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A single element of multiband switched beam antenna for 5G applications

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ABSTRACT

This work proposes a simple design of switched beam antenna on square split-ring resonator to operate in multiband frequencies. The antenna is designed to support fifth generation (5G) wireless applications. The proposed antenna provides two different of the main beams, 45˚/225˚±5˚ and 135˚/315˚±5˚, by shorted circuit at 4 different edges. The designed antenna can support nine frequency bands, 7.071, 9.006, 9.321, 9.906, 10.428, 10.718, 12.967, 13.057 and 14.469 GHz, which are the high-band of 5G spectrum when shorted circuit to the ground conductor. The antenna provides maximum gain of 6.41 dBi. The dimension of the antenna is 6×6 mm^2 which the thickness of 1.73 mm. The proposed design is based on a simple beam switching antenna configuration, compact size and low-cost manufacturing.

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1. INTRODUCTION

Recently, wireless communication technologies such as mobile phones and wireless local area networks (WLANs) have been dramatically increased due to the use of the internet has become a part of daily life. The fifth generation (5G) wireless technologies [1]–[4] are the presented next wireless technologies standards which would replace the present fourth generation/International mobile telecommunications-advanced (4G/IMT-advanced) standards. 5G technologies can cope the issues of the tremendous growth of wireless communications demand. The points of 5G such as providing higher capacity, delivering lower latency than present 4G. The attractive attributes of 5G mobile terminals such as mobile handset or notebook are small size, easy to implemented and able to be operated in multiband frequencies. In 5G technology, the frequency spectrums are classified into three groups, low-band for the frequency below 1 GHz, medium-frequency band or mid-band refer to the frequency between 1 to 6 GHz and high-band refer to the frequency upper 6 GHz [5]. The mid-band and high-band are mostly operated for 5G system in several countries.

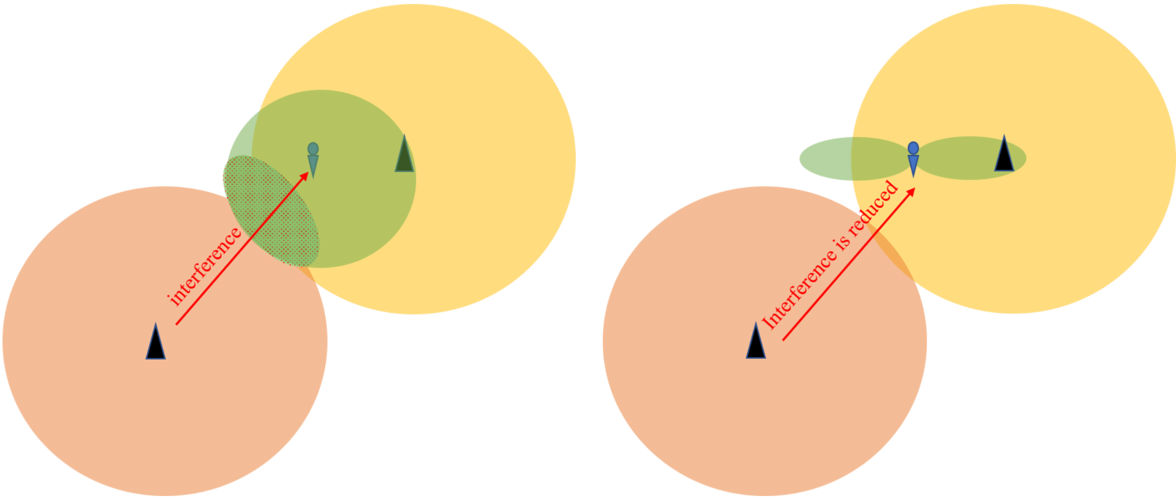
Considerable literature interprets low complex antenna for 5G technologies such as the single patch switched beam antenna with a parasitic ring at 28.5 GHz as presented in [6]. There were two directions of main beam which can be controlled by shorted or open circuit. The dual band antenna, 28 GHz and 38 GHz, designed for 5G applications was presented in [7]. Triangular-shaped slot is etched on the ground plane to increase antenna bandwidth. Also, the dual band, 28 GHz and 38 GHz, multiple input multiple output (MIMO) antennas designed for 5G mobile applications was present in [8]. Also, a flat gain antenna which high radiation efficiency was designed for 5G mobile communication networks at 28 GHz and 38 GHz as presented in [9]. Next, the work presented in [10], was designed a low-cost multiband antenna which good radiation control for 5G communications. The design of four typical planar antenna array for 5G millimeter waves system was presented in [11]. Furthermore, a single element of multiband antenna has attracted to employ at mobile terminal because of the low complex structure and compact size. Therefore, these antenna structures are relatively attention from researchers nowadays.

