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Inverted Diamond-shaped Notched Substrate and Patch for High-frequency Interference on Ultra-wideband Antenna

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ABSTRACT

Notches loaded on a patch antenna can affect significantly on the antenna impedance matching. Therefore, notching technique is an efficient way to reduce the electromagnetic interference with unwanted bands. In this paper, a novel inverted diamond-shaped closed-end slot on a substrate and vertex-fed printed hexagonal patch ultra-wideband antenna is proposed for high-frequency band rejection. This antenna is fed using coplanar waveguide, and it is optimised by veering several patch parameters which further improved the inter bandwidth at both the lower and upper bands. However, the centre-notched band is shifted from 6GHz to 7.5GHz by cutting the inverted diamond shape in a special process. The developed ultra-wideband antenna is verified by comparing the simulation results with the measurement results. The measured results with a fractional bandwidth of 133% have a good agreement with the simulation results 146%. Moreover, the measured radiation showed omnidirectional patterns.

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1. INTRODUCTION

The ultra-wideband (UWB) antenna has been significantly attractive to researchers because it is inexpensive, lightweight, and has a broad bandwidth in modern communication systems. The Federal Communication Commission qualified the inter bandwidth from 3.1GHz to 10.6GHz of UWB radio systems, and variety antenna types have been established for UWB appliances [1-4]. Attaching the radiation patch with a coplanar waveguide (CPW) is used to develop the printed UWB antenna. The advantages of selecting this feed method are distinguished by simple to fabricate, unique planar antenna structure to provide wide bandwidth, reduce manufacturing mistakes, decrease dispersion, and reduce propagation loss [5].

The UWB technology provides a high data rate, large channel capacity, and stable radiation pattern for radio communication [6]. However, using high data rate to transmit information makes UWB systems highly sensitive to interference with the existing bands [4], such as WiMAX (3.3–3.7GHz), WLAN (5.15–5.85GHz), and downlink X-band satellite system (7.25–7.75GHz) [3], [4], [6]. Figure 1 illustrates the UWB bandwidth with the existing bands shared the same spectrum frequencies. The most efficient and easiest method to reduce this electromagnetic interference (EMI) is described by attaching a geometrical notch filter to an antenna [7]. To reduce EMI, the researchers introduced many notched shapes, such as I, C, and L shapes [3], [4], [6]. In [8], small open-end slots to reject an interfered band at a high frequency of 7.5GHz are demonstrated.

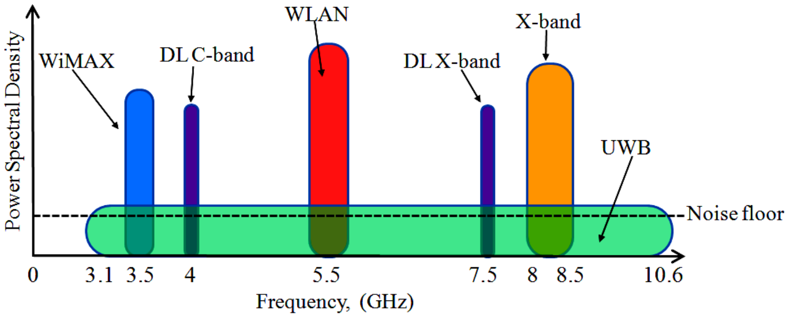


Figure 1. UWB bandwidth and existing bands spectrum frequencies

The small notch size requires a high-accuracy fabrication that may reduce the quality measurement results compared with the simulation. Thus, a new method is introduced to reject the high-frequency band by cutting a new close-end diamond slot on the substrate and radiation patch without changing the slot size. On the other hand, many researchers developed several techniques to improve the UWB bandwidth for upper and lower resonance frequencies such as adding patristic stub, strip, or slotting the ground plane behind the feed line [9-11]. In this design, the inter bandwidth is improved for upper and lower frequencies by modifying the hexagonal radiation patch geometry only, because the proposed design is fed by using CPW technique.

