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Design and Analysis of Rectangular Microstrip Antenna with Defective Ground for UWB Applications

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***Abstract*: This paper presents two designs of rectangular microstrip patch antenna with defective ground plane. In the first proposed design, the geometry operates from 4.57 GHz to 7.91 GHz and provides impedance bandwidth of 53.6%, having stable pattern characteristics over the entire range. The second design is obtained by introducing changes in the shape of the slots in the ground structure in order to get notch in the bandwidth. The antenna operates at three resonant frequencies of 4.45 GHz, 7.32 GHz and 10.31 GHz. Both antennas are designed on a FR4 epoxy substrate of thickness 1.59 mm and relative permittivity of 4.4. and Ansoft HFSS 11 simulation software is used.**

Keywords: Slotted Microstrip Patch Antenna, Impedance Bandwidth, Radiation Pattern, Return Loss.

I. Introduction

In the precedent few years, ultra-wideband (UWB) systems have been used in quite a few sorts of applications, due to their inherent features such as small size, high data transmission rate with short-range, greater bandwidth, easy hardware configuration, little power consumption and omni-directional radiation pattern. Ultra-wideband is a high data rate and short range wireless technology, which utilize the unlicensed spectrum ranging from 3.1 GHz to 10.6 GHz allocated by the FCC [1-8]. In this bandwidth, a number of other kinds of licensed narrowband systems exist for which the UWB systems cause the potential interference. These narrow band systems are namely, IEEE 802.11a Wireless Local Area Network in the frequency band of 5.15 GHz to 5.35 GHz and5.725 GHz to 5.825 GHz, and HYPERLAN/2 in the frequency band of 5.45 GHz to 5.725 GHz. In order to avoid these interferences, a filter circuit is required which adds up to the system complexity and cost also. An antenna able of filter these bands is a more ideal solution. There are figure of customized antenna design schemes reported in recent times. The most frequent method to get a band-notched characteristic in a printed monopole antenna is cutting the slots on the patch or in the ground plane such as cutting a U-shaped slot, cutting a fractal slot etc[9-14]. The other way is use parasitic elements around the printed monopole patch. Recently a new method to realize a band-notch is demonstrated for microstrip-fed Ultra-wideband antennas by cutting the Split Ring Resonator (SRR) and Complementary Split Ring Resonators in the patch [15-19]. Currently, a great interest has developed in Ultra-wideband system design and its realization in the field of industries as well as academic research. Several years ago, exactly in the late 1960's, the concept of UWB radio was first developed. The term "Ultra Wideband" was first founded by the U.S. Defence Department in the year 1989. In the very beginning, the UWB technology was mainly used for the military purposes like radar applications which required wideband signals in the frequency domain or very short duration pulses in the time domain in order to get extremely accurate, reliable and fast information regarding the moving targets like missiles etc. Recently, a signal possessing a minimum absolute bandwidth of 500 MHz is considered to be a UWB signal by FCC and hence it has a fractional bandwidth of about 20% of the central frequency. Very short duration pulses are utilized by the UWB systems for transmitting the data over a large absolute bandwidth of upto 7.5 GHz. In 2002, the unlicensed frequency band of 3.1 GHz to 10.6 GHz was allowed for use in commercial wireless applications by the FCC. According to this, it should possess a limited transmitted power of –41.3 dBm/MHz. In the recent days, it is catching interest of many researchers, scientists and engineers especially in the field of personal and commercial wireless communications [20-22].

The new emerging UWB technology has multiple potential applications that can be utilized in recent personal and commercial communication systems, imaging systems and vehicular radar systems like ground penetrating radar, medical systems, surveillance systems and wall-imaging systems. UWB systems possess many advantages over the other existing conventional Narrowband (NB) systems. One of its advantages is that its complexity is very less compared to conventional NB systems. One of its attractive features that makes it popular for use in commercial communication applications is its low cost. Since, for FCC legal operation, the available power level for the UWB systems is very low, it can work very close to the noise floor level. This develops a noise-like signal spectrum which makes it good at mitigating the severe effects of jamming, interference and multipath fading. Some radar applications that needs excellent time-domain resolution and very high accuracy like tracking the objects, geo-location, localization and positioning etc. can be achieved by using UWB systems rather than conventional narrowband systems [23-24]. UWB technology proves to be an excellent solution for the ultra high speed data services upto 500 Mega bits per second (Mbps) in case of Wireless Personal Area Networks (WPANs). Instead of using single antenna element and various beam forming techniques, an antenna array could be engaged in order to increase the speed further.