Some examples from literatures of single element antenna for multiband are discussed. The paper presented in [12], the PI-shaped slot on double fractal patch with U-shaped and L-shaped slots on the ground plane and double substrate, air and FR4, was presented. The working frequencies can be adjusted when the changing the point of shorting pins. There were five resonant frequencies, range from 1.97-6.31 GHz. The antenna size was 16.95×22.47 mm. The work proposed in [13], the structure of U-shaped patch antenna with multiple substrates, air, foam, teflon and FR4 (lossy) was observed. Two cases of resonant frequency, dual bands and tri bands, depend on type of substrate were observed in this study. The frequency range of 3.2 GHz to 6.32 GHz. The antenna size was 16×21 mm^2. Next, multiband split-ring resonator (SSRR) based planar inverted-F antenna (PIFA), for 5G wireless communication standards, which the antenna was consisted of a PIFA, a rectangular shaped parasitic element, an inverted-L parasitic element and a SSRR etched on the top plate of the PIFA was revealed in [14]. The working frequencies of antenna are 6 GHz, 10 GHz, and 15 GHz. The paper presented in [15], tri bands antenna using a single element microstrip patch by change the dimension of the edge-slots and positions of shorting pins. The work [16] proposed a microstrip antenna that can operate multiband frequencies by placing T-shaped and inverted-L parasitic elements at radiating patch. Moreover, simple structure of microstrip patch antenna which operated frequency can adjusted by changing status pf PIN diode was presented in [17]. The resonant frequencies of the antenna are six bands when status of PIN diode is ON. Conversely, five bands of operating frequency are achieved when status of PIN diode is OFF. Next, a multiband patch antenna with SSRR in non-homogeneous substrate was presented in [18]. The results show that non-homogeneous dual substate patch produces multiple bands of antenna. The antenna resonances at 1.15, 2.45, 3.65, and 5.25 GHz with maximum gain of 5.48 dBi. Also, small simple structure of microstrip patch antenna was presented in [19]. The antenna operates at 5G millimeter waves band ranges 43.5 GHz to 64 GHz with gain of 3.49.

In addition, smart antenna [20], [21] is an antenna system which combines an antenna array with signal processing to transmit or receive in an adaptive mode and it is applied in various wireless technologies including 5G mobile communication system. Smart antenna system has the ability to distinguish between desired signal and interferences by changing the directionality of the main beam in the desired direction while null or low side lobe are generated in certain interference directions. Switched beam antenna is an innovative smart antenna that provide beam steering functionality. It requires simple processing system and algorithm in order to switch beam, this system simply composes of three parts which are beam forming network, beam selector circuit and antenna array. Fixed beams are steered to multiple directions, the beam that provides the maximum signal strength is selected, thereby increasing the signal-to-interferences ratio. Interference signal coming from adjacent cell can be described in Figure 1. The user can receive a high level of interference when omnidirectional antenna is utilized as shown in Figure 1(a). However, interference signal can be reduced when switched beam antenna is applied as illustrated in Figure 1(b). According to this, the efficiency of the wireless communication system can be improved.