In this study, an inverted diamond shape is slotted in the substrate and patch on a reconfigurable UWB vertex-fed printed hexagonal patch antenna (VPHPA) to achieve a single-band notch. The reconfigured VPHPA achieved a broad bandwidth and best impedance matching at low and high resonance frequencies. Moreover, the single-band notch is shifted 1.5GHz to a higher frequency at 7.5GHz by integrating the inverted diamond close-end notch on both substrates and radiation patch compared with slotting the radiation patch only, which has the same notch geometry.

2. RESEARCH METHOD

The demonstrated band-notched antenna structure is presented in Figure 2(a). The proposed radiation patch and two ground-plated CPWs are printed on the top layer of an FR4 substrate with dielectric constant εr = 4.3, tan δ = 0.025 and size of 28mm × 43mm × 1.6mm. The proposed antenna design steps to achieve single-band rejection and broad bandwidth are shown in Figure 3. First, a simple side-fed hexagonal patch of side length S = 8.5mm is used, which has a frequency region from 3.3GHz to 10.3GHz. Second, the radiation patch rotates to be the VPHPA, as shown in Figure 3 (antenna 2). Third, the angle (a) between the patch and ground plate decreases from 30° to 24°.

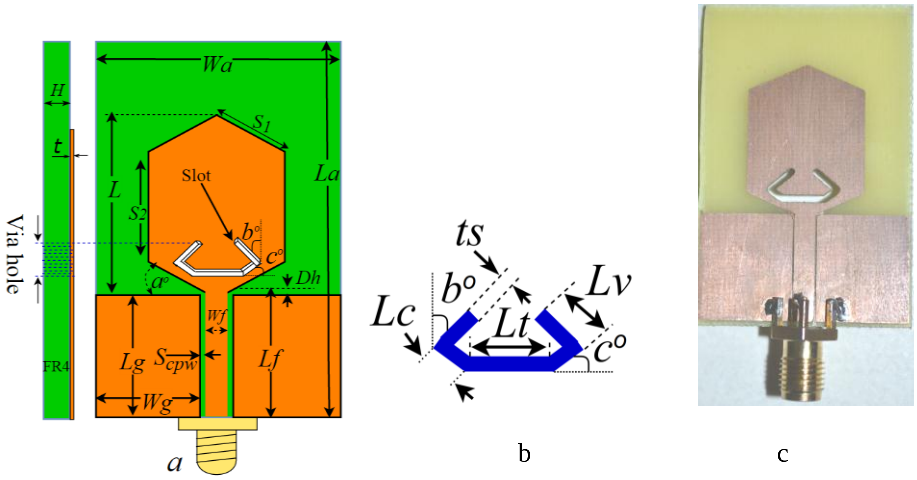


Figure 2. Demonstrated antenna structure, (a) Geometry of proposed design antenna 5, (b) Inverted diamond-shaped slot parameters, (c) Fabricated prototype of antenna 5

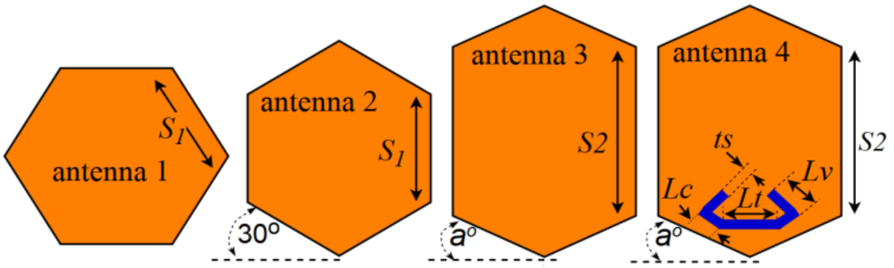


Figure 3. Design steps for proposed antennas 1–4

In addition, the right and left sides are increased to 14mm, as displayed in Figure 3 (antenna 3). Parameter (*L*) in (1) is increased to decrease the low resonance frequency. The equivalent geometry approximation of VPHPA is determined by applying the modified formula of the cylindrical monopole antenna. Voltage standing wave ratio (VSWR) is less than 2 at the low-frequency (*fl*) UWB bandwidth of the VPHPA represented by [12]:

