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Miniaturized Dual-Band CPW-Fed Broadband Slot Antenna with Cross Tuning Stub for Wireless Communication Applications

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ABSTRACT

This paper presents the design and analysis of a multi-band coplanar waveguide (CPW) fed broadband square microstrip patch antenna. The proposed small broadband antenna has achieved frequency bands ranging from 4.3 to 8.05, 10.2 to 13 GHz, respectively, such that multi-operating bands cover IMT (4.4 - 4.9 GHz), ISM (5.725 - 5.875 GHz), Wi-MAX (5.25 - 5.854 GHz), and WLAN (5.15 - 5.35, 5.725 - 5.825 GHz) respectively at lower frequency band and ITU-RF.387 (10.7 - 11.7 GHz) at upper frequency band. The physical dimension of the proposed antenna is 19 (L) ×19 (W) × 1.6 (H) mm^3, which occupies a small volume and printed on FR- 4 epoxy substrate.

The antenna consists of a rectangular slot with cross like structure at the anterior portion of the feed line which acts as tuning stub [3]. The broadband antenna characteristics are obtained by optimizing the dimensions of tuning stub. The impedance bandwidth is mainly determined by the width and length of the tuning stub. The proposed antenna is simulated using CST V.12 microwave studio, and the performance of the antenna parameters has been measured and characterized in the terms of return loss, gain, bandwidth, radiation pattern and surface current distribution at the resonant frequencies respectively. The simulated results are confirmed by the successful design, using 50Ω CPW-fed line of antenna with return loss less than to -10 dB and VSWR < 2 dB [1-3].

Key words: CPW, International Mobile Telecommunication (IMT), Industrial, Scientific, and Medical (ISM), Wireless Local Area Network (WLAN), Worldwide Interoperability for Microwave Access (Wi-MAX), International Telecommunication Union-Radio Frequency (ITU-RF), CST.

1. INTRODUCTION

With the significant advancements in the wireless communications, there is a constant need to investigate and develop novel antennas and components to support modern communication systems, targeted for range of applications in satellite and mobile communications, personal communication, healthcare, defence, sports and public security. The antenna is a vital front-end component in any wireless system. Although many narrow and wide-band antennas have been designed over the past decades, still there are several challenges when designing such antennas for modern systems. These challenges include compactness, space constraints, desired radiation characteristics, low cost, light weight, multi-band operation, interference mitigation, re-configurability, and stable performance under varying conditions.

The recent development in communication system such as different application works over different frequency bands like GSM/UMTS/DCS/PCS/IMT, Bluetooth, ISM, Wi-MAX, and WLAN etc. Gain enhancement and size reduction are the major parameters for practical applications of microstrip antennas. Satellite and wireless communication often require antenna with compact size, low cost, ease of construction and capable of operating more than one band of frequency. This technique is focused the design of patch antenna and the references cited therein [4, 5].

Table 1: Various types are wireless communications operating bandwidths and its frequency bands range [5,10,11].

Wireless Operating Bands	Centre Frequency (f_C, GHz)	Frequency Band (GHz)	Bandwidth (MHz)
UMTS	$f_C = 2.1$	1.900 – 2.170	270
DCS	$f_C = 1.8$	1.710 – 1.880	170
PCS	$f_{C1} = 1.8$	1.750 – 1.870	120
	$f_{C2} = 1.9$	1.880 – 1.990	110
IMT	IMT-2000 fc = 2.0	1.920 – 2.170	250
	$f_{C1} = 2.3$	2.300 - 2.400	100
	$f_{C2} = 2.8$	2.700 – 2.900	200
	$f_{C3} = 3.8$	3.400 – 4.200	800
	$f_{C4} = 4.6$	4.400 – 4.900	500
Bluetooth	$f_C = 2.4$	2.402 – 2.480	78
ISM	$f_{C1} = 2.4$	2.400 – 2.485	85
	$f_{C2} = 5.8$	5.725 – 5.875	150
Wi-MAX	$f_{C1} = 2.5$	2.500 – 2.690	190
	$f_{C2} = 3.5$	3.400 – 3.690	290
	$f_{C3} = 5.5$	5.250 – 5.850	600
WLAN	$f_{C1} = 2.4$	2.400 – 2.484	84
	$f_{C2} = 5.2$	5.150 – 5.350	200
	$f_{C3} = 5.8$	5.725 – 5.825	100