Many switched beam antenna configurations have been investigated such as the work propounded in [22]. Phase shifters for multi-beam for 5G technology at 26 GHz was designed. Main beam directions of 0°, 45°, 90°, 135°, and 180° can be steered. Also, a wideband tapered slot antenna with three directions of beam switching was presented in [23]. In addition, compact array antenna that beam patterns can steered using parasitic elements was revealed in [24] which five main beam directions were achieved. The work presented in [25], a single-arm rectangular spiral antenna which main beam directions were depended on the length of spiral arm. Also, configuration of spiral arm antenna which can change radiations by varying positions of shorted circuit at spiral arm as presented in [26]. In addition, radiations can be switched by changing positions of feeding point of a square loop antenna as proposed in [27]. The paper presented in [28], a rectangular patch which fixed size and fixed position of feeding point at the center, directions of main beam can be switched by shorted circuit at terminal edges. Also, an octagonal patch which fixed feeding point at the center, radiation patterns can be controlled by shorted circuited condition at end edges were revealed in [29], [30]. Moreover, the work proposed in [31], a compact dual band switched beam antenna which radiation patterns can be steered by controlling shorting positions at end edges. Next, a single element switched beam antenna using parasitic element to point main beam directions were presented in [32], [33].

Moreover, considerable literature reveals simple multiple bands structure of switched beam antenna in high-band where the operate frequency range from 6-100 GHz, that mostly operated for 5G application in several countries such as the work presented in [34], the octagonal prism which is surrounded by four elements of sub array patch antenna. The dual band millimeter-wave, 28 GHz and 38 GHz, was operated which three main beam directions. Next, the paper presented in [35], the switched beam antenna which can operate eight frequency bands, from 7-15 GHz. Beam patterns were depended on shorted circuit conditions. The structure of multiband antenna was low complex and simple of beam steering. However, radiation patterns when short circuit were not symmetry. So, some directions have low gain such as 135°, 210°, 215°, 315°, and 335°. Therefore, this work presents multiband switched beam antenna support 5G wireless applications using SSRR patch structure. The antenna works well in high-band from 6 GHz which using only single element. Moreover, there are two different directions of main beam by controlling the positions of shorted circuit at different edges. Main beam directions are symmetry when short circuit in each frequency. Also, the proposed antenna can provide high gain of all directions. Therefore, the compact size, low complex configuration and inexpensive manufacturing switched beam antenna is accomplished.



(a) (b)

Figure 1. Interference signal coming from adjacent cell when using (a) omnidirectional antenna and (b) switched beam antenna

The rest of this paper is organized as follows. Section 2, antenna design, the design of the SSRR patch antenna is defined where design and parameters of the antenna are discussed. Subsequently, the antenna is shorted circuit to switch main beam directions which is discussed in section 3, multiband switched beam antenna. Finally, section 4, conclusion is the conclusion of the study.

2. ANTENNA DESIGN

The antenna is designed on FR4 printed circuit board material with dielectric constant (ε_r) of 4.8 substrate thickness (h) of 1.67 mm and ground plane with thickness (t) of 0.03 mm. The antenna consists of the SSRR [36] which dimensions can be given by

$$l_n = \frac{L_n + S + 4W}{4} \quad (1)$$

where l_n is the nth length of square split ring (SSR). The n stands for number of resonant frequencies and L_n can expressed by

$$L_n = \frac{c}{2 f_n \sqrt{\varepsilon_{eff}}} \quad (2)$$

where,

$$\varepsilon_{eff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left(\frac{1}{\sqrt{1 + 12h/W_s}}\right) \quad (3)$$

$$\frac{W_s}{h} = \begin{cases} \frac{8e^A}{e^{2A}-2} & ; W_s < 2 \\ \frac{2}{\pi}\left[b - 1 - ln(2B-1) + \frac{\varepsilon_r - 1}{2\varepsilon_r}\left\{ln(B-1) + 0.39 - \frac{0.61}{\varepsilon_r}\right\}\right] & ; W_s \geq 2 \end{cases} \tag{4}$$

$$A = \frac{Z_0}{60}\sqrt{\frac{\varepsilon_r + 1}{2}} + \frac{\varepsilon_r - 1}{\varepsilon_r + 1}\left(0.23 + \frac{0.11}{\varepsilon_r}\right) \tag{5}$$

$$B = \frac{377\pi}{2Z_0\sqrt{\varepsilon_r}} \tag{6}$$

where, f_n is the n[th] resonant frequencies which f_1 and f_2 are the 1[st] and 2[nd] resonant frequencies, respectively. In this work, the SSRR is designed at 6 GHz and 15 GHz which are replaced by the first and second resonant frequencies, respectively. The l_1, l_2, W and S represent for the outer-length, inner-length, width and gap of the SSR lines, respectively. The structure of SSRR is illustrated in Figure 2.

