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Bandwidth enhancement and miniaturization of circular-shaped microstrip antenna based on beleved half-cut structure for MIMO 2×2 application

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ABSTRACT

In this paper, circular-shaped microstrip antenna was simulated, fabricated, and measured accordingly. As the novelty, to enhance bandwidth and reduce antenna size, beleved half-cut microstrip structure is proposed. Further, this proposed antenna structure will be applied to multiple input multiple output (MIMO) antenna 2×2. Therefore, this research was investigated conventional circular shape antenna (CCSA), circular shaped beleved antenna (CSBA), and MIMO circular shaped beleved antenna (MIMO-CBSA) as Model 1, Model 2, and Model 3, respectively. An FR4 substrate with er=4.4, thickness h=1.6 mm, and tan d=0.0265 was used. The simulation has been conducted using Advanced Design System (ADS). The antenna CCSA/CSBA/MIMO-CBSA achieve 1.831GHz/2.265 GHz/2.256 GHz, -15.13dB/-17.37dB/-17.25 dB, 1.42/1.31/1.33, and 1.474/2.332/2.322 for center frequency, reflection coefficient, VSWR, and bandwidth, respectively. This antenna has a size 63x90 mm and 51.5x90 mm for CCSA (Model 1) and CSBA (Model 2), respectively. After the structure of MIMO 2×2 was applied, the size of antenna MIMO-CBSA (Model 3) became 180 mm x 180 mm with a mutual coupling (S_{21})=-26.18 dB and mutual coupling (S_{31})=-26.41 dB. The result showed that proposed antenna CSBA (Model 2) has wider-bandwidth of 58,2% and smaller-size of 18.2%. Furthermore, after CSBA (Model 2) structure was applied to MIMO 2×2 (Model 3) and the MIMO antenna obtain good mutual coupling (<-15dB). Moreover, the measured results are good agreement with the simulated results. In conclusion, all of these advantages make it particularly valuable in multistandard antenna applications design such as GSM950, WCDMA1800, LTE2300, and WLAN2400.

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1. INTRODUCTION

In recent years, microstrip patch antenna technology is widely used. The microstrip patch antenna has advantages such as low fabrication cost, light in weight, capable of supporting multiple frequency bands, easily etched on any PCB and integrated them with MICs or MMICs [1-3]. However, it has disadvantages such as low gain, large PCB structure, and narrow bandwidth due to conductor losses, surface wave losses, and dielectric losses [4, 5]. Several studies investigating bandwidth enhancement of microstrip antenna have been carried out by [6, 7]. The proposed methods include defected ground structure (DGS) [6], electromagnetic band gap (EBG) [7, 8], parasitic patch [9, 10], metamaterial [11], metamaterial bilayer substrates (MBS) [12], monopole slot [13], T-shaped slot [14], cylindrical dielectric slot (CDS) [15], polymeric grid [16], spiral split ring (SSR) [17], Jerusalem cross-shaped [18], and characteristic modes [19].

The DGS method was proposed by Marotkar [6], it is realized by etching the ground plane so the current distribution in the ground plane is disturbed. As the results, the antenna has a wide bandwidth of 302 MHz with center frequency of 2.4 GHz, and reflection coefficient of -23.26 dB. Furthermore, Gupta [7] and Hadarig [8] investigated bandwidth enhancement of microstrip patch antennas by implementing EBG structures. This proposed antenna has a center frequency of 10 GHz and 2.4 GHz for X-band Radar and VHF RFID, respectively. Then, to reduce the size of the antenna, Rothwell and Raoul O [21] proposed a metamaterial structure. The metamaterial microstrip structure has advantages such as compact size and broadband. However, the structure has complex geometry, and it is difficult to fabricate. Then, H. Mosallaei and K. Sarabandi [22] proposed bandwidth enhancement by using a reactive impedance substrate (RIS). This method succeeds to increase the bandwidth of the antenna and reduce antenna size.

Moreover, a fascinating method was proposed by Mohamadi [18]. It investigated the bandwidth enhancement of antenna for Long Term Evolution (LTE) technology with multiple input multiple output (MIMO) application. He introduced the basic modes method, this method successfully to enhance the bandwidth of the antenna, but it was still a drawback such as complex microstrip structure. Other methods include, G-shaped band-notched antenna [23], dielectric resonator antenna (DRA) [24], and U-shaped slot antenna [25]. The DRA antenna that is proposed by [24] has good bandwidth. However, the antenna structure is still large.

