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Original Article

Impact of Triangular-Rectangular Slots in the Patch and Partial Ground Plane on Rectangular Patch UWB Antenna Bandwidth Performance

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Abstract - *The effect of triangular-rectangular slots in the patch and partial ground plane on the bandwidth effectiveness of a rectangular patch UWB antenna is presented in this article. Our standard antenna is a rectangular patch microstrip feeding monopole with a partial ground plane. Two different slot configurations, such as triangular and rectangular, have been implanted into the patch to assess the properties of the ordinary antenna bandwidth, and a single slot shape like a rectangular has also been embedded into the partial ground plane on the rear end of the feed line to the suitable. The HFSS simulator is used to investigate the impact of single and multiple-slot cases on bandwidth features. The simulation results show that the antenna bandwidth can be increased based on the slot structures.*

Keywords - *Microstrip UWB antenna, Partial ground plane slot, Patch slots, Bandwidth improvement.*

1. Introduction

Since the FCC approved the low-power, wideband 3.1-10.6 GHz for ultra-wideband (UWB) functions, several studies have focused on developing and reconfiguring antennas in this band over the last 15 years, including minimal cost, compact size, extensive impedance bandwidth, omnidirectional properties, and ease of manufacture. The tiny size monopole microstrip antenna, in addition to being a good choice for this work, might be used for a variety of communication systems, like radar applications, finding and tracking systems, ad-hoc devices, and others. Patch antennas with multiple antenna structural alterations have lately been used for ultra-wideband devices.

The strategy for broadening the bandwidth of ultra-wideband antennas by using ground slot methodologies of various shapes and structures example, rectangular, partly circular, triangular, and hexagonal under the rear end of the radiator feed line, is generally considered for the analysis of impedance matching. The simulation test results revealed the consequence of the grooves on impedance bandwidth evaluation and radiation pattern features output gain and radiation efficiency. A hexagonal slot on the surface of the ground provided the finest fractional bandwidth boost of 136.08 percent for a value of S11 < -10 dB [1] among several proposed slit geometries. The designed antenna may operate properly with VSWR less than 2 in the frequency spectrum of 2.95 - 15.65 GHz and has exclusion bands between 5.13 GHz and 5.91 GHz, according to simulation and experimental results. A circular patch antenna was evaluated and altered in [4] by cutting the ground plane's diagonal ends appropriately and incorporating a T-shaped slot.