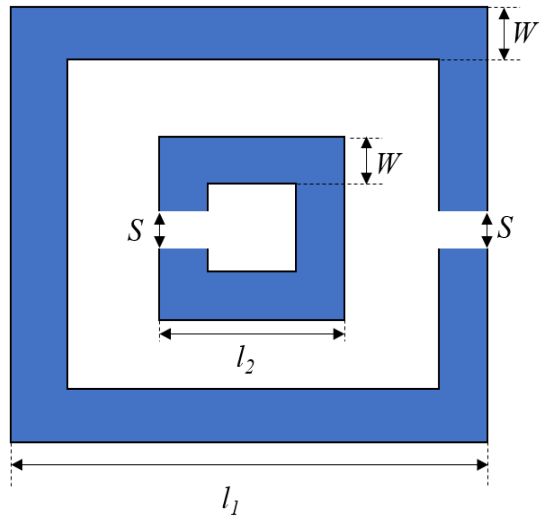


Figure 2. Structure of square split ring resonator

Next, the antenna is designed based on the dimensions of l_1 and l_2, from (1). The dimensions of W, S and the width of patch are varied to consider the minimum of return loss and maximum of operating bands. The coaxial probe feeding is done through a SMA connector at the center of the antenna. The parameters and dimensions of the SSRR are listed in Table 1 and depicted in Figure 3. The antenna can operate in tri bands which are 8.8980, 14.4970 and 14.8980 GHz as shown in Figure 4 in term of S_{11}. Please note that the first resonant frequency is slightly shifted from 6 GHz because of parameters adjusting and position of feeding point. The antenna radiates the beam direction in a vertical plane. Therefore, there are nearly zero antenna gains when horizontal radiation patterns are considered. However, horizontal radiation patterns of the antenna for frequencies of 8.8980, 14.4970 and 14.8980 GHz are illustrated in Figure 5(a) to Figure 5(c), respectively.

Table 1. The dimensions of the SSRR patch antenna

Parameters	Description	Values
f_1	first resonant frequency	6 GHz
f_2	second resonant frequency	15 GHz
l_1	outer-length of the SSR line	3.76 mm
l_2	inner-length of the SSR line	1.76 mm
S	gap of the SSR line	0.60 mm
W	width of the SSR line	0.30 mm
-	width of the patch antenna	6.00 mm
-	width from edge to outer line	1.20 mm

