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An Investigation of Defected Ground Structure Effect on Bandwidth Enhancement of U-Shaped Microstrip Antenna for Small Ultra-wideband Radar Device

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Abstract

Ultra-wideband radar has been widely used for various purposes, including detection of human vital signs, small displacement detection, and ground penetrating radar. In order to work properly, it requires an antenna with a wide bandwidth. This study reports an investigation of a bandwidth enhancement method by combining the U-shaped microstrip patch antenna with the Defect Ground Structure (DGS). In this research, the antennas are operated at 5.8 GHz. The results show the combination of U-shaped patch and DGS produce twice bandwidth performance compared to the one without DGS. In our study the diamond shape DGS gives the best performance among various DGS structures.

Keywords: Ultra Wide-Band (UWB); Microstrip Antenna; Defect Ground Structure (DGS); Radar.

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1. Introduction

Ultra-wideband (UWB) application requires a wide bandwidth. FCC has stated a widely-accepted standard for UWB applications, including a signal bandwidth at greater than 500 MHz or has a fractional bandwidth (Bf) greater than 20% [1]. In terms of its applications, UWB is applied for the detection of vital signs, through-wall radar, ground penetrating radar (GPR), *etc*. [2]. Besides, UWB offers various benefits, including its portability, low-cost, and non-ionizing frequency, hence it is considerably safe in penetrating biological networks [3].

Furthermore, ultra-wideband radar has been gaining attention for its sensitivity to detect small displacements or movements, including detection of human vital signs, object presence, and snow-buried objects. Besides, advanced IC developments have allowed UWB radar to be built in a compact form factor. Basically, an antenna is a critical component of any UWB radar, acting in transmitting and receiving electromagnetic signals. Several designs to achieve ultra-wideband characteristic of an antenna include conical antenna, log periodic antenna, and microstrip UWB antenna. The last one has become a popular solution in fabricating small-sized UWB radar devices because microstrip UWB antenna can be produced in a small form factor.

Furthermore, microstrip antenna offers various advantages, including easy to fabricate, has a smaller form factor for higher frequency applications, and easy to integrate with other devices [4][5]. Hence, the antenna can be integrated into small devices in various applications such as WLAN [6][7], UWB [8], and radar [9]. However, a typical microstrip antenna has a low efficiency and a narrow bandwidth, hence it requires additional improvements to change it natural behavior [10].

In this work, a modified U-shaped microstrip antenna is proposed to increase antenna bandwidth for a UWB radar device. The model (U-shaped patch) is expected to increase the current path to the patch, which will increase the current intensity leading to the increase of antenna efficiency [11]. As a result, the bandwidth of an antenna as such will increase. In fact, researches have proven a U-shaped microstrip antenna to have a wider bandwidth performance than ordinary rectangular patch antenna [12-15].

Due to its broadband characteristics, a UWB system is usually susceptible to any narrowband interference [16]. Hence, a filtering system is required to overcome the problem by producing a notch over spectral response of the antenna. In the literature, various filtering techniques have been explored, including the Defected Ground Structure (DGS). In fact, the DGS filtering method is particularly useful to broaden the bandwidth of a microstrip antenna.

This study has investigated the combination of U-shaped patch antenna and DGS to achieve a wider bandwidth by testing three different DGS structures. Three types of DGS structures, which are double sided, diamond, and rectangular, are selected for trials by considering their simple shapes to design.

Different combinations between the patch and DGS structures are simulated by using software to observe their performance in terms of their bandwidth range. Looking at the results, all combinations successfully widen the bandwidth of initial U-shaped patch antenna. Meanwhile, the diamond DGS model performs the best among the three DGS structures being tested.

2. Basic Theory

2.1 U-shaped Microstrip Antenna

Microstrip antenna is an antenna that has a shape like a thin plate printed on a substrate. Microstrip antenna consists of three layers, i.e. patch layer, dielectric substrate layer, and ground plane layer. In practices, it offers various advantages, including a light and compact size, easy to fabricate, and easy to integrate with other circuits. However, it also has disadvantages, including a small gain, a narrow bandwidth, and a retention to surface waves. Practically, a microstrip antenna can be designed to have one among various possible shapes of patch, including rectangular, circular, triangular, etc. [1]. Then, microstrip antenna is suitable for wireless applications because it is lightweight and compact.

