optimal dimensions were determined from experimental adjustment. The dimensions of the designed antenna, including the substrate, is $L \times W = 26.5\,\text{mm} \times 23\,\text{mm}$, or about $0.4\lambda \times 0.35\lambda$ at 4.6 GHz. A $50\,\Omega$ microstrip feedline with width of $W_1 = 3.4$ mm and length of 4 mm, is used to feed the antenna centrally from the bottom edge of the rectangular strip. The antenna is symmetrical with respect to the longitudinal direction.

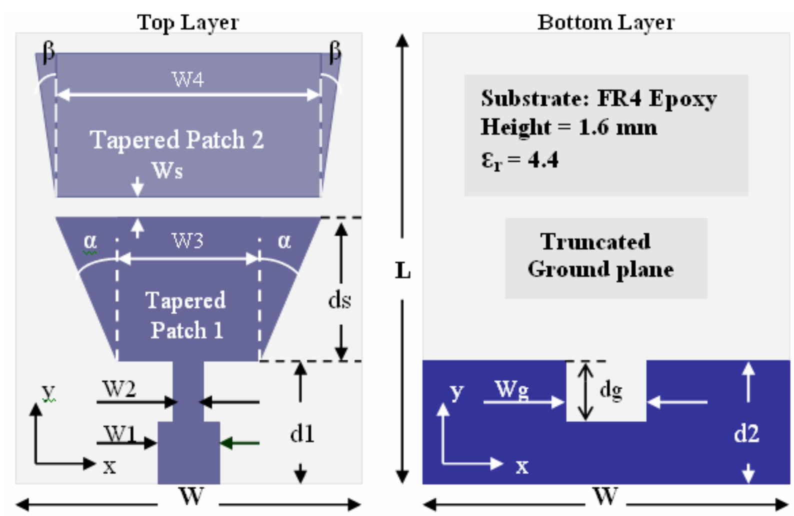

Figure 1. Configuration and parameters of proposed planar tap monopole antenna (PTMA) with two-tapered patch and truncated ground plane.

The basic antenna structure consists of a truncated ground plane and two-tapered radiating patch with different slopes separated by a slot of width $(W_s) = 0.2$ mm and length $(W_4) = 16.8$ mm. In this structure, the slot is added in the tapered radiating element, because provides a wideband behavior with a relatively good matching [5], also on the other side of the substrate, a conducting ground plane of width $(W) = 23$ mm and length $(d_2) = 7.8$ mm is placed. The modified truncated ground plane acts as an impedance matching element to control the impedance bandwidth of a square monopole [6], because it helps matching the patch with the two-step feedline in a wide range of frequencies. This is because the truncation creates a capacitive load that neutralizes the inductive nature of the patch to produce nearly-pure resistive input impedance [1]. The dimensions of the notch ($W_g \times d_g$) embedded in the truncated ground plane are important parameters in determining the sensitivity of impedance matching. In addition, to achieve good wideband matching of the proposed antenna, a separation $d = d_1 - d_2$ ($= 0.1$ mm) between the two-tapered patch and the notch in the ground plane is used. The introduction of a bevel increases the upper-edge frequency, and control of this frequency is possible by adjusting the bevel angle [8]. Therefor the two angles α and β (the slopes of tapered patch 1 and 2, respectively) are other important factors in determining frequency bandwidth and impedance matching.

3. NUMERICAL ANALYSIS AND RESULTS

The important parameters of proposed antenna are α, β, W_2 (the width of second step of the feedline), $d = d_1 - d_2$, W_s and d_s, all in the top layer and also W_g and d_g in the bottom layer. The parameters of this proposed antenna are studied by changing one parameter at a time and fixing the others. The constant factors of this proposed antenna are: $W_1 = 3.4$ mm, $W_3 = 5.0$ mm, $W_4 = 16.8$ mm, $W_s = 0.2$ mm, $d_s = 9.5$ mm, $W_g = 4$ mm and $d_g = 3.8$ mm.

The properties of three general cases specified by values of α and β are summarized in Table 1. Three particular cases where either or both of α and β is zero are specified in Table 2. We recall that in all of these cases W_3 and W_4 are constant.

Table 1. Three general cases of proposed antenna with different angles of α and β.

Case	α (deg)	β (deg)
1	13°	13°
2	31°	7°
3	20°	13°

The simulated VSWR curves for each case of Table 1 are plotted in Fig. 2. From the simulation results in Fig. 2, we found out that the frequency bandwidth and impedance matching of case 2 ($\alpha = 31°$ and $\beta = 7°$) are better than those of cases 1 and 3.

Table 2. Three particular cases of proposed antenna with different angles of α and β.