As the novelty, to enhance bandwidth and reduce antenna size, beleved half-cut microstrip structure is proposed in this paper. Further, this proposed antenna structure will be applied to multiple input multiple output (MIMO) antenna 2×2. Therefore, this research was investigated conventional circular shape antenna (CCSA), circular shaped beleved antenna (CSBA), and MIMO circular shaped beleved antenna (MIMO-CBSA) as Model 1, Model 2, and Model 3, respectively. An FR4 substrate with er=4.4, thickness h=1.6 mm, and tan d=0.0265 was used. In brief, Table 1. provides the research position of this paper compare to another research of bandwidth enhancement and miniaturization of the antenna.

Table 1. The Research Position of Bandwidth Enhancement and Miniaturization of the Antenna

Ref. no	Method	Center Freq.	Wireless Technology	Bandwidth Enhancement	Miniatu-rization	MIMO Application
[6]	DGS	2.4 GHz	WLAN	yes	-	-
[7]	EBG	10 GHz	X-band Radar	yes	-	-
[8]	EBG	2.4 GHz	RFID	yes	-	-
[9]	Parasitic Patch	8.5 GHz	X-band	yes	-	-
[10]	Parasitic Patch	120 MHz	VHF RFID	yes		
[11]	Metamaterial	1.9 GHz	GSM	yes	-	-
[12]	Metamaterial Bilayer	2.6 GHz	LTE	yes	-	-
[13]	Monopole Slot	4.4 GHz	WiMAX	yes	-	-
[14]	T-shaped Slot	6.7 GHz	UWB	yes	-	-
[15]	Dielectric Slot	11.25 GHz	X-band	yes	-	-
[16]	Polymeric Grid	26.8 GHz	5G	yes	-	-
[17]	Spiral Split Ring	5.8 GHz	WLAN	yes	-	-
[18]	Jerusalem Cross-Shaped	5.8 GHz	WLAN	yes	-	-
[19]	Characteristic Modes	1.9 GHz	LTE	yes		yes
[20]	Parasitic Patch	2.6 GHz	LTE	yes	-	yes
[21]	Metamaterial	2.6 GHz	LTE	-	yes	-
[22]	RIS	1.9 GHz	WCDMA	yes	yes	-
[23]	G-shaped band-notched	7.75 GHz	UWB	-	-	yes
[24]	DRA	30 GHz	5G	-	-	yes
[25]	U-shaped Slot	3 GHz	Selular	-	-	yes
This paper	Circular-Shaped with Beleved Halfcut Structure	2.175 GHz	GSM, WCDMA, LTE, and WLAN	yes	yes	yes

This rest of this paper is detailed as follows. In Section 2, the proposed circular shaped beleved antenna and MMO circular shaped beleved antenna are presented. The detail of numerical simulation was also described in Section 2. Furthermore, the measurement results of the fabricated antenna and the comparison with simulation result was explained in Section 3. Finally, Section 4 concludes this research.

2. RESEARCH METHOD

In this section, the proposed circular shaped beleved antenna and MMO circular shaped beleved antenna were designed. Figure 1(a), Figure 1(b), Figure 1(c), Figure 1(d), and Figure 1(e) show conventional circular shape antenna (CSSA) [Model-1], front view of CCSA, circular shaped beleved antenna (CSBA) [Model-2], front view of CBSA, MIMO circular shaped beleved antenna (CSBA) [Model-3], respectively.