Basically, U-shaped patch antenna is a derivative of rectangular patch antenna, in which its upper side is trimmed by a rectangular slot, forming a 'U'-like shape. Fig. 2(a) shows the configuration of a U-shape patch antenna. Technically-speaking, the shape can broaden antenna bandwidth due to an increased current path on the patch.

2.2 Defected Ground Structure (DGS)

In general, Defected Ground Structure (DGS) is a design of slot that is made on the ground plane, making a defected ground plane. A structure as such is mostly used to achieve an optimum null level in antenna frequency response. Benefits of using the technique include its ability in reflecting sufficient energy to yield a good notch response, while in some cases it will widen antenna bandwidth.

Practically, shapes of the defect may differ from a simple to more complicated shapes for achieving a better performance. In the literature, different shapes of DGS structures (*e.g.*, rectangular, square, circular, dumbbell, spiral, L-shaped, concentric ring, U-shaped and V-shaped, hairpin DGS, hexagonal DGS, cross shaped DGS and combined structures) have been widely proposed [17].

Furthermore, the basis of DGS method refers to EBG (Electromagnetic Band Gap) and PBG (Periodic Band Gap) approaches to change the nature of waves by making one or more patterns on the ground plane [18]. Different patterns/shapes can be etched on the ground plane on a microstrip antenna as DGS. In this study, 3 different DGS shapes are tested to investigate their effects on antenna bandwidth. The forms will be etched to disrupt current distribution, changing the antenna impedance. The interference caused by DGS slots will then affect the transmission characteristics of a microstrip antenna [18]..

3. Antenna Design

3.1 Initial Antenna Design

In this work, a microstrip antenna is designed to operate at 5.8 GHz frequency with bandwidth at greater than 500 MHz. The substrate uses Epoxy FR-4 with 1.6 mm thickness (*h*). The excitation applies proximity-coupled method with a microstrip line feed. The method is considerably effective to gain bandwidth and to reduce spurious radiation [19]. The basic patch is set to have a rectangular shape. Calculation to achieve the shape includes width (W_p) and patch length (L_p) into account, which is expressed in Equations (1)-(5) [4].

$$W_p = \frac{c}{2f_0\sqrt{\frac{\varepsilon_r+1}{2}}} \tag{1}$$

$$\varepsilon_{reff} = \frac{\varepsilon_r+1}{2} + \frac{\varepsilon_r-1}{2}\left(\frac{1}{\sqrt{1+\frac{12h}{W}}}\right) \tag{2}$$

$$\Delta L = 0.412\frac{\left(\varepsilon_{reff}+0.3\right)\left(\frac{W}{h}+0.264\right)}{\left(\varepsilon_{reff}+0.258\right)\left(\frac{W}{h}+0.8\right)} \tag{3}$$

$$L_{eff} = \frac{c}{2f_0\sqrt{\varepsilon_{reff}}} \tag{4}$$

$$L_p = L_{eff} - 2\Delta L \tag{5}$$

Constant c is the speed of light (3×10^8 m/s). Variables ε_r and ε_{reff} are the relative permittivity and effective permittivity respectively. Variable W is the width of microstrip line. Variable ΔL is the extended microstrip line width to compensate the fringing effect on the line. Variable L_{eff} is the effective stripe length. To determine the dimension of antenna groundplane, Equations (6)-(7) are applied, where variables W_g and L_g are the width and length of the ground plane. To determine the width of feed (W_f), Equation (8) is applied. Then, variable B is obtained through Equation (9). Table 1 provides the initial dimension of the antenna.

$$W_g = 6h + W_p \quad (6)$$

$$L_g = 6h + L_p \quad (7)$$

$$W_f = \frac{2h}{\pi}\left[B - 1 - \ln(2B-1) + \frac{\varepsilon_r}{2\varepsilon_r}\left\{\ln(B-1) + 0.39 - \frac{0.61}{\varepsilon_r}\right\}\right] \quad (8)$$

$$B = \frac{377\pi}{2Z_0\sqrt{\varepsilon_r}} \quad (9)$$

Table 1: The Initial Dimensions Of The Antenna After Optimization

No	Parameter	Value
1	Dielectric Constant (ε_r)	4.6
2	Thickness (h)	1.6 mm
3	Length of the Groundplane (L_g)	30.68 mm
4	Width of the Groundplane (W_g)	34.64 mm
5	Length of the Patch (L_p)	10.11 mm
6	Width of the Patch (W_p)	15.44 mm
7	Length of the Feed (L_f)	13.5 mm
8	Width of the Feed (W_f)	15.34 mm