Case	α (deg)	β (deg)
1	0°	13°
2	31°	0°
3	0°	0°

Figure 3 shows the effect of α and β parameters (Table 2) in the two-tapered patch on the frequency bandwidth, impedance matching, higher and lower operating frequency. From the simulation results of Fig. 3, it is found that the optimized parameters of α and β are 31° and 0° (case 2), respectively. In the second case, the lower frequency is lowered and the upper frequency is markedly increased. The electromagnetic field coupling between two-tapered patches is effectively changed by varying the size of α and β. Moreover from Figures 2 and 3, consequently we conclude that the parameters of α and β are the critical factors to determine the upper and lower operating frequencies and impedance matching.

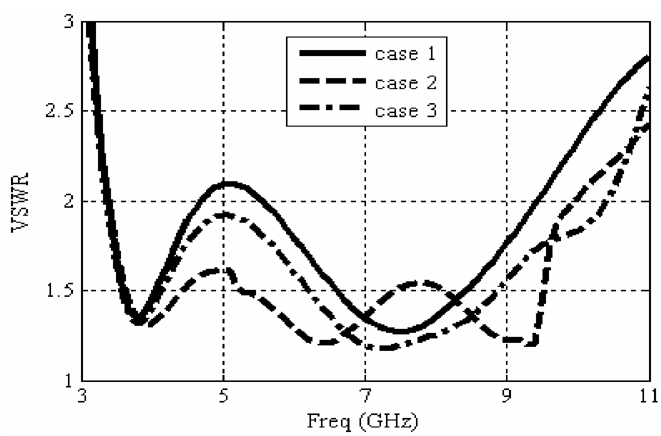

Figure 2. Simulated VSWR characteristics of the proposed antenna with different values of α and β (Table 1) and $W_3 = 5.0\,\text{mm}$, $W_4 = 16.8\,\text{mm}$.

Another important parameter of this structure is the width of the second step (W_2) in the feedline. Figure 4 shows the effects of W_2 on the impedance matching when $W_1 = 3.4\,\text{mm}$ and $W_3 = 5.0\,\text{mm}$. We have observed that the impedance matching is effectively changed by the varying the size of W_2, specially in the middle band. The optimized value of W_2 is chosen as 3 mm.

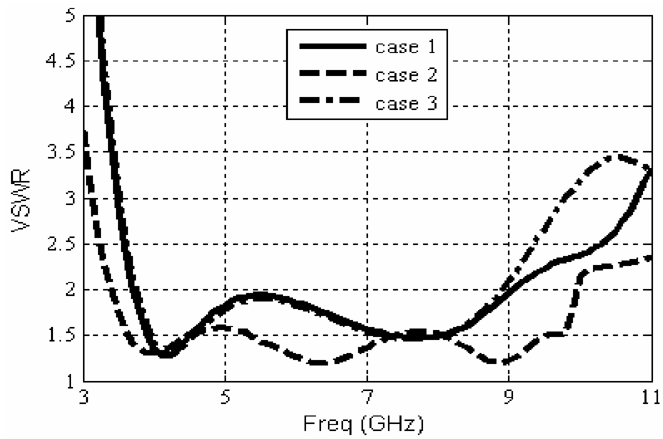

Figure 3. Simulated VSWR characteristics of the proposed antenna with different values of α and β (Table 2).

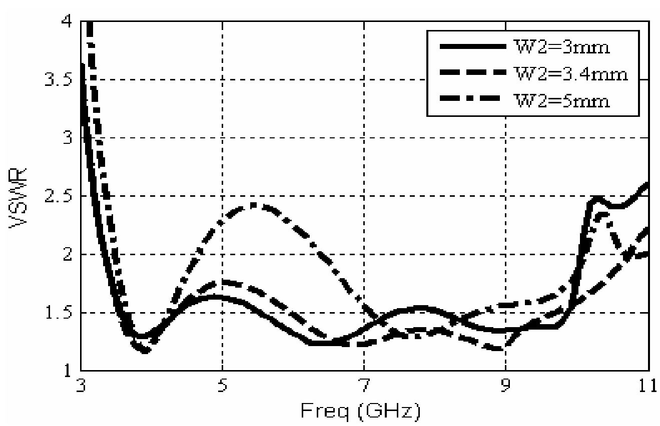

Figure 4. The effect of various W_2 (the width of the second step in the feedline) on VSWR.

At the end of our design procedure the final dimensions are summarized in Table 3. Figure 5, presents the photograph of a realized printed PTMA on an FR-4 substrate with SMA connector.

Figure 6 shows the measured and simulated VSWR characteristics for the proposed antenna. As shown in Figure 6, there exists a discrepancy between measured data and the simulated results

Table 3. Optimized parameters (mm).