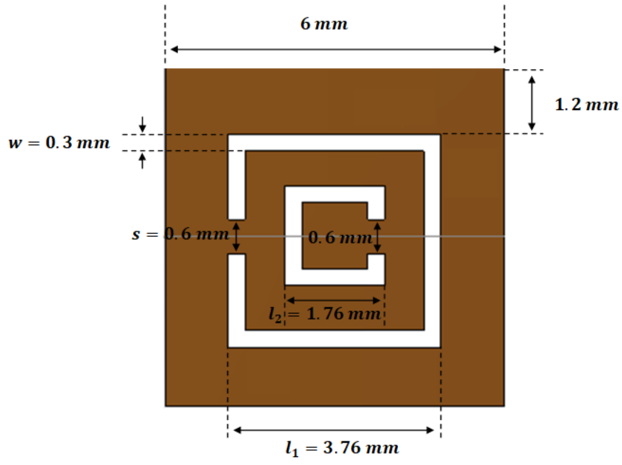


Figure 3. Dimensions of SSRR patch antenna

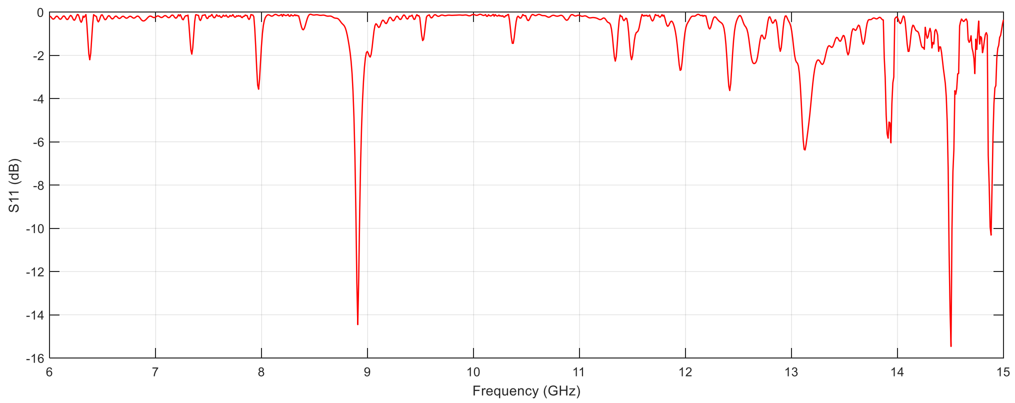


Figure 4. S11 of SSRR patch antenna

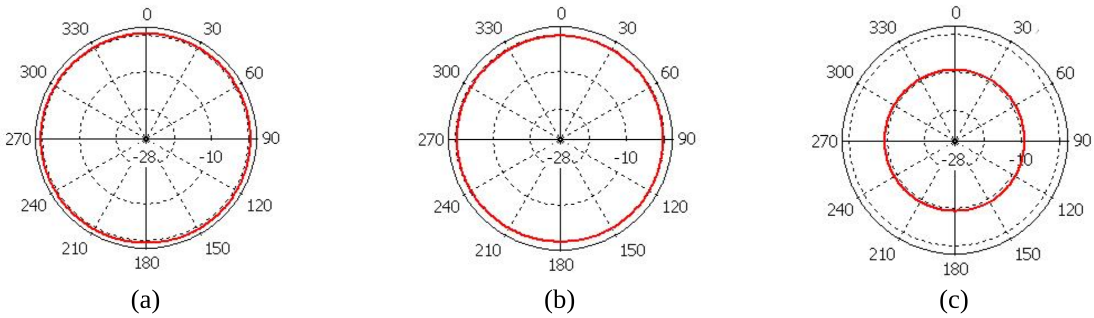
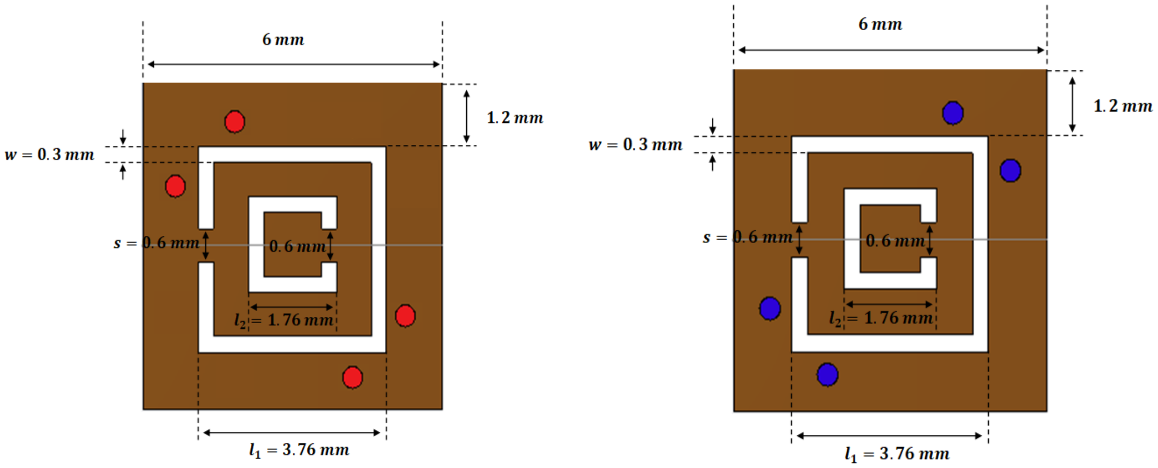


Figure 5. Beam pattern of SSRR antenna at (a) 8.898 GHz (b) 14.497 GHz and (c) 14.898 GHz