In the recent years, UWB antennas have received a great attention and a significant research has been done on them. There has been a great technological advancement in the design of UWB antennas with the increasing popularity of the UWB systems. Implementing a UWB system faces multiple challenges. One of the challenges is to develop an appropriate antenna that fulfills the complete requirement. This is because it is an extremely significant part of the UWB system and its own performance affects the overall performance of the UWB system. Currently we do have multiple antenna designs which are capable of achieving wide bandwidth for Ultra-Wideband systems like Vivaldi antenna, spiral antenna, log periodic antenna and bi-conical antenna. For UWB operation, a Vivaldi antenna is one of the suitable antennas. Since indoor wireless communication or portable/mobile devices needs omni-directional radiation patterns for enabling efficient and easy communication between the transmitters and the receivers in all the directions, Vivaldi antenna is not suitable because its radiation pattern is highly directional. The large and bulky physical dimensions of mono-conical and bi-conical antennas limit their applications. Although log periodic and spiral antennas are two distinct Ultra-Wideband antennas which are capable of operating over 3.1 GHz to 10.6 GHz frequency band but still they are not recommended for the portable/mobile devices or indoor wireless applications for communication because they have dispersive characteristics with frequency and severe ringing effects along with large physical dimensions. Therefore we are looking for such a candidate antenna for UWB applications that can overcome all these shortcomings [25-38].

Printed monopole or the planar antennas are the perfect candidate for this purpose. Planar monopole antennas with different shapes of elliptical, circular, polygonal (like trapezoidal, rectangular etc.) etc. have been presented for Ultra-Wideband applications [39-45]. In this research paper, Rectangular microstrip Patch Antenna with U-slot & W-slot on the ground is proposed.

II.ANTENNA DESIGN-I (Rectangular Microstrip Patch Antenna for with U-Slotted Ground)

The geometry of a rectangular microstrip patch antenna for UWB application with U-slotted ground is shown in Figure 1 & 2. The antenna is printed on the glass epoxy FR-4 dielectric substrate with substrate thickness *'H'* = 1.59*mm*, relative permittivity εr= 4.4 and loss tangent *tan* δ = 0.02. A rectangular patch (10 mm x 11 mm) is printed on the top side of the glass epoxy FR-4 dielectric substrate. A rectangular feed line (1.9 mm x 8 mm) is printed on the same surface of the substrate. The bandwidth is improved by cutting two symmetrical U-shaped slots on the ground plane. Due to this a bandwidth of 3.4 GHz is achieved. The size of this antenna is 22 mm x 24 mm. The performance of this antenna can be diverse by varying the dimensions of the rectangular patch and the slots that have been cut on the ground plane.

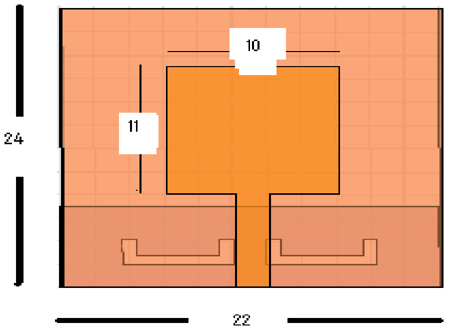


Figure 1 : Top view Rectangular patch antenna

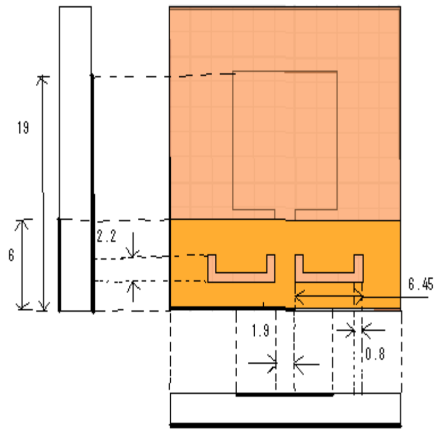


Figure 2: Back view of U-slotted ground with back and side view.