Parameters	Values (mm)	Parameters	Values (mm)
L × W	26.5 × 23	d = d1-d2	0.1
W1	3.4	d2	7.8
W2	3.0	Ws	0.2
W3	5.0	ds	9.5
W4	16.8	Wg	4.0
α	31 (deg)	dg	3.8
β	13 (deg)		

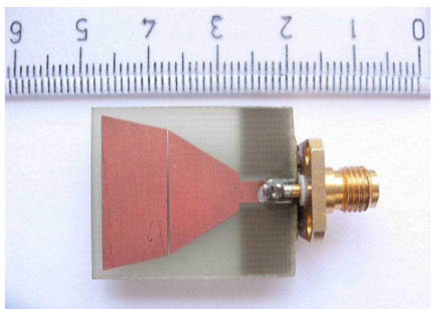

Figure 5. Photograph of the realized printed PTMA.

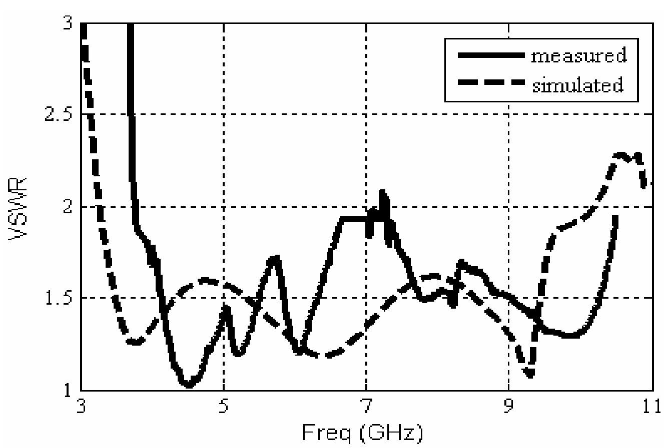

Figure 6. Measured and simulated VSWR for the proposed antenna.

at 4.5 GHz and 5.2 GHz. The measured impedance bandwidth is wider than simulated one. In order to achieve the accurate VSWR characteristics for the designed antenna, it is recommended that the manufacturing and measurement process need to be performed carefully. The fabricated antenna satisfies the 10 dB return loss (VSWR < 2) requirement for 5.2/5.8 GHz of WLAN and 5.5 GHz for WIMAX. Figure 7 shows the antenna gain from 3.5 to 10 GHz for the proposed antenna. The maximum gain variation is less than 2.2 dB with the peak antenna gain of about 6.0 dBi.

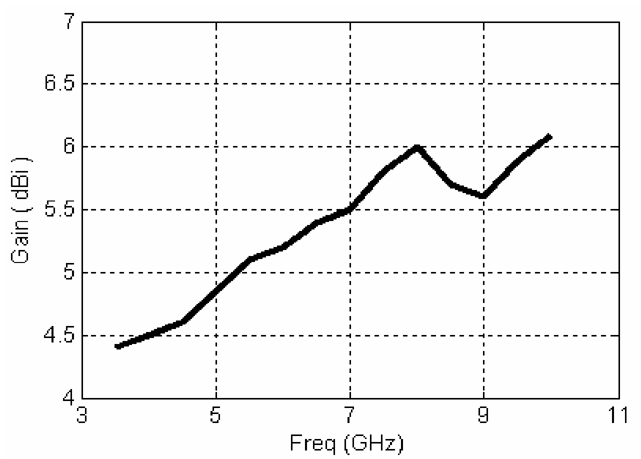

Figure 7. Simulated antenna gain of the proposed antenna.

Figure 8 shows the measured radiation patterns including the co-polarisation and cross-polarisation in the H-plane (x-z plane). It can be seen that the radiation patterns in x-z plane are nearly omnidirectional for the four frequencies, specially 5.2 and 5.8 GHz (WLAN).

A modified inverted T-shaped slot is inserted in the first tapered patch of the proposed antenna as displayed in Figure 9. Two such slots with different sizes are specified in Table 4 as case 1 and 2. Figure 10 shows the effects of T_1 and T_2 on the impedance matching in comparison with the same antenna without slot. It is found out

Table 4. Different values of T_1 and T_2 (parameters of T-shaped slot).

