A New Design and Analysis of Microstrip-fed Ultra-wideband Printed Monopole Antenna

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***Abstract*— A new microstrip-fed monopole antenna with simple planar structure of size *24×28×1.6* mm^3 is presented for ultra-wideband (UWB) applications. The antenna structure consists of V-shaped patch, microstrip-fed line and partial ground plane structure. With the inclusion of U-shaped slot on to the patch, a frequency notched characteristics is achieved which can reject the frequency band of 5.15- 5.825 GHz. The effects of dimensional parameters on antenna performance such as length and width of U shaped slot, size of the ground plane have been investigated through a parametric study and design results from parametric simulations are presented. The electric current distributions on the patch are also exhibited in this paper. Simulation results confirm that the presented antenna has a large bandwidth below (S11≤ -10 dB) covering the ultra-wideband frequency range of (3.15-13.2 GHz) with band notch characteristics at WLAN band. The proposed antenna creates a monopole like pattern in the E-plane and omnidirectional radiation pattern in the H-plane.**

***Index Terms*— UWB, monopole antenna, printed antenna, notch band.**

I. Introduction

Ultra-wideband (UWB) technology has developed rapidly over the past several years due to its high date rate in short range communication. As the antenna is the essential part for UWB technology, both at the receiver and at the transmitter, subject to performance requirements while at the same time supporting demand constraints to incorporate it in terminals, a lot of effort has been expended to date on the development of UWB antenna. The advantages of microstrip antennas such as lightweight, compact and cost effective create them a good contestant for UWB antenna design. However, the main disadvantage of microstrip patch antennas is their narrow bandwidth. Therefore, various designs and techniques have been reported in the literature to improve their bandwidth, including the use of thicker substrates, different shape patches and probes, addition of parasitic patches [1]–[4] and cutting of slot [5].

Recently, different types of microstrip antennas for UWB technology have been examined and implemented with different feed lines, such as microstrip line [6–15], coplanar waveguide (CPW) [16–22], and double-sided microstrip antennas with a modified ground plane. For example in [9] to enhance the impedance bandwidth, antenna parameters are optimized and the ground plane is modified by cutting slots on the top edge to form a symmetrical saw-tooth shape. Furthermore, miniaturization of antennas is also a highly desired attribute, and it represents another challenge in the design of such antennas. There have been many papers about the UWB antenna [23], but these antennas contain many parameters for the complicated structures leading to increased fabrication costs and antenna size. Hence, the aim of this paper is to present a new UWB microstrip antenna with a compact size that operates across the entire ultra-wide spectrum defined by FCC. The characteristics of the presented antenna are investigated through a parametric study. The simulated results show ultra-wide bandwidth performance and stable omni-directional radiation patterns. In addition, the physical size of the proposed antenna is substantially smaller than recently developed UWB antennas in [24] by 42.4%, and in [25] by 37.2%. Moreover, the presented design offers a chance to implement notch characteristic on the antenna itself to create a band rejection in the WLAN range so as to allow the UWB system to operate smoothly without any sort of interference.

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II. Antenna Structure and Design

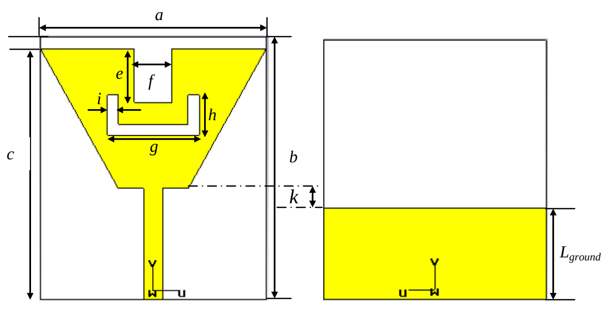

Fig.1 Geometry of proposed antenna (a) top view (b) bottom view

The geometry of the antenna is shown in Fig. 1 which comprises of V-shaped patch, microstrip feed and partial ground plane structure. The surface area of proposed design is *24×28* mm^2. The antenna feed structure consists of a microstrip line of width *2* mm connected to the radiating patch. The patch and feed line are printed on the top side of the FR4 substrate with dielectric constant of *4.4*, loss tangent of *0.02* and thickness of *1.6* mm. The ground plane is printed on the bottom side of the substrate. The antenna is symmetrical and the length of the arms is equal. The height of the feed gap between the radiator and the ground plane is "*k*". The optimized parameter values are given in Table 1. The antenna is located in the *x*-*y* plane and the normal direction is *z*-axis.