It should also be noted that improved bandwidth can also be achieved by increasing the height of the substrate but due to this surface waves are introduced which usually are not desirable because they extract power from the total available for direct radiation(space waves). The surface waves travel within the substrate and they are scattered at bends and surface discontinuities, such as the truncation of the dielectric and ground plane, and degrade the antenna pattern and polarization characteristics. Surface waves can be eliminated , while maintaining large bandwidths, by using cavities. This is why slotted microstrip patch antennas came into existance. One of the main limitations of proposed antenna is that, apart from operating over the wide frequency range, it is also interfering with the already existing licensed bands such as IEEE 802.11a Wireless Local Area Network (WLAN) which operates in the frequency band from 5.15 GHz to 5.35 GHz and 5.725 GHz to 5.825 GHz, and HYPERLAN/2 which operates in the frequency band of 5.45 GHz to 5.725 GHz.

III.RESULTS AND DISCUSSION (DESIGN-I)

Simulated results of the rectangular microstrip patch antenna with broad bandwidth are presented in this section,. Figure 3 shows the variation of return loss with frequency, curve for the proposed design. The range of frequency falling below -10db is from 4.57 GHz to 7.91 GHz. Due to this a Bandwidth of 3.34 GHz is achieved. The central frequency of 6.24 GHz is obtained. Therefore, a bandwidth as high as 53.57% is achieved.

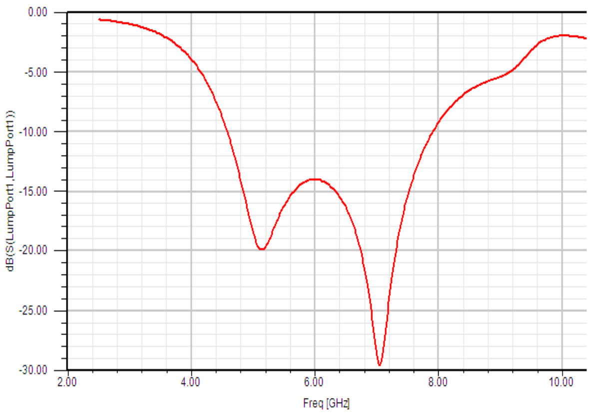


Figure 3: Variation of return loss (S_{11}) with frequency for proposed design-I

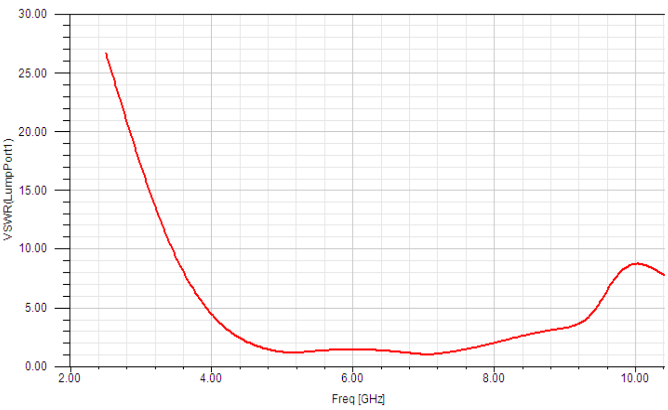


Figure 4: Variation of VSWR with frequency for proposed design-I

Figure 4 shows the variation of VSWR with frequency for proposed design-I. The VSWR falls below 2 for the proposed antenna under the preferred band.

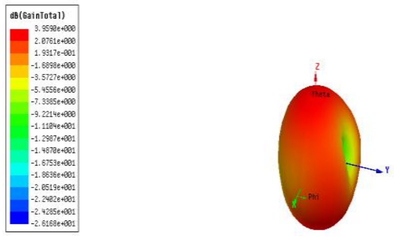


Figure 5: 3D Radiation Pattern of Proposed Antenna

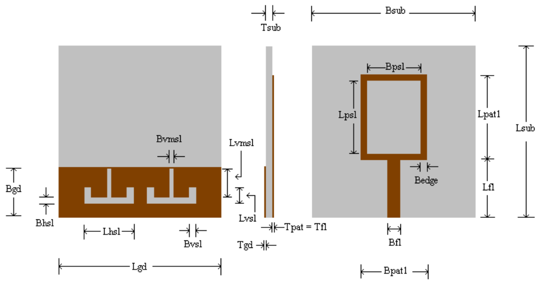
Figure 5 shows the 3D radiation pattern for proposed antenna. We can see that a gain of as high as 3.96 dB is achieved which is shown by red colour whereas a gain of as low as -2.43 dB is achieved.