3. MULTIBAND SWITCHED BEAM ANTENNA

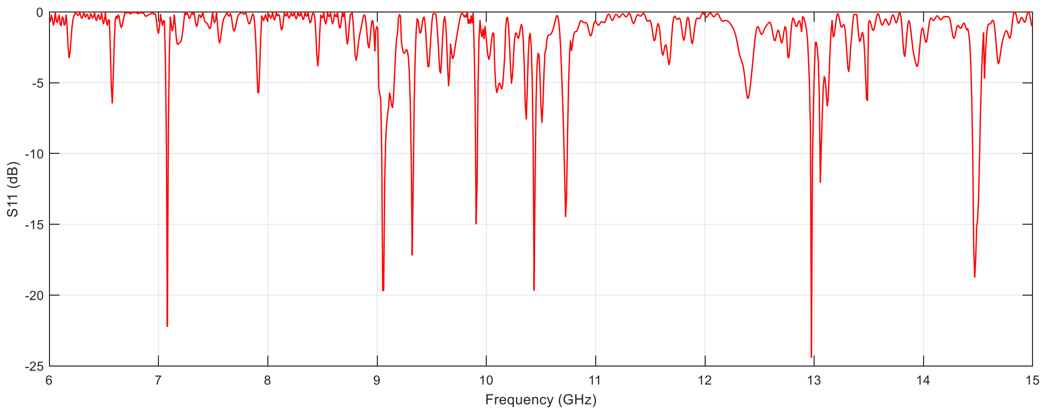
Next, main beam directions of the antenna can be turned by shorted or open circuit at 4 different edges to the ground conductor. At the edges of antenna that having minimum current distributions are chosen to be terminated with shorted circuit to the ground conductor. Consequently, the shorted circuit positions are changed at the antenna edges to beam steerable. Beam switching can be divided into two cases, case A and case B. The positions of shorted circuit of case A are shown in Figure 6(a) which consists of 4 positions of red dots. Also, blue dots are positions of shorted circuit of case B as shown Figure 6(b). Moreover, the antenna can operate nine frequency bands by shorted circuit at each edge while the antenna can operate only tri bands without shorted circuit at edges. The results in term of S_{11} of case A and case B are depicted in

Figures 7(a) and (b), respectively. There are nine operated frequency bands of case A, 7.0715, 9.0062, 9.3215, 9.9065, 10.4280, 10.7180, 12.9670, 13.0570 and 14.4690 GHz. In case B, there are the same results of case A, 7.0715, 9.0062, 9.3215, 9.9065, 10.4280, 10.7180, 12.9670, 13.0570 and 14.4690 GHz, due to the symmetry of antenna structure and shorted circuit positions. Some results such as, operated frequencies, S_{11} and antenna bandwidth are aggregated in Table 2.

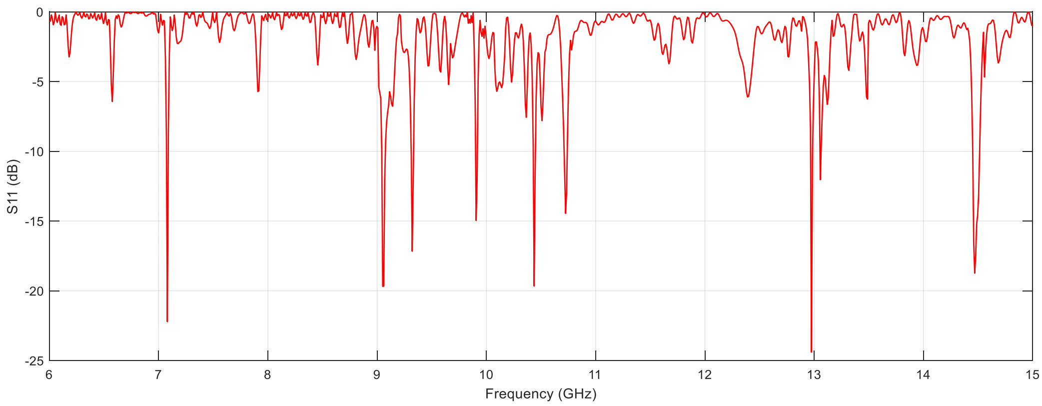


(a) (b)

Figure 6. Shorted circuit positions of SSRR antenna of (a) case A and (b) case B



(a)



(b)