TABLE I. PARAMETER VALUES OF THE PROPOSED DESIGN.

Parameter	*a*	*b*	*c*	*e*	*f*	*g*	*h*	*i*	*k*	L_{ground}
value, mm	24	28	26.7	6.7	4	9.8	4.3	1.2	2.1	9.8

III. SIMULATION RESULTS

The simulated VSWR and S_{11} of the presented microstrip antenna with U-shape slot are shown in Fig. 2 and Fig. 3 respectively. The S_{11} characteristic of the antenna shows that it has a suitable impedance match over a wide frequency band of less than 10 dB. The simulated S_{11} of reference antenna without notched characteristics is also shown in Fig. 4 for comparison. The 2:1 VSWR impedance bandwidth is 10.15 GHz (3.15-13.2 GHz) which is about 124% bandwidth. The band rejection frequency can be changed by the length of U-shaped slot with other parameters fixed.

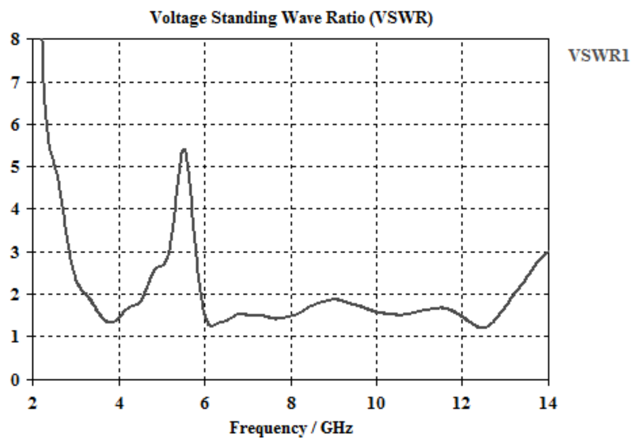

Fig. 2. Simulated VSWR for proposed antenna

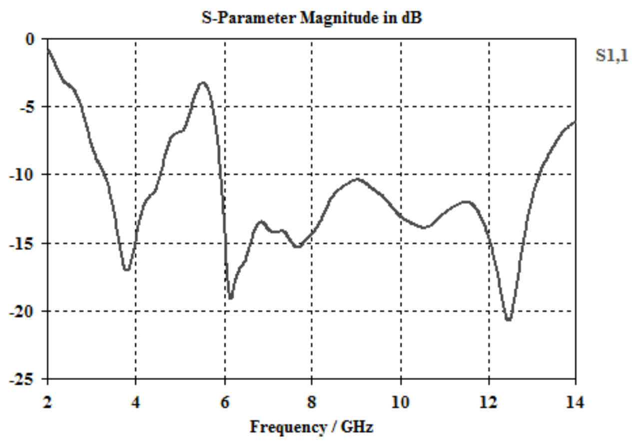

Fig. 3. Simulated S_{11} for proposed antenna.

