Development of New Slot antenna for Multifunctional Communication Systems

A.C.SHAGAR[1], R.S.D.WAHIDABANU[2]
*(Department of Electronics and Communication Engineering, Anna University of Technology-Tiruchirappalli, Tamilnadu) INDIA
** (Department of Electronics and Communication Engineering, Anna University of Technology-Coimbatore, Tamilnadu) INDIA

ABSTRACT

In this paper, a compact design and construction of a wide slot antenna fed by a coplanar waveguide (CPW) is proposed and developed for multifunctional communication systems. Detailed simulations and experimental investigations are performed to understand its behavior and to optimize for 2.4 GHz WLAN and ultra wideband operations. An FR4 substrate with a thickness of 1.6 mm and relative permittivity of 4.4 is used to design the antenna. The antenna has a corrugated stub with CPW feed technique, which improves the impedance matching between 2 GHz and 11.4 GHz for VSWR less than 2. By making a slot on the tuning stub, a notch band around 5.5 GHz is obtained. Prototype of the proposed antenna has been fabricated and measurement was done. The impedance bandwidth and radiation characteristics have also been investigated by using ADS simulation software. The measured and simulated results show excellent agreement.

Keywords **– Co planar Waveguide, Corrugated stub, New Slot antenna, WLAN and UWB, Notch-band**

I. INTRODUCTION

Recently, ultra wideband technology has received great attention in various fields for the short range (<10m) wireless communication systems, particularly in wireless multimedia system. This is because; it has many advantages over conventional wireless communication technology. These are high data rate (> 100 Mb/s), low power consumption, compactness, low-cost, excellent immunity to multipath interference and reduced hardware complexity. In 2002, the Federal Communications Commission (FCC) of the United State officially released the regulation for Ultra-wideband (UWB) technology [1]. In this regulation, the spectrum from 3.1 GHz to 10.6 GHz is allocated to the unlicensed indoor UWB communication systems. Therefore, one of the main issues in UWB communication system is the design of a compact antenna which provides wideband characteristics over the whole UWB range of frequencies. One of the major design considerations of a practical UWB antenna is the co-existence with existing narrowband communication systems. For instance, the 5-GHz band wireless local area network (WLAN) operates at the bands of 5.150–5.825 GHz (HIPERLAN/2: 5.150–5.350, 5.470–5.725 GHz, IEEE 802.11a: 5.150–5.350, 5.725–5.825 GHz), which will most probably interfere with UWB systems. In order to overcome this difficulty, a UWB antenna having notch band characteristics is necessary.

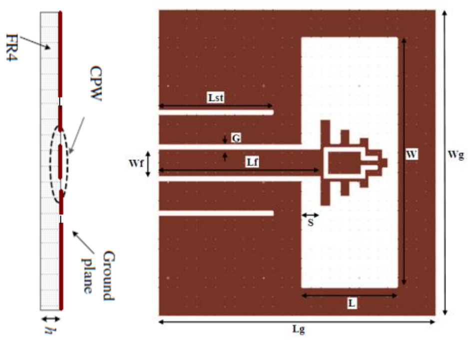
Based on the above requirements, many antenna configurations including planar monopole, dipole and slot antenna have been developed so far. In these antennas, a variety of shapes and bandwidth enhancement techniques has been studied. Several shapes such as diamond [2], ring [3], bow-tie [4], elliptical [5] and square shapes [6] have been proposed to satisfy UWB specifications. In these antennas, several bandwidth enhancement techniques are used to have a continuous UWB bandwidth. Many CPW-fed slot antenna configurations have also been proposed and developed. It includes wide rectangular slot [7], a bow-tie slot [8] and some other broadband designs such as using a patch element loaded in a circular slot [9] and a diamond patch in a rectangular slot [10]. To achieve frequency-rejected characteristic, different techniques are used including an embedded inverted U-shape [11], an embedded two slit on a circular monopole [12], adjusting a V-shaped thin slot length on the bow-tie shape slot antenna [13] and an embedded U-shape on a beveling rectangular patch [14]. A compact CPW-fed ultra-wideband antenna with band notched characteristic has also been studied [15]. In this study, a tuning stub is inserted in the middle of the fork-like patch to achieve the band rejection characteristic. Another compact antenna study has a C-shaped slot to obtain the band-rejection operation of the antenna [16]. A slot-type split-ring resonator (STSRR) is inserted into the center line of the CPW to notch the wireless local area network (WLAN) frequency band [17]. Nowadays, it is often required to design an antenna which can be used for multifunctional systems such as 2.4 GHz and UWB systems.

