EFFECT OF FREQUENCY NOTCHING TECHNIQUE ON ULTRA-WIDEBAND ANTENNA PERFORMANCE

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Abstract

Effect of frequency notching techniques on the performance of ultra-wide band antenna was presented in this paper. Four different frequency notching techniques namely Electromagnetic Band Gap (EBG), Slot, Complimentary Slip Ring Resonator (CSRR), and Stub were study and performed on a 32 × 24 mm rectangular antenna. The lower two corners of the antenna were cut to expand the impedance bandwidth. High frequency structure simulator (HFSS) and Computer simulation structure (CST) was used as simulation tool to examine the antenna responses to the techniques of frequency notch and their effects on the antenna performance. Antenna radiation pattern, radiation efficiency, directivity, and bandwidth of the antenna were simulated, and analyzed to study the notching effect on the antenna. Simulation results show that the frequency notching techniques have an impact on the antenna performance. The results of each of the notching techniques gave an improvement in antenna directivity when certain portion of frequency band was notched to when there was no frequency notch. For instance, the antenna directivity before notch at frequency 7.39GHz, 3.66GHz, 4.35GHz 3.46GHz for EBG, Slot, CSRR, and Stub were 5.694 dBi, 2.535dBi, 3.018dBi, 2.299dBic, and were increased to 4.321dBi, 4.491dBi, 4.709dBi and 3.065dBi respectively except the EBG. From the study, it is clearly seen that with careful design analysis by antenna designer, the frequency notch will only impair the antenna performance at the notched band while improving the antenna directivity, gain and successfully avoiding interferences with any other narrow band applications within the same frequency band.

Keywords: *Microstrip patch antennas, ultra wide band (UWB), return loss, slots, radiation pattern, directivity.*

Introduction

The approval of UWB system to be used for both commercial and civilian purposed by Federal Communication Commission (FCC) led to the development and increase in research focus on UWB communication system and its application in the recent time (Abbas *et al*., 2021). Couple with some of its advantages such as high speed, small power consumption, minimum interferences with other radio systems and wide bandwidth had further increased its popularity (Bhatia *et al*., 2020; Kadam and Deshmukh, 2020). Antenna generally is a major component in any wireless communication that had become a research focus nowadays. UWB antenna has become research focus due to its numerous advantages. Unfortunately, the operation of narrow band systems significantly affects UWB operation if not notched (Ravichandran *et al*., 2020). One of the ways to achieve notching is by filtering out these narrow band frequencies from UWB system (Hongjian and Xia, 2020). Using an external band stop filter usually leads to increase in size, cost and complexity of the antenna design when compared with other methods of band rejection (Sohail *et al*., 2018). The simplest and main techniques to achieve notch include cutting of slot of various shape on the radiator (Bhatia et al., 2020), loading of parasitic branches or elements on the radiator (Qurratul, and Neela, 2018), etching grooves of different shapes (Ahmad *et al*., 2022), and introduction of meta-material structure such as EBG (Fadehan *et al*., 2023).

The introduction of band stop filter on UWB antenna design comes with its inherent challenges and advantages. The main advantages of frequency notch are seen in the purpose of introducing of the notch. Interference reduction within UWB frequency spectrum produces high selectivity antenna that could reject specific frequency while maintaining good performance in the desired frequency range (Bhatia *et al*., 2020). The challenges of achieving the above bring about some undesirable effects on the UWB performance. Some of these effects are seen in radiation pattern, radiation efficiency, directivity gain, bandwidth and increase in complexity of the antenna (Ahmad *et al*., 2022). These effects would be examined and analyzed in this paper to serve as guide during UWB antenna design. A rectangular microstrip antenna in its simplest form is used. To improve the bandwidth, the rectangular patch antenna was beveled at both lower corners. Half ground plane was used and further modified by cutting of 0.5 mm directly at the back of the fed line (Qurratul, and Neela, 2018). Different frequency notching methods (stub, EBG, Slot and CSRR) were used independently on the same antenna to study the effects of frequency notching. HFSS and CST modeling tools were employed to analyze the structure of the patch antenna and notching effects. The gain of the system over the operating frequency, radiation pattern, radiation efficiency, bandwidth as well the input impedance of the structure were scrutinized to evaluate the band-notched features on the antenna performances both at notched frequencies and when the frequencies are allowed.