The patch antennas have advantages like low profile, light weight, simple and inexpensive to fabricate. The disadvantages of microstrip patch antenna include narrow frequency, low bandwidth and low efficiency. In order to overcome the disadvantage of narrow bandwidth, several techniques have been employed [6, 7]. By incorporating a tuning stub, the bandwidth can be increased. The impedance bandwidth is mainly determined by the width and length of the tuning stub. By properly choosing the location and the size of the tuning stub, a wide impedance bandwidth can be obtained. Because the CPW-fed wide slot antennas have the advantages of wide bandwidth and easy integration with monolithic microwave integrated circuits, the designs of the CPW-fed wide slot antennas have recently received much attention [8, 9]. A few attempts have been made to increase the bandwidth of CPW-fed slot antennas, including the use of a wide rectangular slot or a bow-tie slot. Other broadband designs such as using a patch element loaded in a circular slot or the hybrid slot have also been used to obtain a multi-resonance response [10].

Multiple frequencies operation is necessary to wireless communication for application such as IMT, Wi-MAX, and WLAN etc. The multi resonant frequencies are obtained by optimizing the slot dimensions at various locations. The substrate used for the design of square patch antenna is FR- 4 epoxy with dielectric constant (ε_r) 4.4. The proposed antenna is fed by 50Ω CPW-fed line [11, 12].

Antenna design and structure is presented in section 2. The simulation and characterization results are described in section 3, and conclusion is given at section 4.

2. ANTENNA DESIGN AND STRUCTURE

The built-in antenna mounted in square shaped (L=W=20 mm) on the printed circuit board is shown in Figure 1. Main PCB layer has a FR- 4 epoxy substrate with thickness of 1.6 mm. The geometry of the proposed patch antenna is designed for broadband applications, which have operating in various types wireless communications frequency bands as likes IMT/ISM/Wi-MAX/WLAN, and ITU-RF.387 multi-bands.

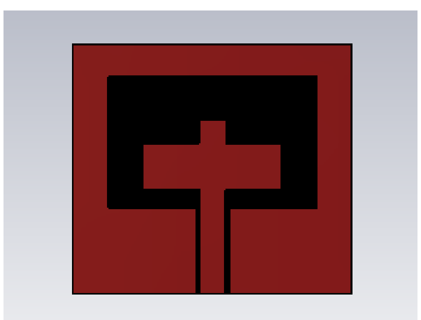


Figure 1: Geometry of proposed antenna

The radiating patch is made of copper and the rectangular shape with cross like structure. The tuning stub patch dimensions are (L2×W2, L3×W3) given in Table 2.

As the thickness and dimension of radiating patch is increased, the impedance bandwidth is broadened. However, the gain decreases. The resonant frequencies and impedance matching are mainly determined by the dimension and thickness of metal, substrate, and the location of slots. In order to obtain the multi-bands, the design parameters of antenna are tuned and optimized [13-16].

Table 2: Optimal parameter values are given of the proposed antenna [3].

Parameter	L_1	W_1	L_2	W_2	L_3	W_3	d
Unit (mm)	10	15	3.5	4	1.8	1.9	1

3. SIMULATION AND CHARACTRIZATION

The simulation of the designed structure is performed with CST-V.12 microwave studio. There is a good agreement with optimal parameter values (shown in Table 2) to each other. The simulated results obtained for return loss of the proposed antenna are shown in Figure 2(a).

The return loss of proposed antenna operates from 4.3 GHz to 8.05 GHz at lower frequency band (-30dB), and from 10.2GHz to 13GHz at upper frequency band (-58dB) respectivily, thus, the wide impedence bandwidth can be achieved. The lower frequency band covers IMT (4.4 - 4.9 GHz), ISM (5.725 - 5.875 GHz), Wi-MAX (5.25 - 5.854 GHz), and WLAN (5.15 - 5.35, 5.725 - 5.825 GHz) bands respectively at resonant frequency 5.5 MHz while the upper frequency band operates in ITU-RF.387 (10.7-11.7 GHz) band at resonan frequency 11.5 GHz (figure 2(a)).