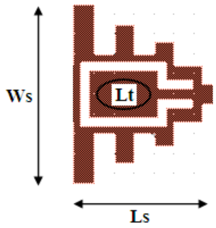
In this paper, a wideband CPW fed slot antenna with 5 GHz notch-band for applications in 2.4 GHz WLAN and UWB systems is proposed. By using corrugated stub and slits in the ground plane, a broad impedance bandwidth for 2.4 GHz WLAN and UWB is easily obtained. For the band-notched operation covering (5.15-5.825 GHz) WLAN band, a slot is embedded on the corrugated stub. By adjusting the length of the slot, the desired band-notched function is realized.

Experimental and simulated results of the constructed prototype are presented. Radiation patterns and current distribution characteristics are also discussed.

II. ANTENNA DESIGN

The configuration of the proposed antenna is shown in Fig.1. The substrate used for this design is FR4 with relative permittivity of 4.4 and thickness of h = 1.6 mm. Dimension of the ground plane is L_g x W_g mm. The antenna is located in y-z plane and the normal direction is parallel to x axis. As illustrated in the figure, a CPW which has a signal strip of thickness W_f and a gap of distance G between the signal strip and the coplanar ground plane is used to excite the rectangular slot. A corrugated stub is connected at the end of the CPW feed line and a wide rectangular slot with dimension W x L mm is etched in the ground plane to obtain wide bandwidth. The CPW feed with corrugated stub strongly influences the performances of wide slot antenna. The characteristic impedance of the CPW feed line is 50Ω. By choosing a suitable slot shape, stub shape and tuning their dimensions, the desired operating bandwidth is obtained in our design. Also, two slits are introduced in the ground plane to improve the impedance matching for 2.4 GHz WLAN. The slits lengthen the surface current to lower the antenna's fundamental resonant frequency. To implement notch band antenna design, a slot is embedded on the tuning stub. The length of the slot is varied to obtain the desired notch-band function. Indeed, the slot introduced inside the tuning stub destroys the surface current on the ground plane so that the antenna makes non- responsive at the notched frequency. The distance between the ground plane and the corrugated stub (S) is taken to be 1.9 mm to couple more energy between the feed line and the rectangular slot. Hence, the corrugated tuning stub along with the slot is the basis of the proposed antenna. The detailed dimensions of the proposed antenna are given in Table1.