Table 1: Dimension of UWB antenna

Parameter	L	W	L1	L2	L3	L4	W1	W2
Dimension (mm)	31	24	17.7	0.5	11.5	1.5	10.25	3.3

Table 2: Dimension of EBG notch method

Parameter	W1	L1	G	r	W2	L2
EBG	5	5	0.2	0.2	4	3

Table 3: Slot frequency notching dimension.

Parameter	L_1	L_2	L_3	W_1	W_2	W_3
Slot (mm)	3.1	5.1	13.8	0.3	0.4	0.5

Proposed patch antenna design

UWB antenna design

The antenna was designed on a FR4 substrate printed circuit board (PCB) of height 1.6 mm of dimension 31 × 24 mm, having a dielectric constant (ε_r) 4.4. A thickness 0.038 mm was used for the patch made of copper material. Partial ground plane was exploited in the design of size 11.5 mm. At both lower corner of the rectangular patch small portion of the patch was cut to increases the impedance bandwidth. Directly at the back of the feed line a squared shape was cut at the partial ground plane for enhanced impedance matching (Ahmad *et al*., 2022). Figure 1 shows the antenna derived based on the design equations in (1) to (3) as postulated by Constantine (2005) and Qurratul, and Neela (2018). The antenna achieved a bandwidth between 3.1 GHz to 14 GHz from its S-parameter (return loss) of S_{11} < -10dB. For the effective dielectric constant, Equation (1) was used.

$$\epsilon_{eff} = \frac{\epsilon_r+1}{2} + \frac{\epsilon_r-1}{2}\left[1 + 12\frac{h}{W}\right]^{-1/2} \quad (1)$$

where ϵ_r is dielectric constant of the substrate and $\frac{w}{h} \gg 1$ is the radio of substrate width to its height for fringing effect reduction. The width W, and length L, of the patch is calculated from Equations (2) and (3)

$$W = \frac{1}{2f_r\sqrt{\mu_0\epsilon_0}}\sqrt{\frac{2}{\epsilon_r+1}} = \frac{v}{2f_r}\sqrt{\frac{2}{\epsilon_r+1}} \quad (2)$$

$$L = \frac{1}{2f_r\sqrt{\epsilon_{eff}}} - 2\Delta L \quad (3)$$

where h is the substrate height, μ_0 is the permeability of free-space, ϵ_r is the dielectric constant, ϵ_0 is the relative permittivity, v is the speed of light, ΔL is the extended length of the rectangular patch at each end, and f_r is the resonant frequency. The dimension of the UWB antenna is given in Table 1. The geometry configuration is shown in Figure 1 with bandwidth between 3.1 GHz to 14 GHz from its S-parameter (return loss) of S_{11} < -10dB.