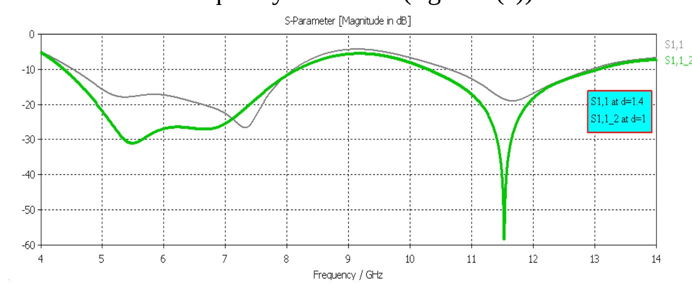


Figure 2 (a): Return loss at optimal parameter values, d =1.4 and 1.0 respectively

Voltage standing wave ratio (VSWR) is the ratio of peak amplitude of standing wave to the minimum amplitude of standing wave. It is a function of reflection coefficient which describes the power reflected from the antenna. The simulated VSWR of proposed antenna is shown in Figure 2(b).

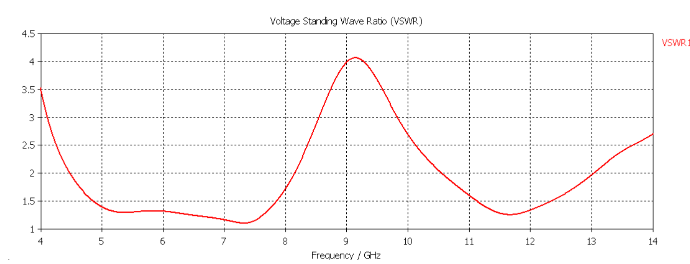


Figure 2(b): VSWR of proposed antenna

Figure 2(b) clearly shows the VSWR is less than 1.5 dB for wide band lower side frequency band from 4.3GHz to 8.05

GHz and 2 dB for narrow band upper side frequency band from 10.2GHz to 13GHz.

In this section, various parameters of the antenna for broadband applications have been analyzed. The analysis and optimization has been performed for the best impedance bandwidth. The optimal parameters values of the antenna are listed in Table 2. The simulated return loss (S_{11}) of the proposed antenna is shown in Figure 2(a), which indicates that the impedance bandwidth of the antenna have 3.75GHz (4.3 - 8.05GHz) and 2.8GHz (10.2 - 13GHz) at less than -10dB. The wide bandwidth is due to the coupling between the square slots and tuning stub. The resonant frequency and bandwidth are controlled by the size of the rectangular slot, antenna, and tuning stub respectively.

Simulated Results: Effect of cross length parameter, L_1 varies from 9 mm to 11 mm.

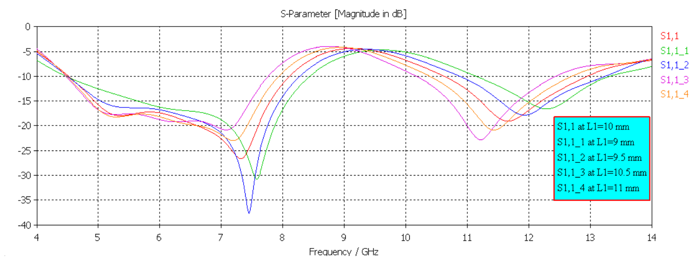


Figure 3(a): Return loss with different slot lengths, L_1

Simulated Results: Effect of cross width parameter, W_1 varies from 13 mm to 17 mm.