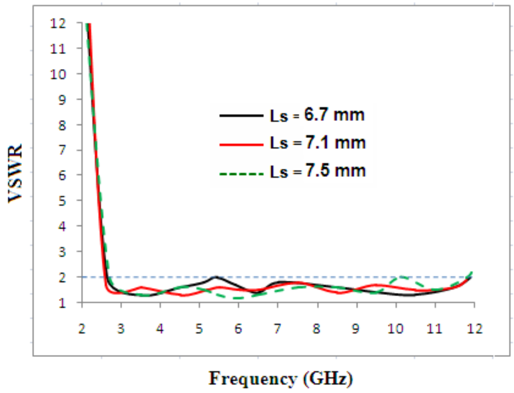


Corrugated stub

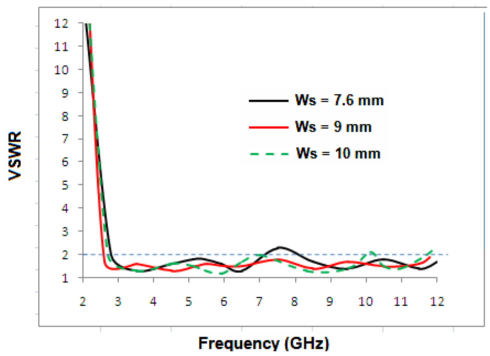
Fig.1 Geometry of the proposed antenna

In the parametric study, the width 'Ws' and length 'Ls' of the corrugated stub are varied and their effects on the impedance matching are investigated. The simulated VSWR curves of the CPW fed slot antenna for various values of 'Ls' and 'Ws' are illustrated as in Figures 3a and 3b. From the figures, it is seen that curves for different values of 'Ls' and 'Ws' have similar shape and variation trend. But, the optimum value is Ls = 7.1 mm and Ws = 9 mm (Fig.3) which has been found after performing an optimization and is identified in Table1; because, it provides the widest impedance bandwidth (2.2 – 11.8 GHz) for 2.4 GHz WLAN and UWB operations. The wide bandwidths are due to the resonances introduced by the combination of the rectangular slot and the corrugated stub. When proper dimensions (Ls and Ws) are selected, the resonant modes are shifted close to the antenna's fundamental resonant mode, resulting in high impedance bandwidth for 2.4 GHz WLAN and UWB systems. In order to improve the impedance matching further, two slits are also made in the ground plane so that the antenna covers (2 – 11.6 GHz) bandwidth. Each slit is 12 mm in length parallel to the CPW feed line. All the dimensions are summarized in Table 1.

Fig.2 Photograph of the proposed antenna



(a)



(b)

Fig.3 VSWR values in terms of (a) L_s and (b) W_s

The influence of slot embedded on the corrugated stub is also investigated for notch band function. Fig.4 shows the simulated VSWR of the proposed antenna with different length 'Lt' of slot (its width is kept at 0.4mm).

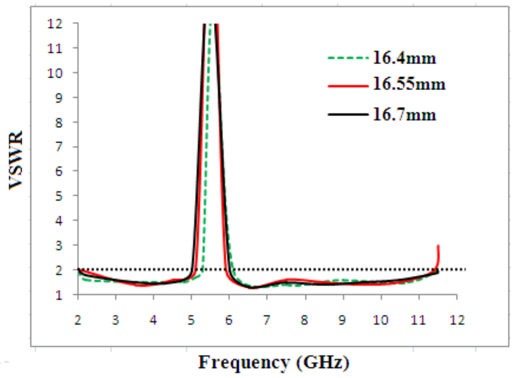


Fig.4 VSWR values in terms of slot length Lt

From the figure, it is observed that the length of the slot line in the stub determines the frequency range of the notched band. As 'L_t' increases, the centre frequency of the notched band shifts towards the lower frequency.

Parameters	Optimum Values (mm)
L_g	29
W_g	32
L	10
W	26
L_f	16.9
W_f	2.8
G	0.5
S	1.9
L_s	7.1
W_s	9
L_t	16.5
L_{st}	12

TABLE 1

With the increasing of 'L_t' from 16.4 mm to 16.7 mm, the center frequency shifts from 5.57 to 5.4 GHz. Therefore, when 'L_t' is 16.55 mm, the notch band is from 5.1 to 5.9 GHz centered at 5.5 GHz. From this, it can be concluded that the rejected band is easily obtained by tuning the length of the slot introduced inside the stub. Finally, the antenna covers a wide bandwidth between 2 GHz and 11.4 GHz.

III. RESULTS AND DISCUSSIONS

(a) VSWR Vs Frequency:

The designed antenna is modeled and simulated using momentum software package of the Advanced Design System and CST microwave studio. The proposed antenna was constructed as shown in Fig.2 and VSWR Vs frequency of the antenna was measured by a HP8722ES vector network analyzer. Fig.5 shows the measured VSWR which is compared with the simulated result. Result of the antenna without slot in the stub is also given. Simulation and measurement results show that the proposed antenna performs well over the required frequency bands. i.e. it yields a wide bandwidth ranging from 2 to 11.4 GHz for VSWR less than 2, which covers the 2.4 GHz WLAN and UWB bands with notch-band from 5.1 to 5.9 GHz. Hence, basic agreements are achieved between the simulated and the measured results. The differences between them might be caused by the fabrication error and soldering effects of SMA connector. Fig.6 shows the impedance of the proposed antenna over the operating frequency from 2 to 12 GHz. It confirms the impedance matching performance between 2 GHz and 11.4 GHz with notch band function (5.1- 5.9 GHz).