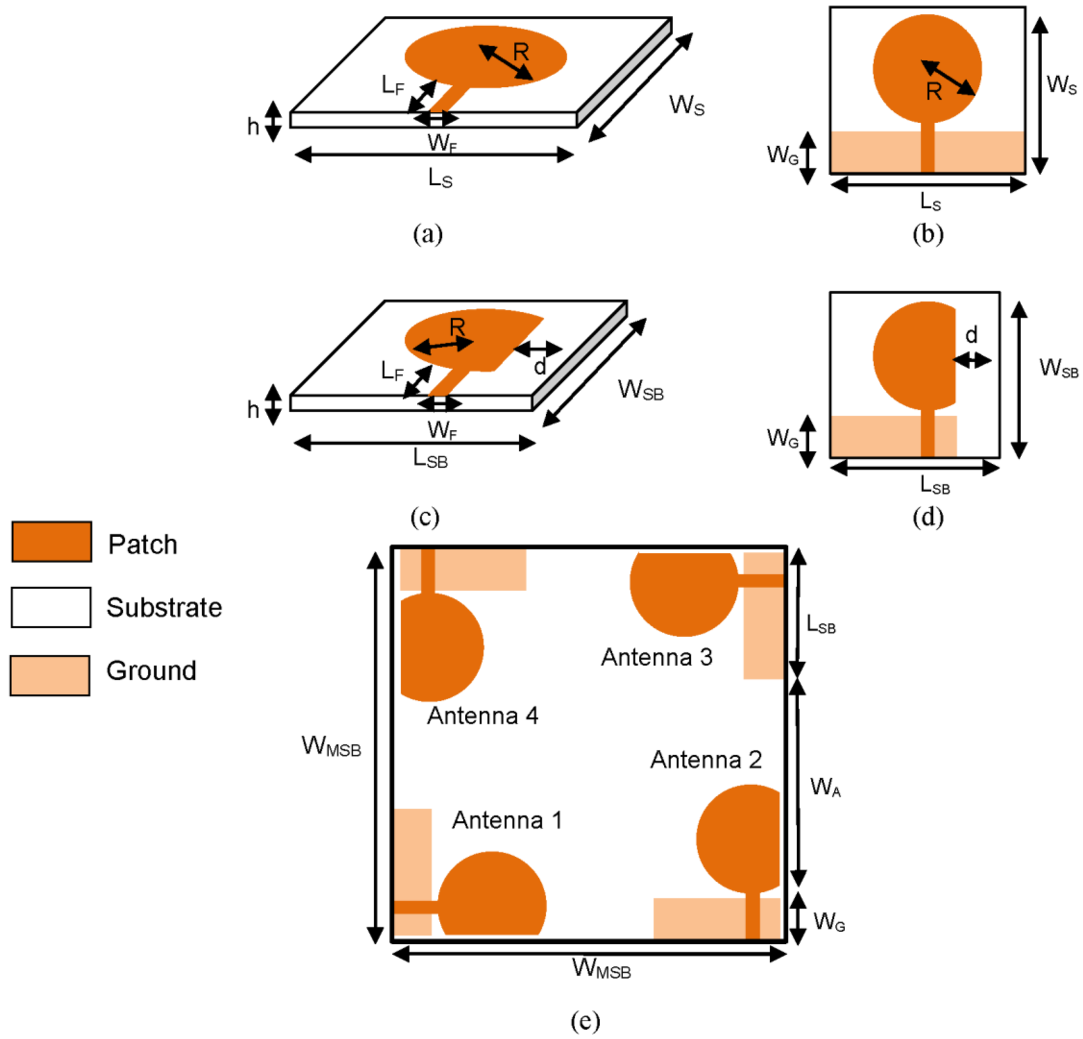


Figure 1. (a) Conventional Circular Shape Antenna (CCSSA) [Model-1], (b) Front view of Conventional Circular Shape Antenna, (c) Circular Shaped Beleved Antenna (CSBA) [Model-2], (d) Front view of Circular Shaped Beleved Antenna, (e) MIMO Circular Shaped Beleved Antenna (MIMO-CSBA) [Model-3]

The radius of circular-shaped microstip patch antenna is formulated by [26], [27]:

$$R = \frac{F}{\sqrt{1 + \frac{2h}{\pi \varepsilon_r}\left[ln\left(\frac{\pi F}{2h}\right) + 1.7726\right]}} \quad (1)$$