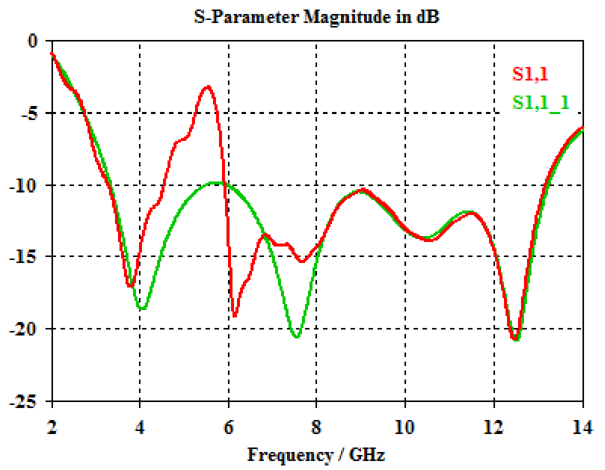

Fig. 4. Simulated S_{11} for proposed antenna with(red) and without (green) U-shaped slot

The return loss only describes the behaviour of the antenna as a lumped load at the end of the feeding line. However, Omni-directional radiation patterns are often required for UWB applications. As a result, radiation pattern is important to estimate the performance of UWB antenna. The radiation pattern is related to the current distribution of the antenna over the frequency range of operation. Therefore, current distribution of the proposed antenna are computed which are presented in Fig. 5. Fig. 5a shows the electric current distribution at 3.5 GHz. As shown in Fig. 5a, the electric current is mainly distributed on the top edge of the ground plane and in the outer edge of the V-shaped patch. The strong current distribution on the upper edge of the ground plane confirms that this portion of the ground plane which is near to the V-shaped patch acts as a part of the radiating structure. Consequently, the ground plane width affects the impedance matching. The Fig. 5b shows the electric current distribution at notch frequency 5.5 GHz. As shown in Fig.5b, the current is concentrated around the inner edge of two vertical arms of U-slot and is oppositely directed. As a result, the fields cancel each other at the notch frequency which in turn leads to the desired high attenuation near the notch frequency. The electric current distribution at 8 GHz is given in Fig. 5c. It is observed that the current distribution is more complicated than 3.5 GHz frequency current distribution. It is mostly distributed in the lower portion of the patch radiator and on the upper edge of the ground plane. As a result, the feed gap, the ground plane width strongly affects the antenna return loss curve. Fig. 5d shows the electric current distribution at 11.5 GHz. The current is distributed on the top edge of the ground plane and on the outer edge of the patch in the lower portion of the patch radiator. The current distributions on the antenna ground plane at the different frequencies confirm that the top edge of the ground plane is a part of radiating structure. It is observed that by increasing the frequency, the current distributions are more complicated, which affect the antenna patterns. It is also noticed that based on the difference among current distributions at lower frequencies and higher frequencies, the patterns of the antenna at lower frequencies differ from the patterns at higher frequencies.

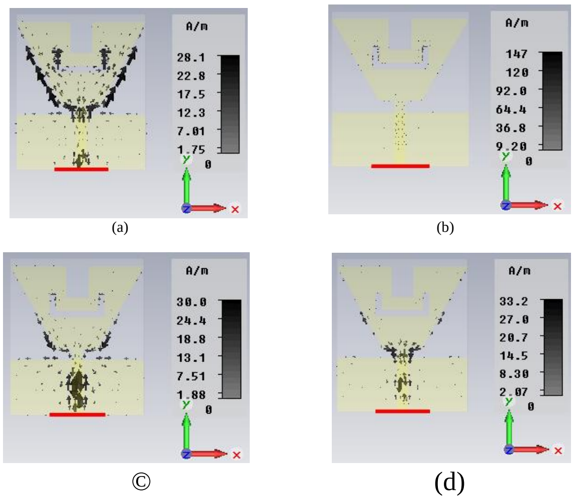

Fig. 5. Simulated current distribution (a) (f=3.5 GHz) (b) (f=5.5 GHz) (c) (f=8 GHz) (d) (f=11.5 GHz)

The radiation pattern of the presented antenna is shown in Fig. 6. The normalized results clearly show the stable omnidirectional behaviour in the H-plane and unsymmetrical bidirectional in the E-plane. It is obvious from these results that the omni-directional radiation patterns are acceptable over the UWB bandwidth.