IV. ANTENNA DESIGN-II

The main motive of the development of this design is to overcome one of the major limitations of the antenna design-1. Therefore, in this design, band notching characteristics have been developed in order to avoid interference with the already existing licensed bands.

The design of a rectangular U-Slotted patch antenna for ultra wideband application with W-slotted ground is shown in Fig. 6. The complete geometry of this antenna is same except some additional changes. The designed antenna is printed on the glass FR4-epoxy dielectric substrate having relative permittivity of ε_r = 4.4 and loss tangent of $tan\ \delta$ = 0.02. The dimensions of the rectangular substrate are taken as L_{sub} mm x B_{sub} mm. The thickness of the substrate is taken as T_{sub} mm. After this, a rectangular patch of dimension L_{pat1} mm x B_{pat1} mm is fabricated over the patch. The material which is used for fabricating the patch is *pec (Perfect Electric Conductor)*. The thickness of this rectangular patch is kept as T_{pat} mm. Now, a rectangular slot of L_{psl} mm x B_{psl} mm is cut at the centre of the patch leaving a boundary of *Bedge* mm wide. In order to energize the patch, a rectangular feed line of L_{fl} mm x B_{fl} mm in dimension is also printed on the same side of the substrate. The thickness of the feed line is taken as T_{fl} mm. This makes the complete front view of the rectangular microstrip patch antenna.

At the back side of the substrate, a rectangular ground plane of L_{gd} mm x B_{gd} mm dimension is developed. The material of the ground plane is taken as *pec*. The thickness of this ground plane is taken as T_{gd} mm. Now, two symmetrical U-Shaped slots are cut in the ground plane. The width of each U-Shaped slot is uniform throughout i.e. B_{hsl} mm = B_{vsl} mm. At the last, two symmetrical vertical rectangular slots are cut on the ground plane at centre of two symmetrical horizontal slots whose lengths are L_{hsl} mm. Thus, it makes a W-Shaped slot with centre arm extending longer than its other two arms.



(a) (b) (c)

Fig. 6. Design-II Antenna Geometry: (a) Back View (b) Side View (c) Front View

The dimensions of the antenna are shown in the tabular format which is as follows:-

Name of Variables	**Dimensions (in mm)**
Substrate Length, L_{sub}	24 mm
Substrate Breadth,Bsub	22 mm
Substrate Thickness, Tsub	1.59 mm
Patch1 Length, Lpat1	12 mm
Patch1 Breadth, Bpat1	9 mm
Patch thickness, Tpat	0.03 mm
Feed Line Length, Lfl	8 mm
Feed Line Breadth, Bfl	1.9 mm
Feed Line Thickness, Tfl	0.03 mm
Ground Plane Length, Lgd	22 mm
Ground Plane Breadth, Bgd	7 mm
Ground Plane thickness, Tgd	0.03 mm
Patch Slot Length, Lpsl	10 mm
Patch Slot Breadth, Bpsl	7 mm
Edge Breadth, Bedge	1 mm
Horizontal Slot Length, Lhsl	6.45 mm
Horizontal Slot Breadth, Bhsl	0.8 mm
Vertical Slot Length, Lvsl	2.2 mm
Vertical Slot Breadth, Bvsl	0.8 mm
Vertical Middle Slot Length, Lvmsl	4 mm
Vertical Middle Slot Breadth, Bvmsl	0.4 mm

Here, we get a bandwidth of 2.2 GHz by varying the dimensions of the patch and cutting additional symmetrical vertical slots on the ground plane. Apart from this, a rectangular slot of *Lpsl* mm x *Bpsl* mm dimension is cut on the patch in order to generate band notching characteristics. The optimum values of the dimensions of the complete antenna are mentioned in the table.