A Pacman-shaped antenna with a square ground cut back underneath the upper edge of the feed line is evaluated in [2] to increase impedance bandwidth adeptness. The suggested antenna has an omnidirectional radiation pattern and an impedance bandwidth of 2.9 to 15 GHz. By altering the intended square antenna shape, the researchers of [3] were able to develop a unique compact square grooved antenna with a configurable band-stop requirement for UWB usage. Two G-shaped slots in the ground and a T-shaped ring slot at the square patch antenna were added to make the change. This methodology gives the antenna a broader bandwidth of 3-12.62 GHz (123.32 percent) than the normal FCC 3.1-10.6 GHz bandwidth (109.45 percent). A few of the designs with separate ground cutting have been explored to raise the bandwidth features having received reconfiguration from 117 % to 175 %, including the M-shaped arrangement presented in [5], some projects used U-shaped structures [6,7], and the reversed T-shaped antenna employed [8] was analyzed with an altered fork-shaped monopole antenna with two L-shaped etched grooves [9]. Furthermore, W-shaped and boat-shaped slot geometries give good results on the ground plane [10], beak-shaped structure [11], and right C-shaped slot created a large bandwidth with two band elimination properties for the 96 GHz WLAN working range [12], different square structures connected to each other [13], and circular slits [14]. To reduce electromagnetic interference between UWB and narrowband devices, the monopole antenna was changed by embedding rectangular and arc-shaped slots on the ground [15]. This resulted in a higher input coefficient of reflection and bandwidth. To use a defective ground structure (DGS) with varied locations of the additional patch in the ground, a modest microstrip rectangular antenna with a bandwidth of 133.33 percent and a gain of 1.5-4.8 dB for UWB systems was developed in [16]. To satisfy bandwidth and superior performance requirements, a microstrip antenna design based on the defective ground structure (DGS) and horizontal patch gap (HPG) was constructed [17]. The antenna had a gain of 2.8 decibels and a bandwidth of 764.4 MHz. L-shaped DGS and U-shaped dual parasitic elements, as well as U and Quad L-shaped slots, were investigated by Raviteja et al. [18]. This antenna has a gain of 7.2 dB and a 1.40 GHz bandwidth. A contemporary semi-circular ultra-wideband antenna [19] with a huge bandwidth of 130.3 percent from 3.16 to 15 GHz with gain ranging from 4.9 to 10.9 dB was exhibited for broadband applications. Based on a defective ground structure, D. Gopi1 et al. [20] designed a compact monopole circular-shaped patch antenna for ultra-wideband applications. The impedance bandwidth of the antenna ranges between 2.5 and 10.6 GHz. The gains are 8.4 dBi and 8.2 dBi for the two resonant frequencies, respectively. The air gap approach was used to create a rectangular microstrip patch antenna for improvement in [21]. Based on the simulation results, the gain is boosted from 6.907 dB to 9.179 dB. In [22], metamaterial (MTM) double-side planar periodic structures were used to design a tiny expanded bandwidth UWB patch antenna. The antenna has a large bandwidth of 3.2 to 23.9 GHz and a 6.2 dB highest gain at 8.7 GHz. J. Vijayalakshmi et al. [23] discussed a miniature high-gain (MHG) ultra-wideband (UWB) unidirectional monopole antenna with a defective ground structure (DGS) for ultra-wideband applications. This antenna has a frequency range of 3.2 to 10.6 GHz, a gain of 7.20 dB, and a 95 percent efficiency. On the basis of an FR4 substrate, K. G. Tan et al. [24] designed a redesigned UWB antenna with a gain enhancement for wireless systems. The findings show that an impedance bandwidth extending from 2.2 GHz to more than 12 GHz, or 138 percent fractional bandwidth, may be detected with a maximum gain of more than 6.5 dB. Using computer simulation technology (CST) software, A.F. Darweesh and G.O. Yetkin [25] presented a reduced-size ultra-wideband microstrip antenna based on a metamaterial array for UWB applications. With a boost of 5.6 dB, the results showed an increased bandwidth of 2.6 GHz - 20 GHz. T. Sarkar et al. [26] present a comprehensive study of a modest ultra-wide-band (UWB) microstrip antenna for DS-UWB applications. Simulation findings show that the impedance bandwidth is 109 percent. A lightweight mace-shaped ground plane modified circular patch antenna was developed in [27] for ultra-wideband applications. The highest gain and fractional bandwidth of this antenna, according to simulation results, are 3.2 dB and 118 percent (3.1 to 12.13 GHz), respectively. In [28], the authors propose a small stepped slot antenna for ultra-wideband (UWB) applications. The impedance bandwidth of the antenna extended from 3.05 to more than 12 GHz. The notched-band properties of a very compact ultra-wideband (UWB) slot antenna with three L-shaped slots was investigated in [29]. The antenna has an impedance bandwidth of 2.65 to 11.05 GHz, according to current simulation results. The center frequency and notched bandwidth of a tiny ultra-wideband (UWB) antenna were controlled using a customized patch and electromagnetic bandgap (EBG) design [30]. According to the analysis, a greater bandwidth of 3.1-12.5 GHz and a maximum gain of 4.5 dBi might be achieved. A tiny UWB planar antenna with a corrugated ladder ground plane for a variety of applications is presented in [31]. The antenna has a high gain of 3.5 dB and a 130.4 percent impedance bandwidth (2.4 – 11.4 GHz).

The impact of triangular-rectangular slots in the patch and partial ground plane on UWB antenna bandwidth performance is investigated in this paper. A traditional monopole UWB antenna with a simple rectangular patch and partially ground plane, as well as a type of microstrip transmission feed line, is being studied. The optimal size of the proposed antenna is determined using a parametric analysis. The patch has been embedded into two distinct slot configurations (triangular and rectangular) and a single slot configuration, including a rectangular one, into the partial ground plane at the back of the upper edge of the feed line to assess the bandwidth properties of the reference antenna (conventional antenna).