$$fl = c/\lambda = 7.2/[(L + r + \rho) \times k] \tag{1}$$

where k is a constant that depends on the dielectric, equivalent cylindrical monopole antenna with effective radius r, length L, and the feed-line length ρ. The aforementioned three steps improved the inter bandwidth of the suggested antenna to achieve proper impedance matching plotted in Figure 4 from 2.8GHz to 18GHz by simulating antenna 3. Fourth, the inverted diamond slot is loaded on the radiation patch, as shown in Figure 3 (antenna 4), to avoid the EMI with the existing band at the frequency of 6GHz. The diamond slot is designed and slotted on copper patch based on a structure by European Gemological Laboratories, USA to cut the natural diamond [13]. The dimensions of the inverted diamond slot are presented in Figure 2(b). This slot achieved VSWR of 5.4, as plotted in Figure 4 (antenna 4). Because of the high-notch frequency requires a small slot length, the slot is designed as a close-end notch to reach the centre band rejection that equals half of the guided wavelength (λg/2). The total slot length is calculated by using (2) to achieve the required rejection frequency as [14]:

$$L_{ds} \simeq c/[2 \times f_{notc\,h} \times \sqrt{\varepsilon_{reff}}] \tag{2}$$

where f_{notch}, c, Lds, and ε_{reff} are the rejected frequency, speed of light, entire slot length, and effective relative dielectric constant respectively. Finally, the substrate below the slot is cut with the same copper slot dimensions using the air as a dielectric for calculating the effective dielectric of the notching band.

3. RESULTS AND DISCUSSION

A simulated band-notching characteristic shifted to the downlink X-band 7.5GHz with a VSWR of 4.5 of antenna 5 is significantly satisfied by notching the substrate further and the radiation patch with the same slot size, as shown in Figure 4. The demonstrated antenna and inverted diamond slot parameters are specified in Table 1. The simulated VSWR results are illustrated in Figure 4 for antenna 1 to 5. Antenna 1 achieved impedance matching with a fractional bandwidth (FBW) of 103%. However, the impedance matching of antenna 3 is improved significantly with a total FBW of 146%. The diamond slot is cut, and the FBW of antenna 5 is reduced to 133% based on notching harmonics and SMA connector losses.

Table 1. Dimensions of demonstrated antenna

Parameter	$S1$	$S2$	L	Wa	La	Lf	Wf	Lg	Wg	S_{cpw}
Value (mm)	8.5	14	21	28	43	14.5	2.54	14	12.2	0.5
Parameter	Dh	H	Lv	Lc	Lt	ts	t	a	b	c
Value (mm)	0.5	1.6	3.3	2.4	6	1	0.035	24°	50°	36°

The demonstrated prototypes of antennas 4 and 5 are printed on the FR4 substrate and fabricated based on the simulated design as shown in Figure 2(c). The VSWR is measured using a B&S ZVB 14 vector network analyzer. The measured VSWR of 5.8 with the rejection FBW of 18.5% at the centre frequency of 6GHz was tested for antenna 4, as shown in Figure 5(b). The rejected band is obtained by cutting the patch based on the closed-end diamond-slot length. However, the measured VSWR of 6 with the rejection FBW of 8.7% is at the downlink X-band 7.5GHz of the prototype (antenna 5). The band notch is shifted 1.5GHz by cutting the substrate and copper patch with the same slot dimensions. Figure 5(a) illustrates the validation of the tested VSWR magnitude of antenna 3, 4, and 5. Moreover, Figure 5(b) shows a good agreement between the simulated and measured results.

The gain of both antenna 4 and antenna 5 are simulated by using CST Microwave Studio. Figure 6 desplay the antenna gain validation verse frequency. The results show an acceptable gain between 2dB to 6.2dB for both tested antennas. However, the rejected bands (6GHz and 7.5GHz) gain is dropped to -3dB and 0.8dB of antenna 4 and 5 respectively. Therefore, the proposed diamond slot is successfully blocked the proposed antenna to radiate a signal at the rejected band.