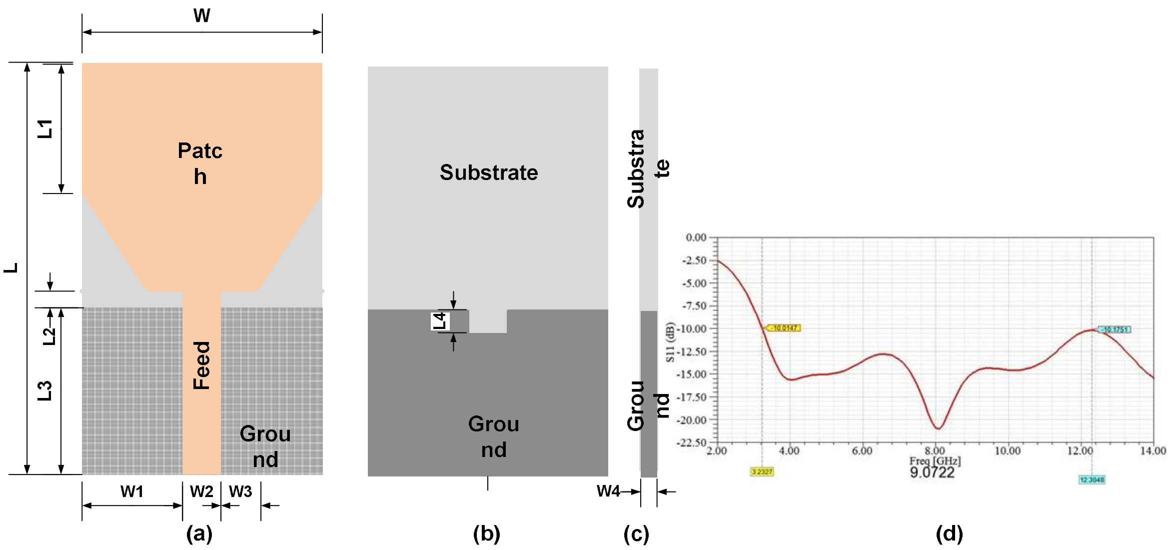

Figure 1: Structure of proposed antenna, (a) front view (b) side view (c) side view (d) S-parameter

Antenna notching process

Some techniques commonly used in notching frequencies in UWB system are further discussed in this section. These methods include, etching of slot, slip rings on the radiator, embedding of EBGs, and introduction of stub on the patch (Bhatia *et al.*, 2020; Abbas *et al.*, 2021; Ahmad *et al.*, 2022). There are principles and equations guiding this process as discussed further in the following subsections.

Electromagnetic Band Gap (EBG) Notching Techniques

EBG works on the principle of embedding electrical material in close proximity to the radiator creating field gap via ground plane (Abbas *et al.*, 2021). A shorting pin between EBG structures and its ground plane is known as "via". Equation (4) to (6) gives the relation that governs construction of EBG on the patch antenna (Hongjian and Xia, 2020).

$$L = 0.20h\left[\ln\left(\frac{2.0h}{r}\right) - 0.75\right] \quad (4)$$

$$C = \varepsilon_0\, \varepsilon_r \frac{w^2}{h} \quad (5)$$

$$w_0 = \frac{1}{\sqrt{LC}} \quad (6)$$

where ε_0 is the absolute permittivity and ε_r is the relative permittivity of the material, h is the substrate height, w_0 is the frequency, r is the via radius normally equals in substrate height, w represent the width of the EBG, L is the inductance and C is capacitance values related with the EBG structures. A squared shape EBG was used to examine the notching effect on the patch antenna as seen in Figure 2, the structure of the antenna designed and the s-parameter representing the return loss are also shown. The dimensional values of the designed EBG are given in Table 2.

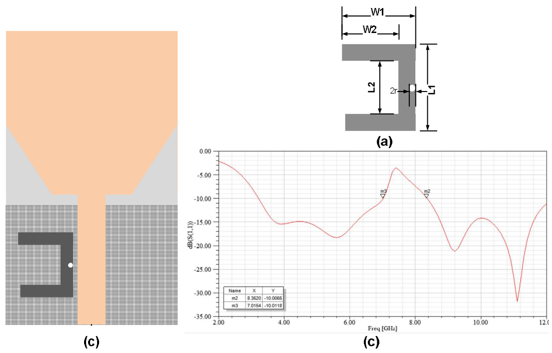

Figure 2: EBG notch (a) EBG Structure, (b) antenna structure, (c) s-parameter

Slot Notching Techniques

Slots notching techniques employed the process of cutting various slots of dissimilar and miscellaneous shape along the radiating patch (Abbas *et al.*, 2021). These shapes include U, L, H, and T among others in the radiating patch. The notch frequency are characterizes with the empirical formula approximated by Nikolaou and Quddious, (2020) as show in Equation (7) and the dimension of the slot used is given in Table 3 while the diagram of the slot as calculated from the equation is given in Figure 3(a). The antenna structure using slotted notch and s-parameter showing the return loss are presented in Figure 3(b) and 3(c) respectively.

$$f_{notc\ (slot)} = \frac{V}{2 \times l_{slot} \times \sqrt{\epsilon_{eff}}} \quad (7)$$

where l_{slot} is total length of slot that correspond to the desired center frequency of the notched band.