Where

$$F = \frac{8.791\ X\ 10^9}{f_r\sqrt{\varepsilon_r}} \quad (2)$$

with h=thickness of substrate (cm), εr=permittivity of substrate, and f_r=resonant frequency (Hz). A direct feeding method was used in this paper. Moreover, the impedance characteristic (Z_0) can be determined by the ratio of a thickness of substrate (h) and its width (W) [28].
When $Z_0\sqrt{\epsilon_{re}} > 89.91$, W/h ratio is given by [29], [30]:

$$W/h = \frac{8\exp(A)}{\exp(2A) - 2} \tag{3}$$

when $Z_0\sqrt{\epsilon_{re}} \leq 89.91$, W/h ratio is given by [29], [30]:

$$W/h = \frac{2}{\pi}\left\{B - 1 - \ln(2B-1) + \frac{\epsilon_r - 1}{2\epsilon_r}\left[\ln(B-1) + 0.39 - \frac{0.61}{\epsilon_r}\right]\right\} \tag{4}$$

where

$$A = \frac{Z_0}{60}\left\{\frac{\epsilon_r + 1}{2}\right\}^{1/2} + \frac{\epsilon_r - 1}{\epsilon_r + 1}\left\{0.23 + \frac{0{,}11}{\epsilon_r}\right\} \tag{5}$$

$$B = \frac{60\pi^2}{Z_0\sqrt{\varepsilon_r}} \tag{6}$$

$$\epsilon_{re} = \frac{\epsilon_r + 1}{2} + \frac{\epsilon_r - 1}{2}F\left(\frac{W}{h}\right) \tag{7}$$

Furthermore, the conductivity loss ($\propto_C$) of microstrip transmission line feeding is given by [29], [30];

$$\propto_C = \begin{cases} 1{,}38D\dfrac{R_S}{hZ_0}\dfrac{32 - (W/h)^2}{32 + (W/h)^2} & \left(\dfrac{W}{h} \leq 1\right) \\ 6{,}1x10^{-5}D\dfrac{R_S Z_0 \epsilon_{re}(f)}{h}\left[W_e/h + \dfrac{0{,}667\,W/h}{W_e/h + 1{,}444}\right] & \left(\dfrac{W}{h} \geq 1\right) \end{cases} \tag{8}$$

where

$$D = 1 + \frac{h}{W}\left\{1 + \frac{1{,}25}{\pi}\ln\frac{4\pi W}{t}\right\} \tag{9}$$

with
$R_S = \sqrt{\pi f \mu_0 \rho_C}$,
ρ_C = resistivity of the conductor,
f = frequency (Hz), and
$\mu_0 = 4\pi \times 10^{-7}$ N·A^{-2} is the magnetic permeability of free space,

The numerical simulation of the antenna parameters has been conducted by using Advanced Design System (ADS). The FR4 substrate with εr=4.4, thickness h=1.6 mm, and tan d=0.0265 was used. Figure 2(a) shows the extracted reflection coefficient with varied R. The data shows that by modifying the radius (R), the reflection coefficient can be tuned. However, for R=22 mm and R=24 mm, the antenna is not resonance. Furthermore, Figure 2(b) shows the voltage standing wave ratio (VSWR) value by varied radius (R). The simulation result shows that VSWR value is better than 2 at R=28 mm and R=30 mm.

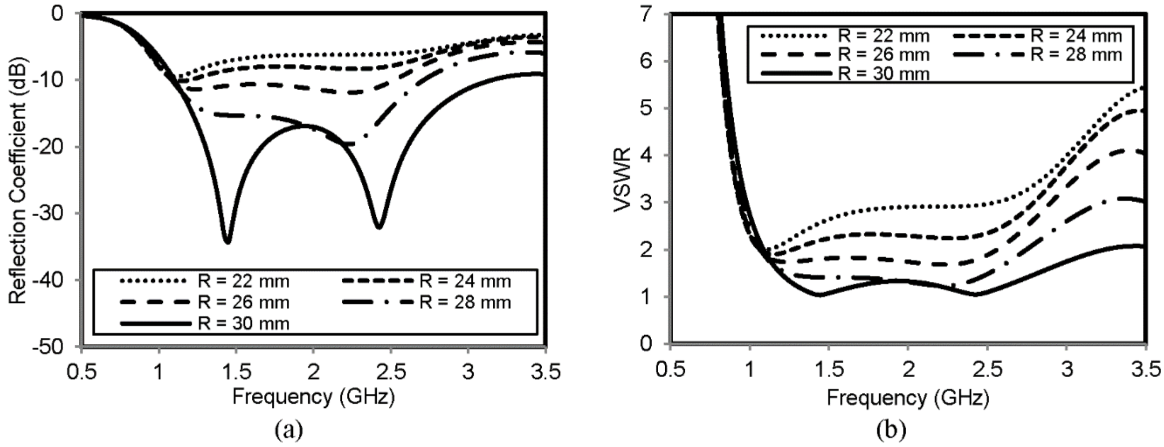


Figure 2. (a) The extracted reflection coefficient with varied R (mm); (b) The extracted voltage standing wave ratio (VSWR) with varied R (mm)