2. Proposed Antenna Design

A simple rectangular patch UWB antenna has been employed as a reference antenna. It comprises a rectangular copper patch with a dielectric constant of 4.4 and a tangent loss of 0.02 that is positioned on the upper side of an FR4-epoxy substrate and supplied by a microstrip feed line with a characteristic impedance of 50Ω. The lower portion of the substrate contains a partial copper ground plane, as shown in Fig.1. Table I shows the size of the various antenna parts.

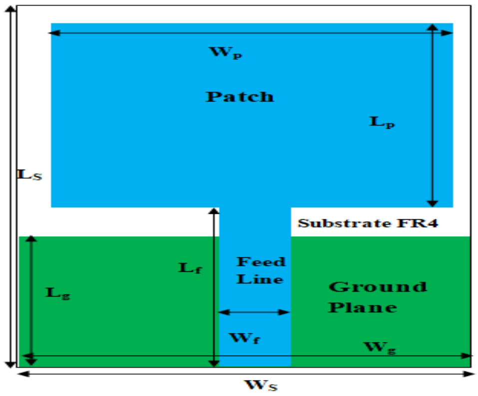

Fig. 1 The geometrical structure of the reference microstrip UWB antenna

Table 1. Proper dimensions of the components of the reference microstrip UWB antenna

Antenna's element	Dimension (mm)
Substrate	Ws =20, Ls =30
Patch	Wp =18,Lp=14
Microstrip feed line	Wf =2, Lf =15
Partial ground plane	Wg=20, Lg=14
Thickness	h = 0.8
Dielectric constant	4.4

A variety of configurations, such as triangular-rectangular slots, are inserted into the patch, and a single slot structure like a rectangular slot is embedded into the partial ground plane on the back of the feed line (slot antenna) to study the bandwidth performance of the investigated antenna in the UWB frequency spectrum, as shown in Fig.2. The dimensions of the slots are shown in Table 2.

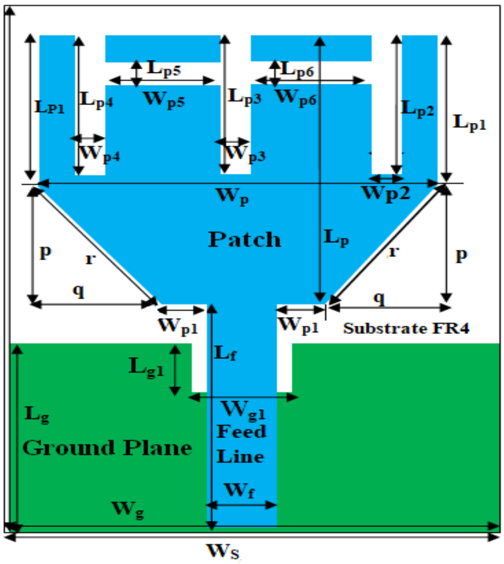

Fig. 2 Multiple slot configurations (triangular and rectangular) on the patch and single slot configuration (rectangular) on the ground plane in the feed line backside

Table 2. Dimensions of different configurations of the slots

Slot Configurations	Dimension (mm)
Rectangular and Triangular	Wp1=2,Lp1=8,Wg1=2, Lg1=3, Wp2=Wp3=Wp4=0.5, Lp2=Lp3=Lp4=7, Wp5=Wp6=6.5, Lp5=Lp6=0.5, p = q= 6, r = 8.48

3. Simulation Results and Discussion

A simulation evaluation was carried out using the HFSS simulator software to explore the different antenna bandwidth characteristics. The frequency range across which a particular return loss can be maintained is referred to as the bandwidth (also known as impedance bandwidth). The antenna's impedance must match the transmission line's impedance for optimal power transfer since return loss is a measurement of how much power the antenna absorbs from the transmission line.

Indeed, the antenna's impedance changes with frequency, resulting in a finite range for matching the antenna to the transmission line. The bandwidth is used to determine this range. It's frequently linked to a particular return loss or VSWR value. In Fig. 3 and Table III, the simulated return loss of the reference antenna (without slot) and with various slot configurations, including triangular and rectangular, is illustrated.