Results of software simulations on the initial design (Table 1) are provided in Fig. 1. Looking at the result, the initial antenna has a return loss at about -17.78 dB and circa 463.3 MHz bandwidth. In fact, the results do not fulfill FCC-expected UWB characteristic. Thus, improvements are required to achieve a better UWB antenna performance. Proposed solution is taken by modifying the patch shape, which is followed by implementing DGS on the groundplane side.

3.2 U-shaped Microstrip Patch Proximity Coupled

Next, increasing antenna bandwidth is critical to fulfill the FCC-based UWB specification. In this work, a modification on antenna resonator is conducted by cutting the top middle part of the resonator, making it to have a "U"-like shape. The modified antenna form is shown in Fig. 2. The size of the slot is 3.44 mm and 6 mm for its width and length, respectively.

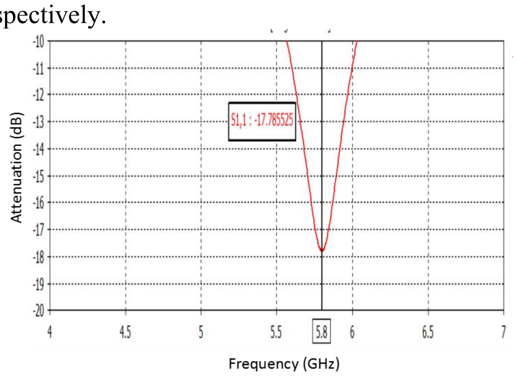
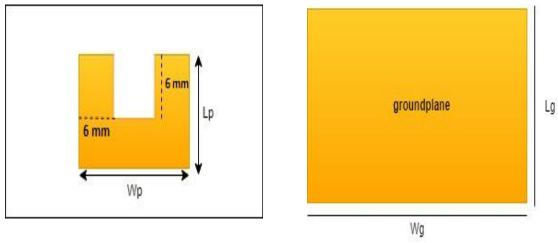


Figure 1. Return Loss of Initial Antenna Design



(a)
(b)
Figure 2. Design of Microstrip U-shaped Proximity Coupled: (a) Front side of Antenna. (b) Rear side of Antenna

The new resonator model is then simulated by using software. Fig. 3 provides results of the simulation. The minimum return loss value is at -28.22 dB with 573.7 MHz bandwidth. The modification appears to successfully make the bandwidth wider.

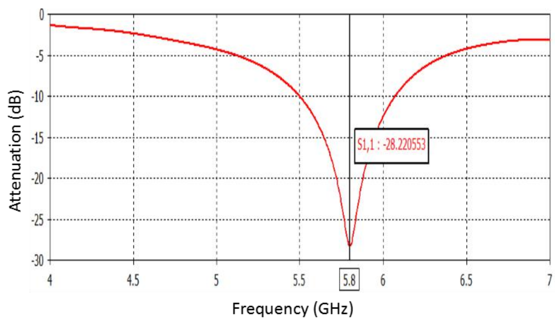
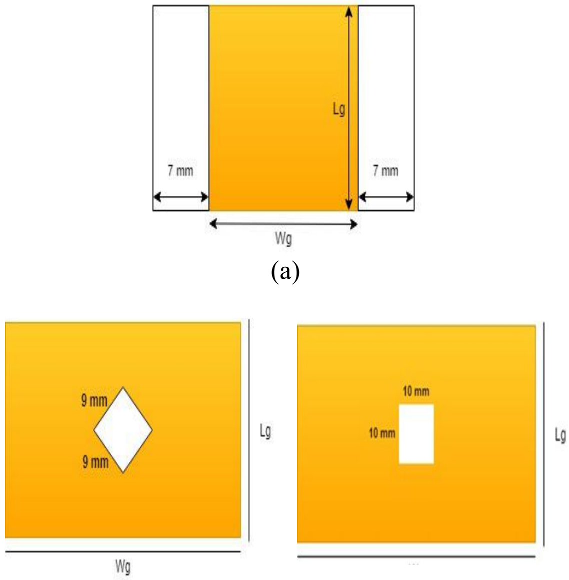