Figure 3(a) and Figure 3(b) illustrate the reflection coefficient with varied W_G and voltage standing wave ratio (VSWR) with varied W_G, respectively. From the data in Figure 3(a), we can see that the W_G is essential parameters to make the antenna resonate. The Figure 3(a) shows that by increasing the W_G (mm), the antenna will be more resonate. Moreover, Figure 3(b) shows clearly trend that the VSWR of the antenna is better than 2 (two) for W_G is longer than 28 mm. However, the dimension of this antenna is large. The next step explains the miniaturization process.

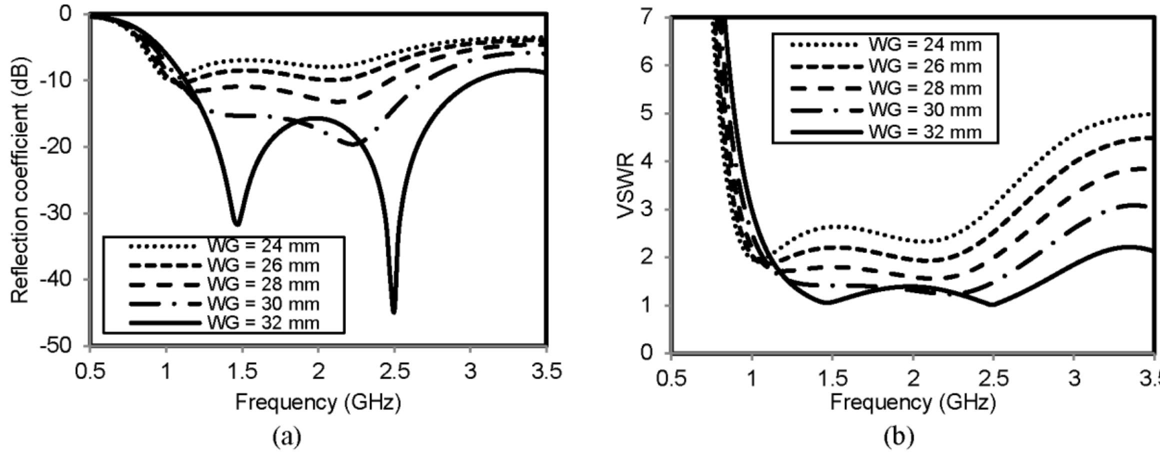


Figure 3. (a) The extracted reflection coefficient with varied W_G (mm); (b) The extracted voltage standing wave ratio (VSWR) with varied W_G (mm)

In this paper, the bandwidth enhancement and miniaturization of the antenna is obtained by the beleved method as shown in Figure 1(b) and Figure 1(c). The beleved method was applied by cut one side of the antenna, partially. Furthermore, the size of the antenna will be reduced by d (mm). Moreover, the result of numerical simulation based on the beleved method is depicted in Figure 4(a) and Figure 4(b). Figure 4(a) illustrates the extracted reflection coefficient with varied d (mm). Base on Figure 4(a), the data shows that at d=10 mm produce large bandwidth. However for d=10 mm at the frequency of 2.8 GHz, the reflection coefficient is higher than -10 dB at frequency of 2.8 GHz. Therefore, the value d=10 mm is not chosen because the reflection coefficient is too high. Therefore, the data shows that the largest bandwidth is generated at d=8 mm. This result is also indicated in Figure 4(b) which presents the extracted center frequency and bandwidth with varied d (mm). For instance, the circular shaped beleved antenna (CSBA) [Model-2] is represented by the antenna with d=8 mm and the conventional circular shape antenna (CCSA) [Model-1] is represented by the antenna with d=0 mm.