Case	T1 (mm)	T2 (mm)
1	5.5	4.5
2	2.0	9.0

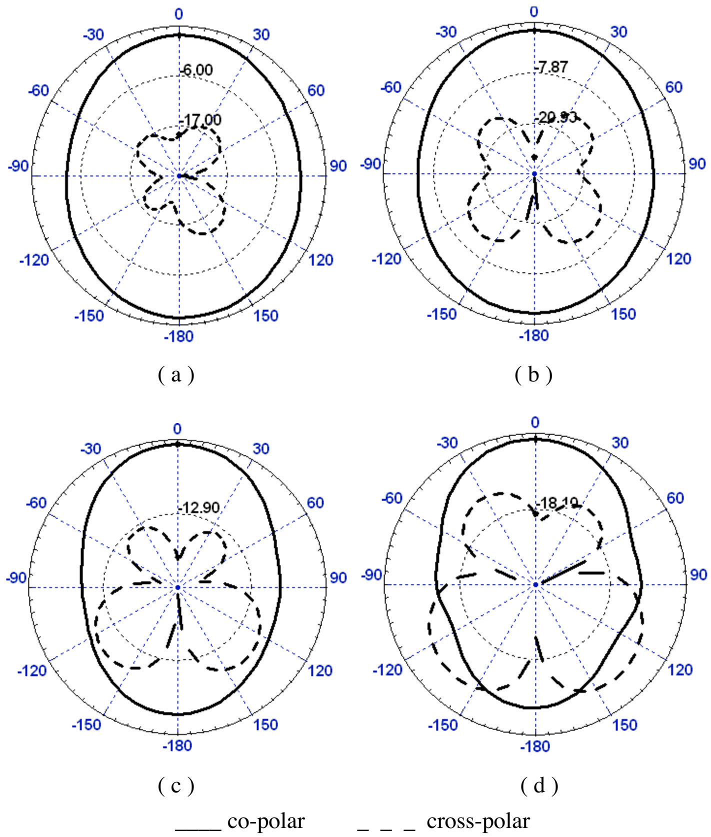

Figure 8. Measured radiation patterns (*H*-plane, *x*-*z* plane) of the proposed antenna at: (a) 4.2 GHz, (b) 5.2 GHz, (c) 5.8 GHz, and (d) 8.6 GHz.

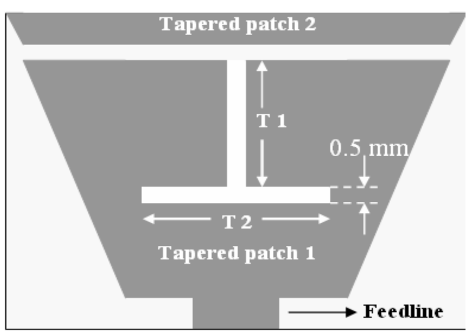

Figure 9. Geometry of the tapered patch 1 with a modified T-shaped slot.

that the impedance bandwidth increases when the length T_1 decreases and T_2 increases (case 2). On the other hand, the lower frequency is insensitive to the change of T_1 and T_2. The inserting of the modified T-slot, divides the surface current paths on the first tapered patch, therefore the electromagnetically coupling value between two-tapered patches is increased. Note that here the coupling in the right and left hands of the T-slot between two patches is considered.

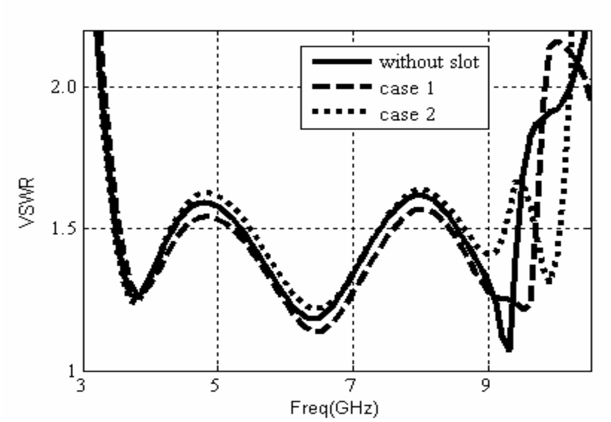

Figure 10. Simulated VSWR characteristics for the proposed antenna without slot and two cases 1 and 2 with slot as shown in Table 4.

4. CONCLUSION

A simple printed monopole antenna with two-tapered patch separated by a slot and truncated ground plane has been presented. The use of two-tapered patch with different slopes, a slot between them, our modified feeding structure and a slot in the ground plane has increased impedance bandwidth.

A better impedance matching can be achieved by insertion a modified T-slot on the first tapered patch and carefully choosing its parameters. The proposed antenna has the frequency band of 3.6 to over 10.8 GHz for VSWR less than 2.0, which has a bandwidth increment of 72% with respect to the previous similar antenna. This antenna covers the 5.2/5.8 GHz WLAN bands and 5.5 GHz WIMAX band. Experimental results show that the proposed antenna can be a good candidate for hand-held UWB, WLAN and WIMAX applications.

ACKNOWLEDGMENT

The authors are thankful to Iran Telecommunication Research Center (ITRC) for its financial support and also the Antenna Lab of the Khaje Nasir Toosi University of Technology (Tehran, Iran) where the proposed antenna has been tested.

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