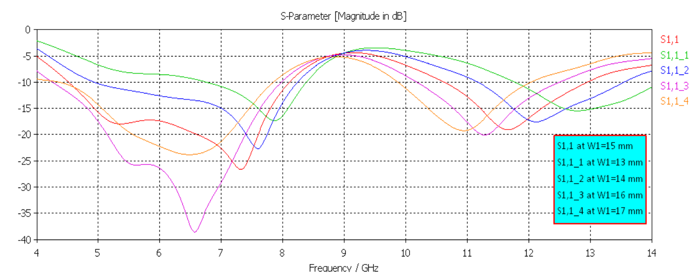


Figure 3(b): Return loss with different slot widths, W_1

Simulated Results: Effect of fed gap parameter, d varies from 0.6 mm to 2.1 mm.

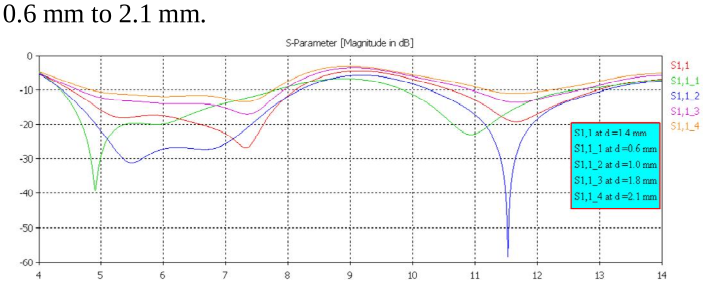
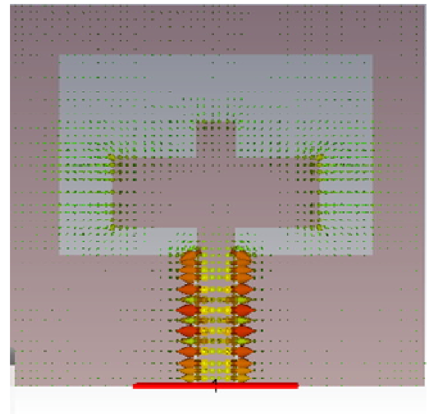
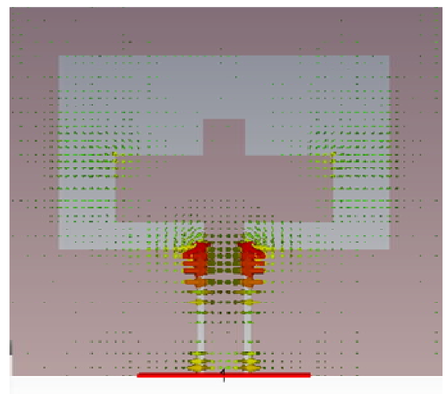


Figure 3(c): Return loss with different fed gaps, d

In order to check the current flow density at the resonant frequencies, the simulation results of the excited patch surface currents density at the maximum deep frequency 5.5 GHz, and 11.5 GHz respectively, are shown in Figure 4.



(a) At f_r = 5.5 GHz



(b) At f_r = 11.5 GHz

Figure 4: Surface current density of proposed antenna at resonant frequencies, (a) 5.5 GHz and (b) 11.5 GHz

The radiation pattern is defined as a mathematical function or a graphical representation of the radiation properties of space coordinates. In most cases, the radiation pattern is determined in the far-field region and is represented as function of the directional coordinates. This helps in better understanding about the variation of the radiation pattern in space. The simulated radiation patterns of the proposed antenna at 5.5 GHz, and 11.5 GHz along both y-z plane (E-plane) and x-z plane (H-plane) are illustrated in Fig. 5. At both resonant frequencies, it is seen that the proposed design exhibits a broadside radiation antenna and with the increase of frequency, the proposed antenna becomes more directive.

Table 3: Miniaturized designs against resonsnt frequencies indicate that feed-gap, d [5].