Figure 3. Return loss and Bandwidth of Microstrip U-shaped Proximity Coupled without DGS

3.3 Microstrip U-shaped Proximity Coupled with DGS

A modification from a regular rectangular into U-shaped patch has been done to increase antenna bandwidth. Despite having successfully increased the parameter, the last design has not yet reached the minimum desired requirement for a UWB antenna. Thus, this work attempts to combine it with a DGS structure. In the literature, DGS has been recognized to increase the bandwidth performance of an antenna by increasing the capacitive effect at the antenna [20]. The U-shape patch contains greater capacitive gap between the 'U' arms when it is combined with the DGS. Hence, the combination increases the total capacitive effect of the antenna.

However, DGS may take different shapes of structure, which will deliver different result if they are implemented to the same antenna. In this research, three types of DGS structure have been separately tested at physically different UWB antennas with the same designs to improve antenna performance. The first type is a side cut, the second one is a diamond cut placed at the center of groundplane, and the last one is a rectangular placed at the same pos ition as the second alternative. The sizes (width) of these structures are set at about 10-25% of respective ground plane size. Fig. 4 provides an overview of these structures.



(a)

(b) (c)

Figure 4. Design of DGS Structures: (a) Shape 1, (b) Shape 2, (c) Shape 3

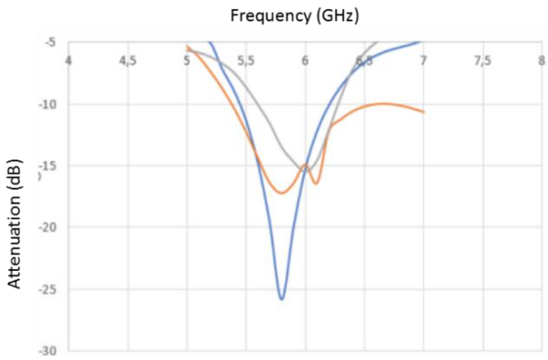


Figure 5. Return loss and Bandwidth of Microstrip U-Patch Proximity Coupled using Three Different DGS Structure

These three DGS models have been simulated, showing the shape 2 (diamond cut) to produce the biggest additional bandwidth at 690.3 MHz. The antenna with DGS structure as such has 1264 MHz bandwidth with the return loss at -17.2 dB. Meanwhile, the shapes 1 and 2 deliver added antenna bandwidths at about 30% and 56.6%, respectively. Fig. 5 shows the simulation results of DGS implementation on the U-shaped microstrip antenna. Shape 1 (blue line) and shape 3 (red line) exhibit similar performance in terms of return loss, while shape 1 (blue line) shows the lowest return loss level.

Table 3 provides a comparison of simulation results on three DGS types. The shape 2 produces the wider bandwidth due to its angled defected area that perturbs the electromagnetic wave on the patch. It has also the smallest DGS structure investigated in this research. It does not only cause a better electromagnetic wave dispersion but also perturbs the propagated electromagnetic wave on the patch. Although the shape 1 provides the biggest defected area on both ground plane side, it is not overlapped with the patch at the other side so it gives less effect on increasing the antenna bandwidth compared with the other two DGS shapes.

Table 3: Comparison Table of different shapes in DGS

Shape	**Return Loss (dB)**	**VSWR**	**BW (MHZ)**	**Gain (dB)**
W/o DGS	-28.22	1.08	573.7	4.551
Shape 1	-25.81	1.1	761.1	3.054
Shape 2	-17.2	1.32	1264	4.477
Shape 3	-26.72	1.096	899.5	1.9

4. Conclusion

This study has successfully designed and investigated a combination of U-shaped antenna with DGS for ultra-wideband (UWB) applications. The U-shaped resonator has a 20% broader bandwidth than initial rectangular-shaped patch. Furthermore, the DGS addition makes the bandwidth performance twice higher than the one without it. Among three investigated DGS shapes, the diamond shape delivers the best performance due to its small defected area. The angled side of the diamond shape is interpreted to produce a better capacitive effect to the the antenna. In short, the combination of the U-shaped patch with DGS is potential model to be used in UWB radar applications.

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