A typical UWB antenna has a bandwidth of 3.68 GHz (3.25-6.93 GHz) with a return loss <-10 dB. On the other side, using a triangular slot design boosts the antenna's bandwidth. It can be expanded to 5.9 GHz by incorporating triangular slots in the lower corners of the patch that are between 3.15 GHz and 9.05 GHz. The antenna has a bandwidth of 3.76 GHz, with frequencies spanning from 3.35 to 7.11 GHz, due to five rectangular slots inserted into the patch's top border. When a single rectangular slot is added to the partial ground plane, which is between 3.23 GHz and 5.55 GHz, the antenna's bandwidth improves to 2.32 GHz. Various slot structures, such as triangle slots and five rectangular slots, are inserted into the lower corner and top of the patch, and a single slot configuration, such as a rectangular slot, is also introduced into the partial ground plane, which is referred to as a suggested antenna.

The antenna's bandwidth is raised to 19.7 GHz (3.15 GHz to 22.85 GHz) by incorporating triangular-rectangular slots into the patch and a single rectangular slot into the partial ground plane. This is almost 5.35 times greater than the reference antenna's bandwidth. This antenna can be used for X band, C band, Ku band, S-band, STM band, WiMAX, WiFi, WLAN, radio astronomy, military communications, communications and sensors, positioning and monitoring, radar, and satellite communication. From the above discussion, it is clear that the intended antenna's bandwidth has greatly improved over the standard patch antenna (reference patch antenna). We believe that the antenna is a good choice for satisfying the UWB bandwidth requirements.

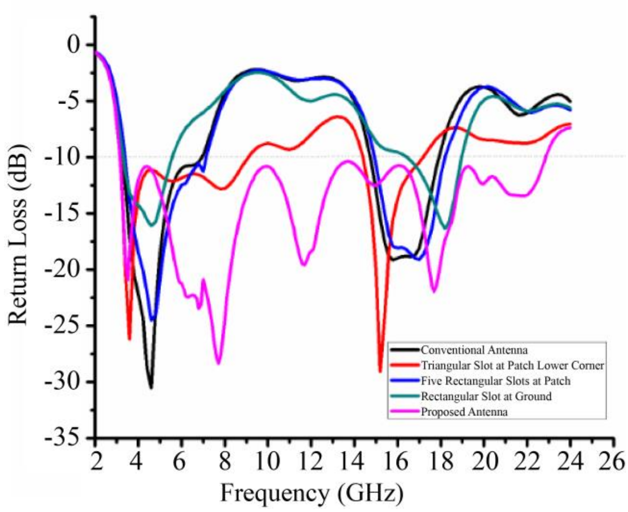

Fig. 3 The simulated return loss of the conventional antenna (reference antenna) without slots and with various slots

Table 3. Characteristics of the bandwidth for the reference antenna without slots and for the proposed antennas with various slot configurations

Antenna Name	Return Loss (dB)	Resonance Frequency (GHz)	Operating Bandwidth (GHz)	Bandwidth (GHz)
Reference antenna (without slots)	-30.40	4.55	3.25-6.93	3.68
Antenna with triangular slots at patch lower corners	-26.16	3.60	3.15-9.05	5.9
Antenna with five rectangular slots at the patch	-24.50	4.60	3.35-7.11	3.76
Antenna with single rectangular slots at the partial ground plane	-16.36	4.60	3.23-5.55	2.32
Proposed antenna	-28.35	7.7	3.15-22.85	19.7

4. Conclusion

The influence of triangular-rectangular slots in the patch and partial ground plane on the performance of rectangular patch microstrip UWB antenna bandwidth has been analyzed in this paper, and conventional and slot antennas have been effectively developed. The reference antenna is a rectangular patch with a microstrip feed line and a partial ground plane (conventional antenna). A parametric analysis is utilized to find the accurate size of the designed antenna. Two different slot shapes, such as triangular and rectangular, have been inserted within the patch, and one slot configuration, like rectangular, has been introduced to the partial ground plane on the rear end of the feed line to vary the traditional antenna bandwidth characteristics. The effects of single and multiple slots on bandwidth characteristics have been investigated. The simulation's final findings reveal that depending on the slot layouts and the number of slots introduced, the antenna bandwidth can be increased.

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