Antennas	**Length×Width ($L \times W$, mm^2)**	**Feed-Gap (d, mm)**	**Resonant Frequencies (f_r, GHz)**	
			f_{rL}, lower	f_{rU}, upper
Ref. [1]	19×20	1.0	6.0	12.2
		1.4	7.5	12.1
Proposed	19×19	1.0	5.5	10.5
		1.4	5.5	11.6

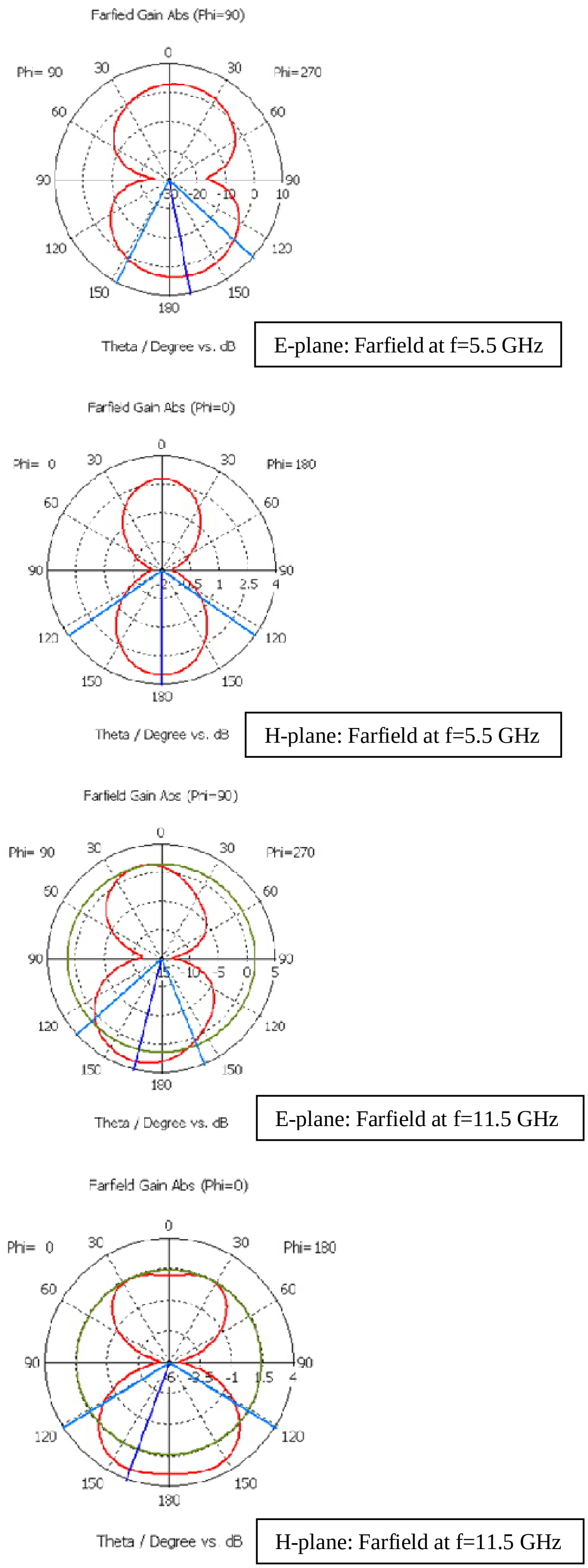


Figure 5: Farfield radiation pattern of proposed antenna at resonant frequencies, (a) 5.5 GHz and (b) 11.5 GHz

4. CONCLUSION

A CPW-fed broadband slot antenna suitable for IMT/ ISM/Wi-MAX/WLAN/ITU-RF.387 bands has been proposed and verified with simulation. The simulation results of the proposed antenna show a good agreement in term of the return loss, VSWR, and radiation patterns. As shown in Table 3, the simulated return loss of the miniaturized designs against frequency indicate that the feed-gap with d = 1.0 mm and 1.4 mm respectively, revealing two resonant frequencies shifted from 6.0 to 5.5, 7.5 to 5.5 GHz, respectively at lower frequency band and from 12.2 to 10.5, 12.1 to 11.6 GHz, respectively at upper frequency band. Two resonant bands of the miniaturized design show the size reduction 9.75% with broadside radiation patterns. Accordingly, this antenna is expected to be a good candidate in various broadband systems. These features are attractive for Wi-MAX (5.5 GHz), WLAN (5.8 GHz), and ITU-RF (11.2 GHz) internal antenna applications.

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