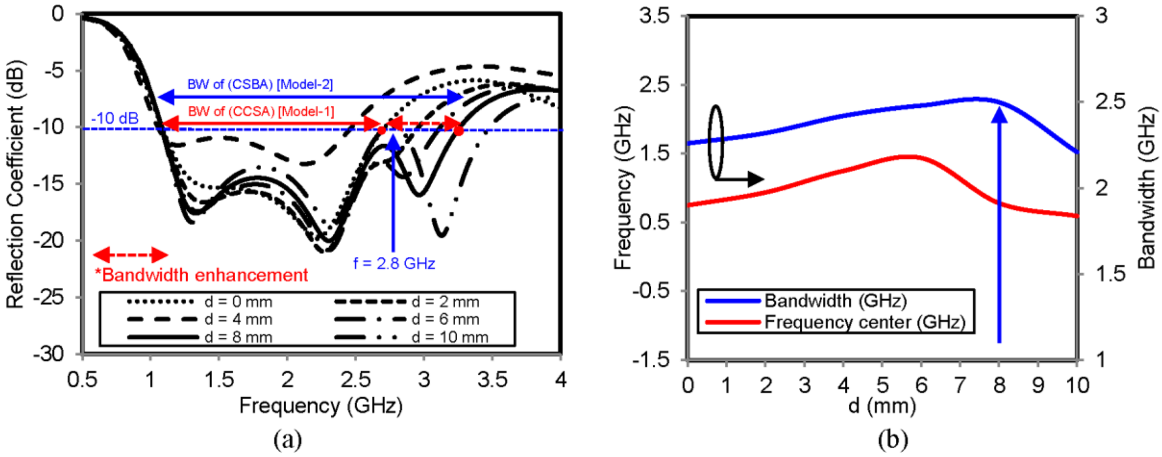


Figure 4. (a) The extracted reflection co efficient with varied d (mm); (b) The extracted frequency center and bandwidth with varied d (mm)

The next step is to apply the CSBA [Model-2] to MIMO-CSBA [Model-3] antenna as shown in Figure 1(e). Furthermore, Figure 5(a) shows the extracted reflection coefficient with different W_{SMB} (mm) and Figure 5(b) illustrates the extracted voltage standing wave ratio (VSWR) with varied W_{SMB} (mm). Figure 5(a) shows a clear illustration that the reflection coefficient is stable for the different length of W_{SMB} and it shows that the reflection coefficient values are lower than -10 dB. However, the reflection coefficient for W_{SMB}=180 mm generates lower bandwidth than others. Furthermore, it appears from Figure 5(b) that the VSWR values are still lower than 2 (two). This data shows that the antenna is working properly with good performance.

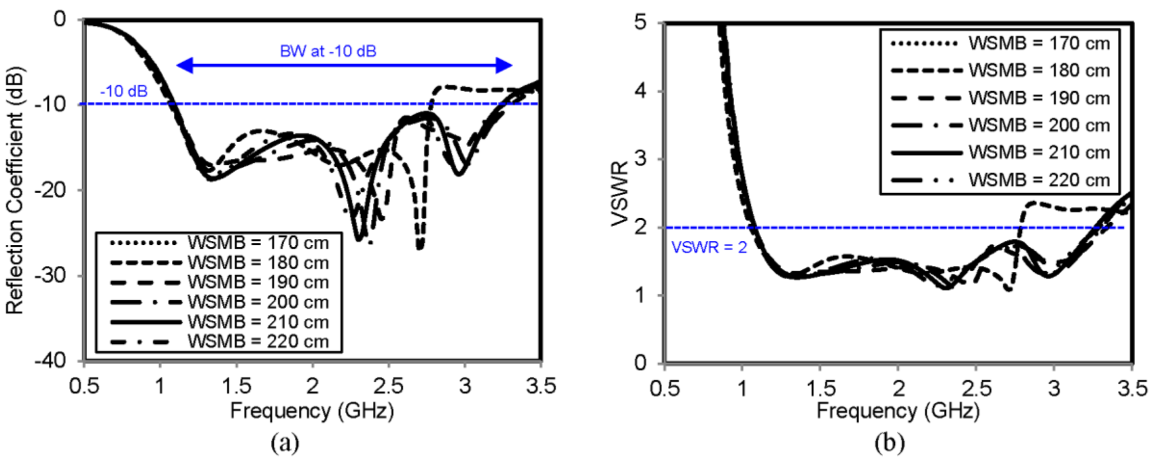


Figure 5. (a) The extracted reflection coefficient with varied W_{SMB} (mm); (b) The extracted voltage standing wave ratio (VSWR) with varied W_{SMB} (mm)