V.RESULTS AND DISCUSSION (DESIGN-II)

In this section, predicted results of a novel compact rectangular slotted microstrip patch tri-band antenna with a pair of symmetrical W-shaped (with middle arm extending longer than other two side arms) slotted ground having band-notched characteristics is presented. Fig. 7 shows the variation of return loss with frequency curve for the proposed antenna. Return loss shows the range of frequency of operation of the antenna with minimum loss of the signal. The return loss below -10 dB is considered to be under the acceptable limits. Here, the range of frequency falling below -10 dB is from 4.09 GHz - 4.80 GHz, 6.96 GHz – 7.68 GHz and 9.92 GHz – 10.69 GHz. Due to this tri-band, an overall bandwidth of 2.2 GHz is achieved with three central frequencies of 4.45 GHz, 7.32 GHz and 10.31 GHz.

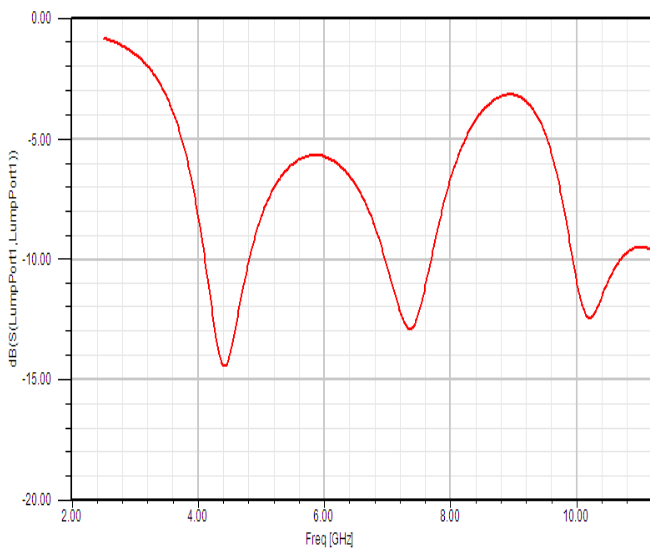


Fig. 7 Variation of return loss (S_{11}) with frequency for proposed design-II

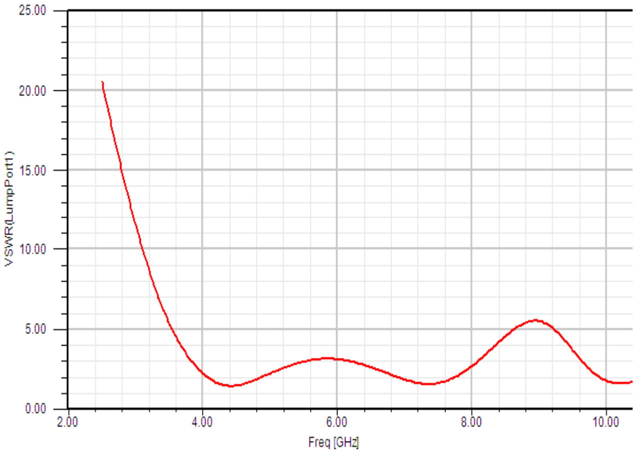
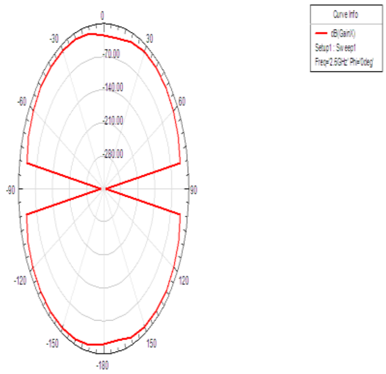
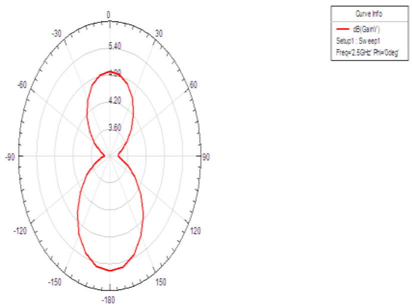


Fig. 8 Variation of VSWR with frequency for proposed design-I

Voltage Standing Wave Ratio (VSWR) is defined as the ratio of the maximum signal voltage to the minimum signal voltage attained by the standing wave. The greater the amplitude of the standing wave, the greater the impedance mismatch. The ratio of the maximum voltage to the minimum voltage would be 1 (1:1) in case of perfect impedance matching which is achieved when standing waves are not generated. The Voltage Standing Wave Ratio (VSWR) falling below 2 is considered to be under the acceptable limits. Fig. 8 shows the variation of VSWR with frequency of the proposed antenna. We can notice in Fig. 8 that the VSWR is falling below 2 for the proposed antenna under the desired bands which is falling under the acceptable limits.