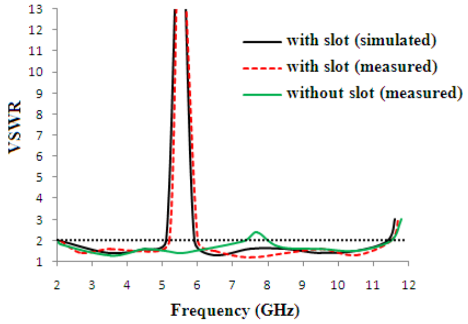


Fig.5 Comparison of simulated and measured results of the antenna

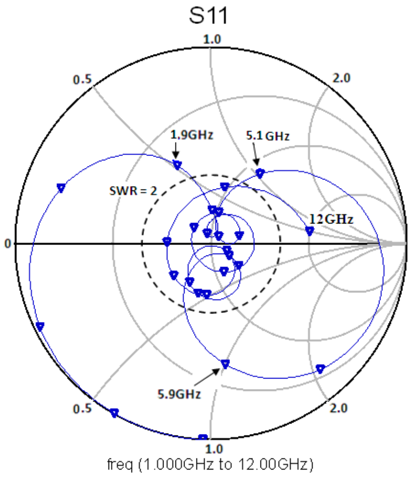


Fig.6 Simulated input impedance on Smith chart

(b) Radiation pattern and Gain:

The radiation patterns and gain measurements are performed in anechoic chamber of Antenna Laboratory. The radiation characteristics of the antenna were experimentally investigated across the impedance bandwidth of (2 - 11.4 GHz). Fig.7 shows the measured radiation patterns at 2.4 GHz, 4 GHz, and 9 GHz in the two principal planes, namely the x-z and x-y planes. As shown, a figure of eight pattern in the E-plane and nearly Omni directional pattern in the H-plane is obtained. In the patterns, both co-polarization (solid line) and cross polarization (broken line) are shown. Radiation patterns are acceptable over the whole 2.4 GHz WLAN/UWB bandwidth. Also, it is observed that radiation patterns at other frequencies out of the notched frequency band are about stable, suggesting the usefulness of the antenna in the entire band.