Figure 7. S11 of SSRR antenna (a) case A and (b) case B

Table 2. S_{11} and bandwidth of the SSRR patch antenna

Frequencies (GHz)	case A		case B	
	S_{11} (dB)	Bandwidth (MHz)	S_{11} (dB)	Bandwidth (MHz)
7.0715	-21.545	17.0 (7062-7079)	-21.550	17.0 (7062-7079)
9.0062	-19.176	22.0 (8995-9017)	-17.658	21.0 (8995-9016)
9.3215	-13.506	15.0 (9313-9328)	-12.373	13.0 (9315-9328)
9.9065	-16.137	18.0 (9897-9915)	-16.072	14.0 (9898-9912)
10.428	-17.593	39.0 (10403-10442)	-19.462	45.0 (10405-10450)
10.718	-10.226	6.0 (10714-10720)	-10.524	11.0 (10714-10725)
12.967	-24.605	28.0 (12950-12978)	-23.099	28.0 (12955-12983)
13.057	-12.601	20.0 (13044-13064)	-11.647	28.0 (13051-13079)
14.469	-16.182	22.0 (14445-14467)	-16.250	19.0 (14460-14479)

Subsequently, antenna beam patterns with shorted circuit are interpreted to verified beam switchable. Radiation patterns in horizontal plane are illustrated in some frequency bands such as, 7.0715, 9.9065, 10.4280 and 10.7180 GHz. Radiation patterns of case A at 7.0715, 9.9065, 10.428, and 10.718 GHz are illustrated in Figures 8(a) to 8(d) which main beam directions are 229˚, 225˚, 224˚ and 227˚, respectively. Also, radiation patterns of case B at 7.0715, 9.9065, 10.428 and 10.718 GHz are depicted in Figures 9(a) to 9(d) which main beam directions are 319˚, 135˚, 316˚ and 315˚, respectively. As a result, the main beam direction is steered in dissimilar directions of shorted circuit positions. Therefore, these two cases of direction are based on shorted circuit configuration where 45˚/225˚±5˚ for case A and 135˚/315˚±5˚ for case B. The antenna with condition of shorted circuited provided the maximum gain of 6.41 dBi at 7.0715 GHz. However, the antenna gain provides lower when the antenna bandwidth provides wider. Conclusion results of the proposed antenna with and without shorted circuit configuration are illustrated in Table 3 when gray cells describe the results of antenna without shorted circuit. Please note that in Table 3, the results in terms of antenna gain without shorted circuit are considered in vertical radiation pattern which are nearly zero when consider in the horizontal radiation pattern. The antenna gains are nearly zero when considered in horizontal plane. Therefore, these results can confirm its beam switchable in multiband for 5G applications.

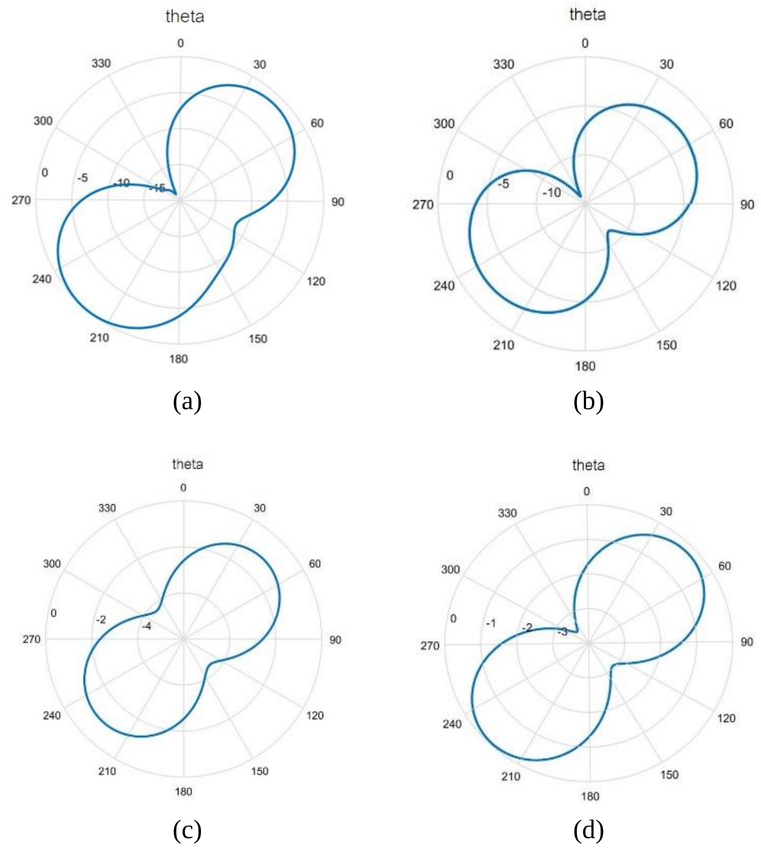
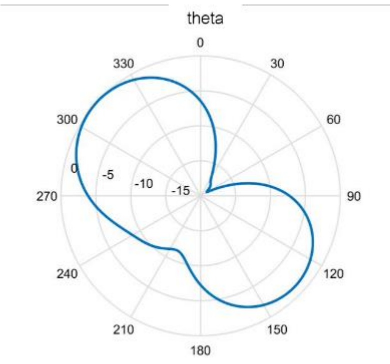
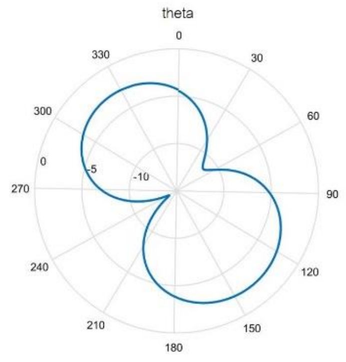