(a)



(b)

Fig. 9 Radiation Pattern of the proposed Design-II (a) E-Plane (b) H-Plane.

The variation of the power radiated by an antenna as a function of the direction away from the antenna is defined by the radiation pattern. Fig.9 shows the E-Plane and H-Plane representation of the radiation pattern of the proposed antenna which are 2D (Two-Dimensional) radiation patterns. We can notice that the antenna is generating an omni-directional radiation pattern and hence it is fulfilling the desired condition of the proposed Ultra-Wideband microstrip antenna.

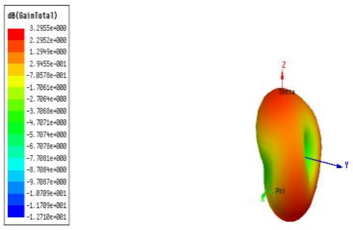


Fig. 10 3D Polar Plot of Design-2 Antenna

3D polar plot of an antenna is nothing but the 3D (Three-Dimensional) radiation pattern of an antenna. Fig.10 shows the 3D polar plot of the proposed antenna. We can see that a gain of as high as 3.3 dB (shown by red colour) and as low as -1.28 dB (shown by blue colour) is achieved by the proposed antenna.

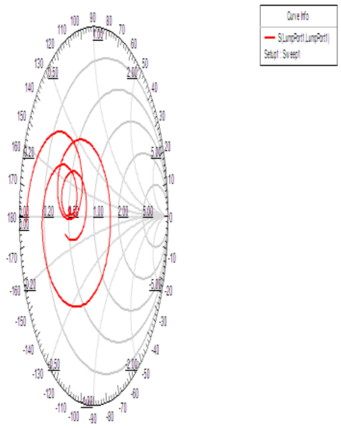


Fig. 11 Variation of input impedance for design-II

For high frequency circuits, the Smith chart is one of the most useful graphical tools. In order to visualize any complex function, Smith chart proves to be extremely beneficial. The Smith chart, from a mathematical point of view, is a representation of all the possible complex impedances with respect to the coordinates which are defined by the reflection coefficient. The circle of radius 1 in the complex plane is the domain of definition of the reflection coefficient. This can be considered as a satisfactory result for the proposed antenna. The variation of input impedance with frequency is shown in figure-11, at resonant frequencies the impedance is close to 50 with very little imaginary part.

VII. CONCLUSIONS

The design-I has demonstrated a broad bandwidth microstrip patch antenna can be designed by embedding two symmetrical U-Shaped slots on the ground with rectangular patch. A bandwidth of around 3.34 GHz is achieved at the central frequency of 6.24 GHz. Due to this a bandwidth of as high as 53.57% is achieved. The design-II has demonstrated that by changing the shape of the slots in the ground, antenna possessing band notching characteristics can be designed. Here, it is achieved by varying the dimensions of the rectangular patch and also by cutting slots on the patch and the ground plane simultaneously. This means that this design provides a wide operational bandwidth and it does not interfere with the already existing licensed bands. Hence, it has overcome the limitation of design-I. The range of frequency falling below -10db is from 4.09 GHz - 4.80 GHz, 6.96 GHz – 7.68 GHz and 9.92 GHz – 10.69 GHz. Due to this tri-band, an overall bandwidth of 2.12 GHz is achieved with three central frequencies of 4.45 GHz, 7.32 GHz and 10.31 GHz. Currently, recent communication systems need antennas with broadband and multi-band operation. These goals have been accomplished employing slotted ground for the radiating element, with the aim to preserve compactness requirements and to maintain the overall design as simple as possible and keeping the realization cost very low.

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