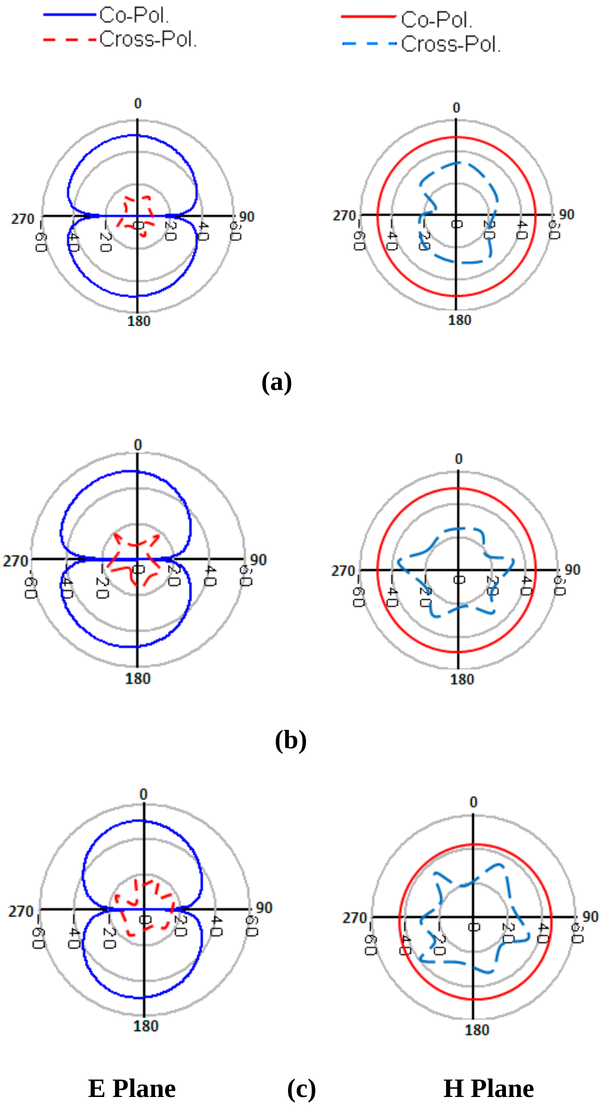


Fig.7 Radiation patterns at (a) 2.4 GHz (b) 4 GHz and (c) 9 GHz

Fig.8 shows the measured gain Vs frequency of the proposed antenna. Gain of the antenna without slot on the stub is also included for comparison. For the antenna without slots, the peak gain is relatively constant over the band from 2.2 to 11.8 GHz. But, for the proposed antenna, a sharp gain decrease occurs in the vicinity of 5.5 GHz due to the frequency notched function and the peak gain is nearly constant outside the notched band from 2 to 11.4 GHz. Thus, the antenna exhibits a stable gain across the operation band. These factors demonstrate the band notched function of the proposed antenna.

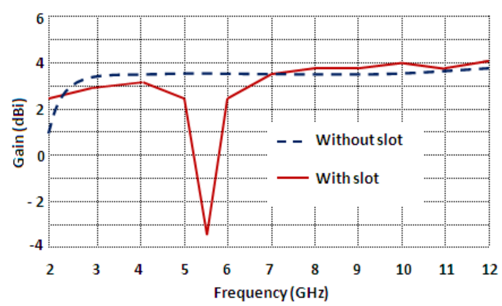
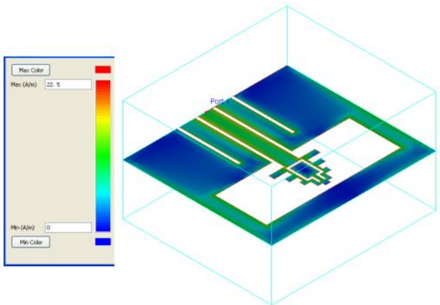


Fig.8 Peak gain of the proposed antenna

(c) Current Distributions:

The surface current distribution has been studied using ADS simulation tool. Fig.9 shows the simulated current distributions of the proposed antenna at frequencies 2.4 GHz and 5.5 GHz. At frequency 2.4 GHz, the maximum current flow occurs and the antenna radiates signal (Fig.9a). But, at the notch band centre frequency 5.5 GHz, current is concentrated around the edge of the slot on the corrugated stub while there is almost no current at the feeding point. Therefore, it prohibits the current flow at that frequency, giving maximum attenuation. Therefore, there is no radiation (Fig.9b).



(a)

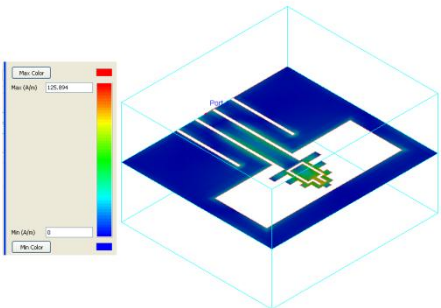


Fig.9 (a) radiation at 2.4 GHz and (b) No radiation at 5.5 GHz

IV. CONCLUSION

A compact design and construction of a wide slot antenna fed by a coplanar waveguide (CPW) has been developed for multifunctional communication systems. Detailed simulations and experimental investigations were performed to understand the behavior of the proposed slot antenna for 2.4 GHz WLAN and ultra wideband systems. The antenna has a corrugated stub with CPW feed technique, which improves the impedance matching for 2.4 GHz WLAN and UWB operations. Band notch function was also explored. Prototype of the proposed antenna has been fabricated and measurement was done. The antenna has VSWR value less than 2 between 2 GHz and 11.4 GHz. The performance analysis such as the radiation pattern, antenna gain and current distribution was discussed. It shows better performance over the required bandwidth.

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