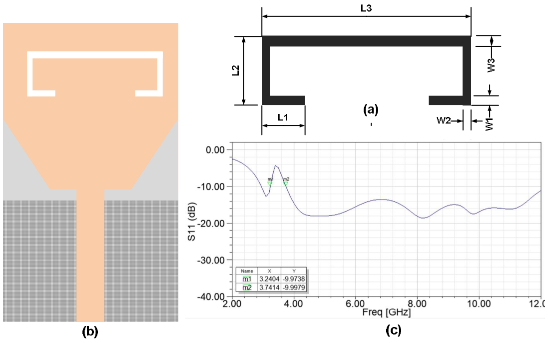

Figure 3: Slot notch (a) dimension of notching slot (b) antenna structure, (c) s-parameter

Complementary Split Ring Resonator Techniques

CSRR is employed to create a split gap in the patch radiator. CSRR mimic electrical behaviour of LC resonant elements of high quality factor especially at the microwave frequency that used a periodic structure of meta-material (Bhatia *et al*., 2020). The prohibited frequencies of each of the narrow band to be filtered are force to be the center frequency of the CSRR. The center frequency w_0 corresponding to CSRR can be expressed as postulated by Nikolaou and Quddious, (2020) in Equation (8).

$$w_0 = \sqrt{\frac{2}{\pi r_0 LC}} \quad (8)$$

where L represent the inductance corresponding to the ring slots length, C gives the capacitance of the CSRR, and r_0 is the radius of the rectangular ring slots. Figure 4(a) is the structure of the split ring used for frequency notching showing it dimensions. The antenna structure and the s-parameter showing the S-parameter (return loss) of the antenna are presented in Figure 4(b) and 4(c).

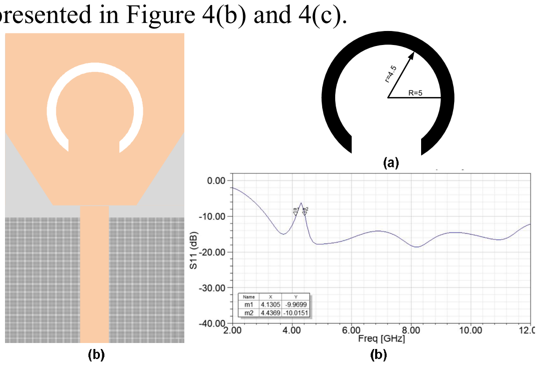

Figure 4: CSRR notch (a) dimension of CSRR, (b) antenna structure, (c) s-parameter

Stub Techniques

Stubs are accommodated easily on any small area and provide lower operating frequency notching characteristics (Kadam and Deshmukh, 2020). It works on the same principle of slot and governed by the same empirical formula as stated in Equation (7). Each stub length is tuned as desired to correspond to the notching band frequencies required. The tuning is approximately equivalent to quarter wavelength of the stub at corresponding center frequencies (Abbas *et al*., 2021). Figure 5(a) shows the construction of stub on the antenna with corresponding s-parameter after stub was introduced in Figure 5(b)