Figure 7 illustrates the measured radiation pattern for the demonstrated prototype (antenna 5). The maximum electric-field radiation tested at 3.4 and 5.2GHz are 85.7dBμV/m with an angle of 14° and 77.4dBμV/m with an angle of 194°, respectively. Moreover, the measured results display that the demonstrated antenna has an omnidirectional radiation pattern.

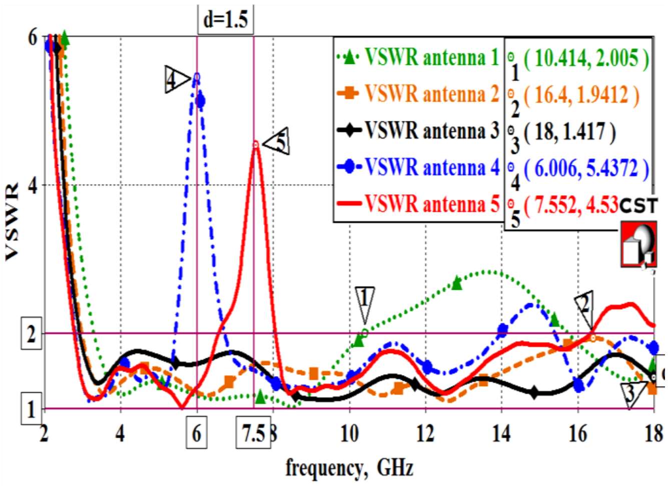
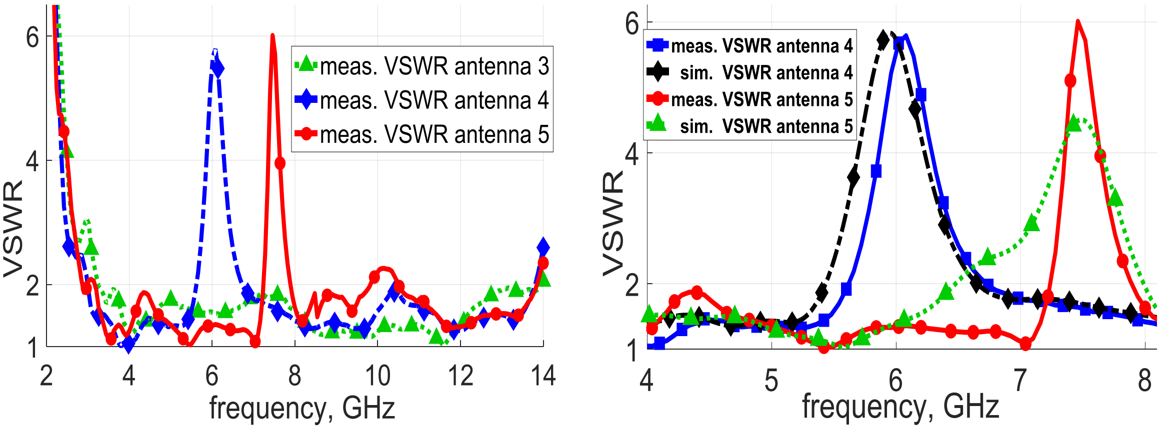


Figure 4. Simulated VSWR validations of design steps for antenna 1–5



(a) (b)

Figure 5. Evaluation of VSWR in various situations, (a) measurement VSWR of antennas 3, 4, and 5, (b) Validation of simulated and measured VSWR of antennas 4 and 5