Figure 8. Beam pattern of case A at (a) 7.0715 GHz, (b) 9.9065 GHz, (c) 10.428 GHz, and (d) 10.718 GHz



(a)



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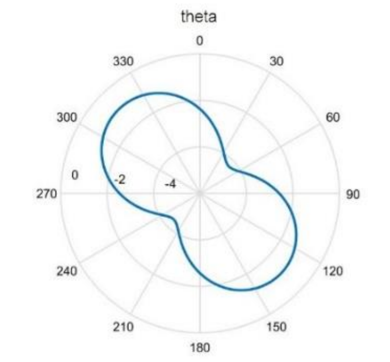
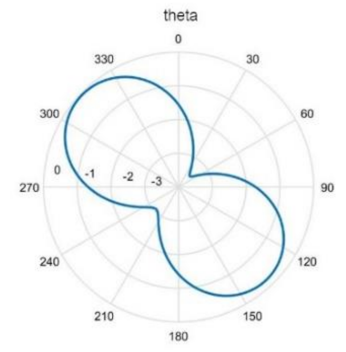


(c)



(d)

Figure 9. Beam pattern of case B at (a) 7.0715 GHz, (b) 9.9065 GHz, (c) 10.428 GHz, and (d) 10.718 GHz

Table 3. Results of the proposed antenna with and without shorted circuit

Frequencies (GHz)	Without shorted circuit		With shorted circuit			
			case A		case B	
	Main beam (˚)	Gain (dBi)	Main beam (˚)	Gain (dBi)	Main beam (˚)	Gain (dBi)
7.0715	-	-	221	6.41	319	6.39
8.898	-	3.95	-	-	-	-
9.9065	-	-	211	3.05	328	3.05
10.428	-	-	224	2.80	316	2.80
10.718	-	-	223	3.11	317	3.10
13.057	-	-	228	2.34	312	2.35
14.497	-	5.61	-	-	-	-
14.898	-	5.58	-	-	-	-

4. CONCLUSION

This work proposes a simple design of single element multiband SSRR which can be employed in 5G applications. The proposed design can switch the main beam into two directions which are controlled by shorted or open circuit at 4 different edges to the ground conductor. These two cases of direction are based on shorted circuit configuration where 45˚/225˚±5˚ for case A and 135˚/315˚±5˚ for case B. Without shorted circuit, the designed antenna can operate in tri bands which are 8.8980, 14.4970, 14.8980 GHz. However, the antenna could operate up to 9 frequency bands with shorted circuit configuration where its maximum gain is at 6.41 dBi. These all frequency bands are in the hi-band 5G spectrum which are 7.071, 9.006, 9.321, 9.906, 10.428, 10.718, 12.967, 13.057 and 14.469 GHz. Moreover, the proposed design is based on a simple beam switching antenna configuration, compact size and low-cost manufacturing.

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