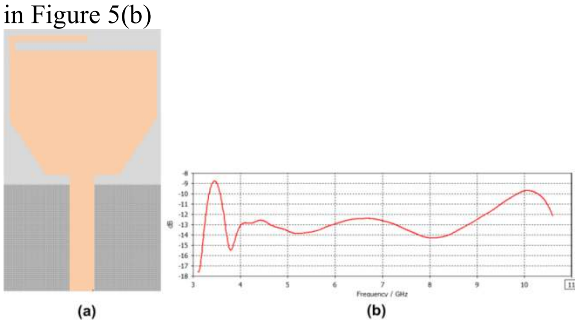

Figure 5: CSRR frequency notching (a) Structure (b) s-parameter

Results and Discussions

The antenna behavior was investigated and the results were presented. The effect of each of the notching technique on radiation pattern, radiation efficiency, directivity gain, bandwidth reduction, and increase in antenna complexity was presented in comparison to the antenna without notch. Table 4 gives the lower and upper band of the notch and the minimum depth of notch that represent the centre frequency for investigations purpose of frequency notched on radiation pattern.

Table 4: The notching frequency of notching techniques

Notch	Lower	Upper	Centre	Minimum Notch Depth
EBG	7.02	8.35	7.69	7.40
Slot	3.24	3.74	3.49	3.66
CSRR	4.13	4.43	4.28	4.35
Stub	3.32	3.57	3.45	3.46

Effect of Frequency Notched on Antenna Radiation Pattern

Figure 6 shows the radiation pattern of each of the techniques in comparison with same antenna at no frequency notch. At each of the notching frequency, the change in radiation pattern was observed to deviate from 8-shape pattern. This shows some form of impaired radiation pattern at those frequencies of notch for each technique. The implication of this is that the antenna would not operate at those notched frequencies by successfully blocking both its signal and interference from other applications.