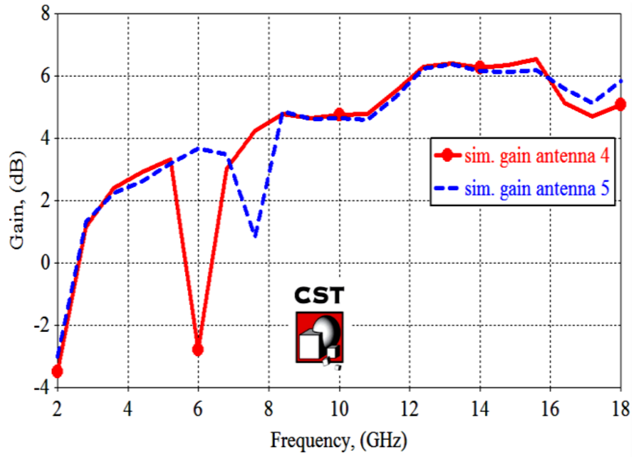


Figure 6. Simulated gain of antenna 4 and 5

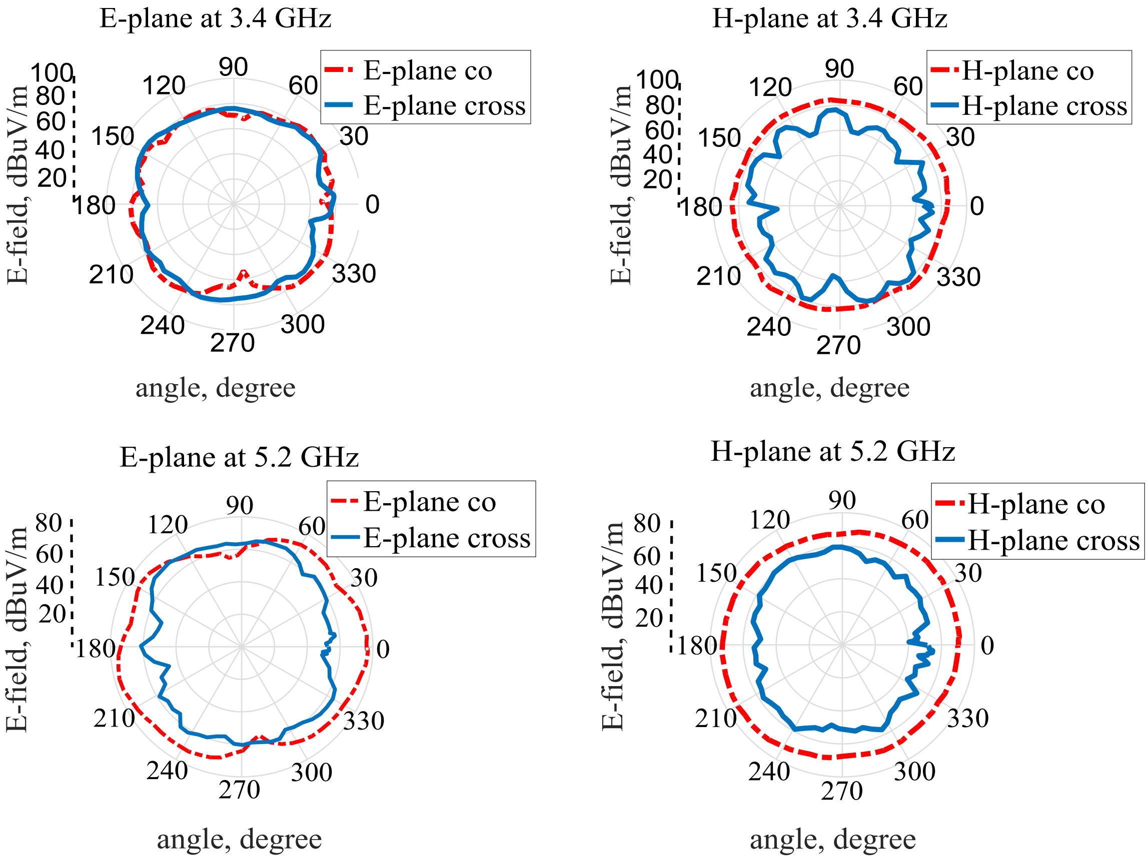


Figure 7. Measured radiation patterns at 3.4 and 5.2GHz of antenna 5

4. CONCLUSION

The method in this study demonstrates a new diamond slot for a single-band notched characteristic on a wide-bandwidth UWB antenna to overcome the EMI at high frequencies by integrating the substrate behind the proposed slot. The tested prototypes achieved 18.5% notching bandwidth and good band rejection at 6GHz by embedding the diamond slot on the radiation patch only. However, the measured VSWR achieved 8.7% rejection bandwidth at downlink X-band by slotting both the substrate and the patch. The measured results exhibit excellent compatibility with the simulation. The proposed method enables the avoidance of the EMI band in high-frequency wireless applications.

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