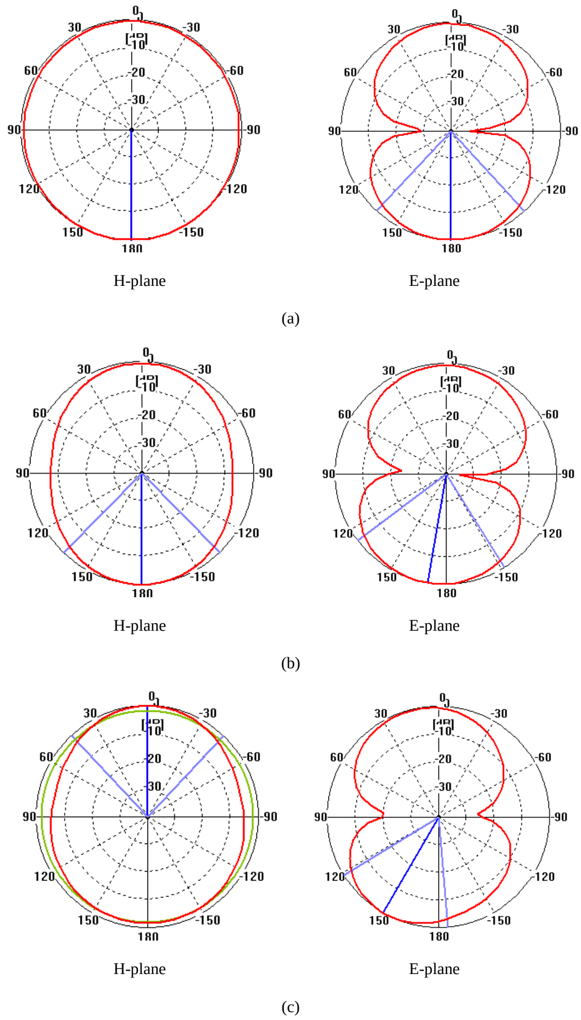

Fig.6 Normalized radiation pattern of the proposed antenna at different frequencies (a) 3.5GHz (b) 5.5GHz (c) 8 GHz

The next step will be fabricating and measuring the performance of the antenna which is not possible at this moment as we don't have equipment at our institution. However, a parametric study has been done to estimate the performance of the antenna using CST MWS and the results look credible indeed.

IV. Effects of Key Parameters

A. *Feed Gap Effects*

The electric current, which is distributed around the feed gap, as shown in Fig. 5, indicates that it affects the return loss performance of the antenna. As shown in Fig. 1, the feed gap represented by *'k'* is the distance between the radiating element and the ground plane. The simulated return loss for different values *'k'* is exhibited in Fig. 7. The results show that by decreasing *'k'*, the return loss response improves (between 3.15–5 GHz and between 6 and 11 GHz); however, the impedance bandwidth of the antenna decreases. To have a wider impedance bandwidth, the feed gap needs to be optimized. It is noticeable that the values of *'k'* in Fig. 7 cover the UWB spectrum defined by the FCC.

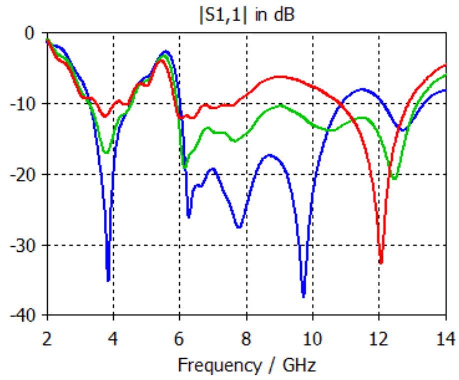

Fig. 7 Simulated return loss performance as a function of antenna parameter *'k'* (Feed gap, red=3.05 mm, green=2.05 mm, blue=1.05 mm)

B. *Effect of the ground plane width*

Since the ground plane acts as a radiator, its dimensions influence the antenna's return loss characteristics. Fig. 8 depicts the return loss curves for various value of *"a"*. Other parameters are as presented in *Table 1*. There are no significant effects on the lower edge of the return loss curves but it can be seen that these variations affect the upper edge of the return loss curves. It can be also seen that a change in the ground plane width shifts the resonance frequencies. Owing to the upper edges shift influences the antenna impedance bandwidth.