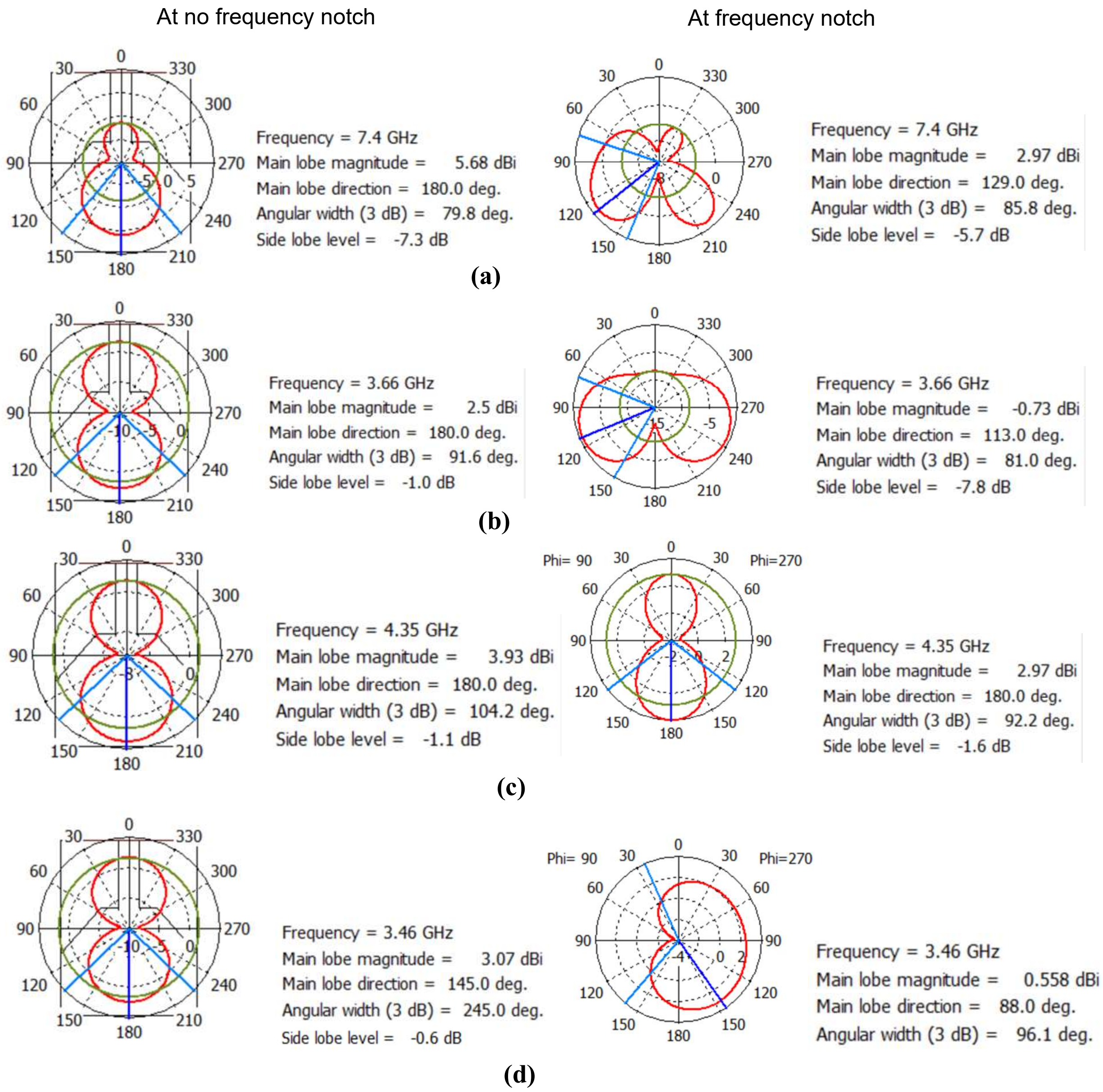

Figure 6: Effect of frequency notch on radiation patter (a) EBG (b) Slot (c) CSRR (d) stub

Table 5: Directive gain of UWB antenna before and after frequency notching

	EBG (dBi)	Slot (dBi)	CSRR (dBi)	Stub (dBi)
Before notch	5.694	2.535	3.018	2.299
After notch	4.321	4.491	4.709	3.065

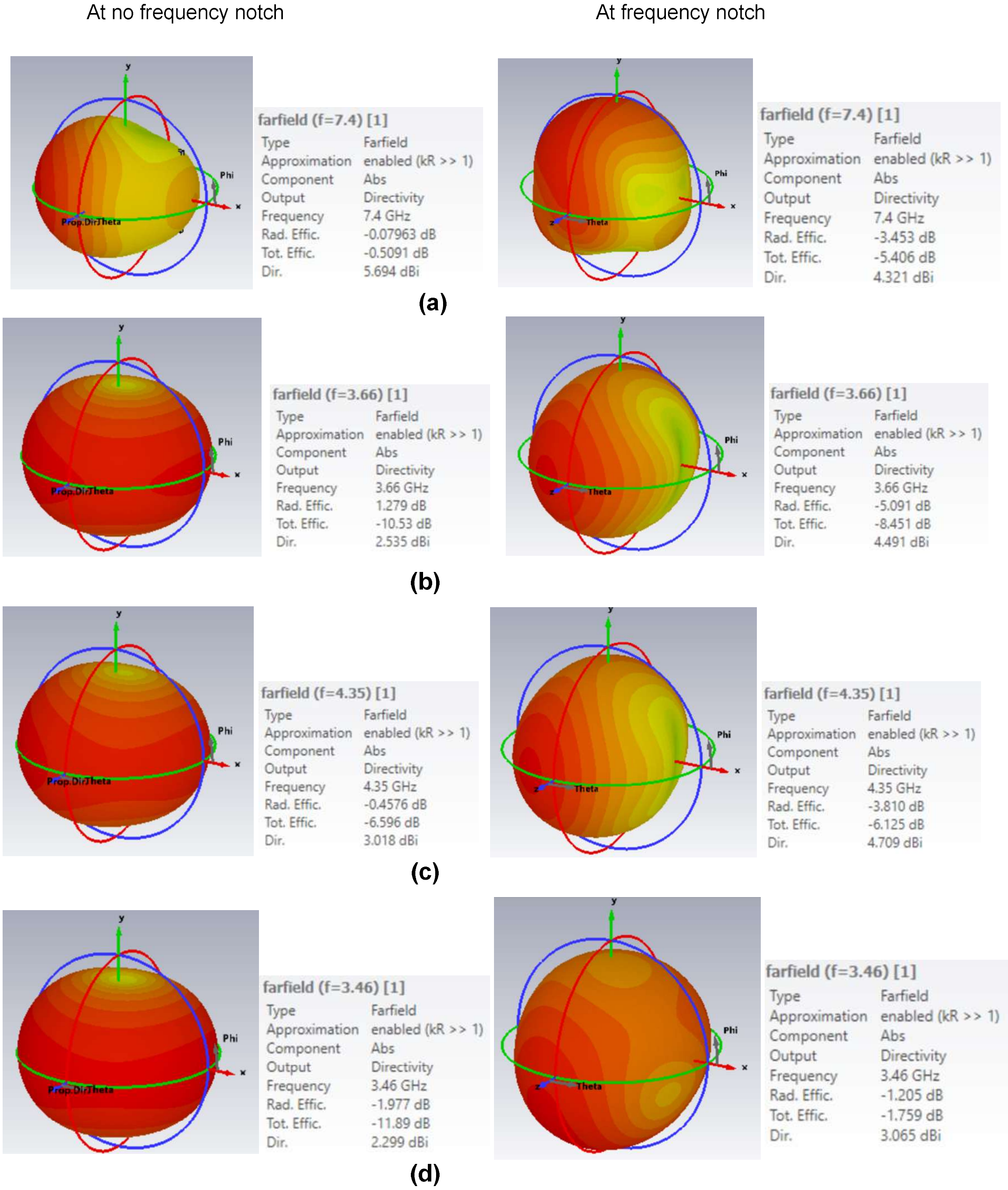

Figure 7: Effect of frequency notch on radiation efficiencies and directivity (a) EBG (b) Slot (c) CSRR (d) stub

Effect of Frequency Notched on Antenna Radiation Efficiency and Directivity

The plot of radiation efficiency and directivity with and without the notch technique is given in Figure 7. The effect could be examine both from desirable and undesirable point of view depending on the purpose and application the antenna is been used for. The directivity of the antenna is measured in dBi which shows that the antenna under test have certain value more than isotropic antenna directivity of 1dB. Table 5 gave the summary of the directive value of the antenna before notch and after notch.

The antenna with notched frequency has higher directivity value than antenna without notched except an exception of EBG notching technique as seen in Figure 7 and Table 5. This is desirable and makes the antenna to be more selective and directional depending on the applications it may be serving. On the other hand the total radiation efficiency of the antenna without notched frequency and with notched frequency does not follow a specific pattern. This implied that the total efficiency of the antenna is not despoiled with frequency notch.

Effect on Antenna Complexity

The design of a frequency band rejection could be easily achieved with only one notching element been embedded in the patch or ground. This is different when dual or multiple band notches are to be done. There are various method been reported which focuses more on loading diverse parasitic element on the antennas like strip, split ring resonators, stepped impedance resonators, ring-shaped while other uses slots of different and dissimilar shapes along the patch. However, all these approaches possess some practical application problem such as cross coupling effect (known as mutual coupling effects) among the notching elements creates additional problem, and taking of too large space on the antenna. Indeed, multiband notched antenna realized by loading the rejection element of different types, different number at different space will result in too much space and complicated design.

Conclusion

In this paper, effects of frequency notching on UWB antenna performance was investigated. While frequency notching is inevitable in UWB antenna designs due to the presence of some narrow band applications within the same frequency band, it is worth noting that there are consequences attached to the process. Antenna frequency notching effect could be desirable or undesirable depending on the application and functional use of the design. Some of the mentioned desirable effects are increase in selectivity of the antenna (the antenna is more directional) by rejecting unwanted signal. But these in turn reduced the bandwidth availability, impaired radiation patter and efficiencies most especially at the notching band, and further increase the complexity of the designed antenna.

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