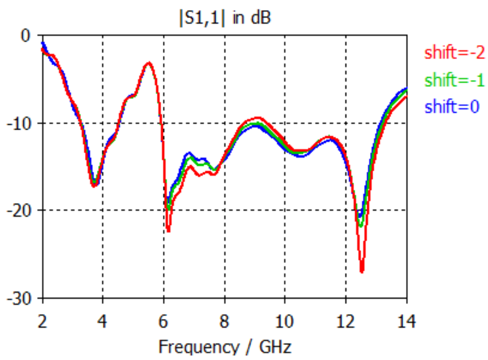

Fig. 8 Simulated return loss performance as a function of antenna parameter '*a*'

C. *Effect of the length of U-shaped slot*

The simulated return loss curves with different values of slot length are plotted in Fig. 9. As the slot length increases from 4.3 to 6.3 mm, the centre frequency of notch band is varied from 4.5 to 5.5 GHz. From these results, we can conclude that the notch frequency is controllable by changing the slot length.

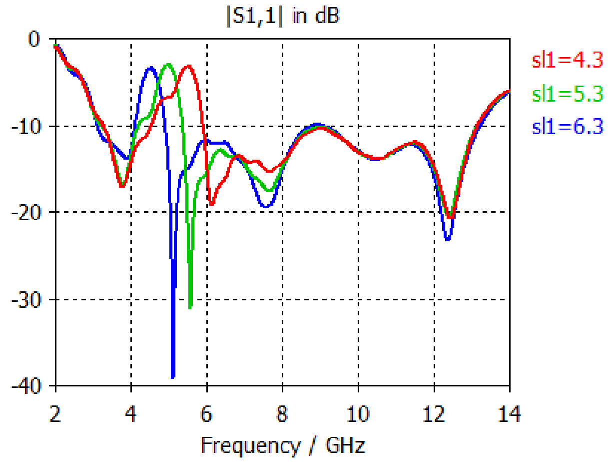

Fig.9. Simulated S_{11} characteristics for various length of slot

D. *Effect of the width of U-shaped slot*

The effect of the width of U-shaped slot on S_{11} parameter is shown in Fig. 10. It is observed that the resonance frequency of the notch band is shifted with the variation of slot width.

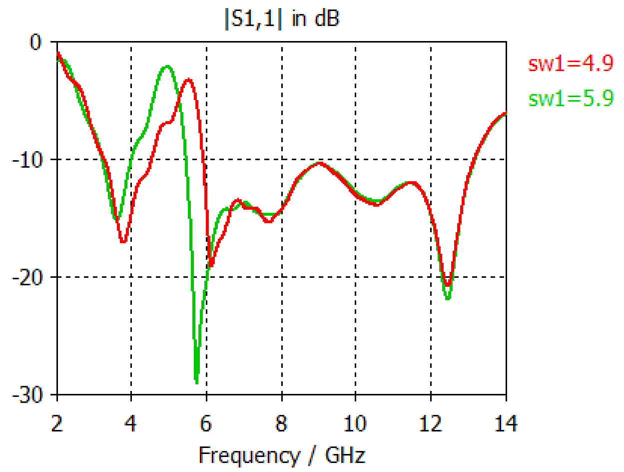

Fig.10. Simulated S_{11} characteristics for various width of slot

V. Conclusions

A new low cost, compact U-slotted V-shaped patch having a partial ground plan structure has been presented in this paper which is simulated and analyzed. The S_{11} of the proposed structure is -10 dB across the frequency band 3.15-13.2 GHz with a notch band ranges from 5.15- 5.825 GHz. At lower frequencies, the radiation pattern of the proposed antenna in the E-plane creates a monopole like pattern and in the H-plane omnidirectional. The radiation pattern at higher frequencies corresponding to the presented current distributions is distorted. The simulation results show that the proposed antenna is apt for UWB applications.

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