The numerical simulation result of mutual coupling MIMO antenna is shown in Figure 6(a) and Figure 6(b). Figure 6(a) exhibits the extr acted mutual coupling (S_{21}) with varied W_{SMB} (mm) and Figure 6(b) illustrates the extracted mutual coupling (S_{31}) with varied W_{SMB} (mm). The mutual coupling value of S_{21} (dB) and S_{31} (dB) demonstrate the coupling between Antena 1 to Antenna 2 and Antena 1 to Antenna 3, respectively. The coupling coefficient is lower than -15 dB almost over the whole band which shows a good isolation performance. However, the coupling coefficient for W_{SMB}=180 mm is higher than -15 dB at the frequency of 2.8 GHz. So, the W_{SMB}=180 mm cannot be chosen. The distace between antenna effects on mutual coupling. The mutual coupling can be decreased by increasing the distance between the MIMO antennas. However, the size of the antennas cannot be made too large.

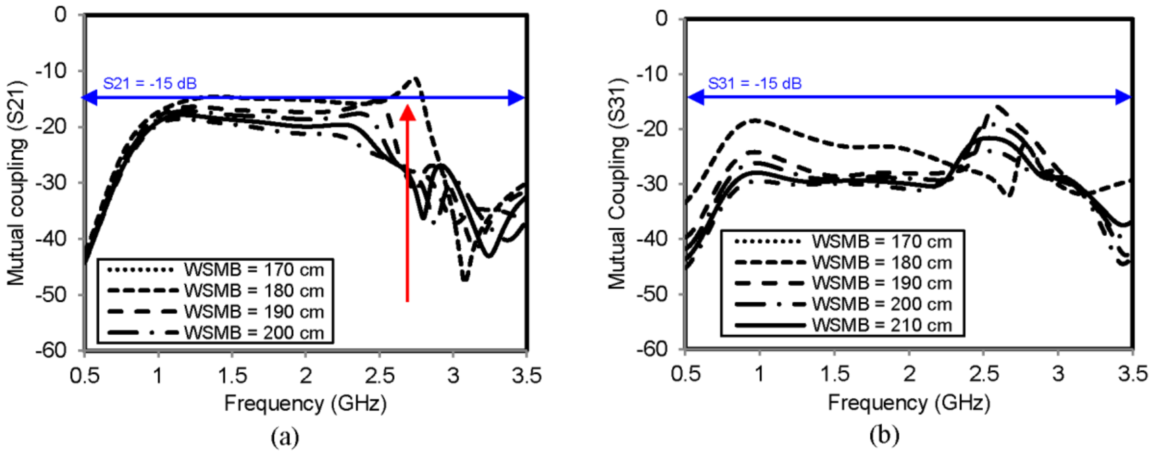


Figure 6. (a) The extracted mutual coupling (S_{21}) with varied W_{SMB} (mm); (c) The extracted mutual coupling (S_{31}) with varied W_{SMB} (mm)

3. RESULTS AND ANALYSIS

To verify the simulation result, the measurement of the antenna prototype must be carried out. The photograph of the fabricated proposed antenna is depicted in Figure 7(a), Figure 7(b), and Figure 7(c). Figure 7(a) shows the photograph of conventional circular shape antenna (CCSA) [Model-1], and Figure 7(b) illustrates the photograph of circular shaped beleved antenna (CSBA) [Model-2]. Furthermore, Figure 7(c) presents the photograph MIMO circular shaped beleved antenna (MCSBA) [Model-3]. The FR4 substrate with εr=4.4, thickness h=1.6 mm, and tan d=0.0265 was used. The simulation and optimization has been conducted using Advanced Design System (ADS). The detailed geometric parameters are R=28 mm, L_S=63 mm, W_S=90 mm, W_G=30 mm, L_F=34 mm, W_F=3mm, d=8 mm, L_{SB}=51.5 mm, W_{SB}=90 mm, W_{MSB}=190 mm, and W_A=98.5 mm, Moreover, the full size of the PCB board is 190×190 mm^2.

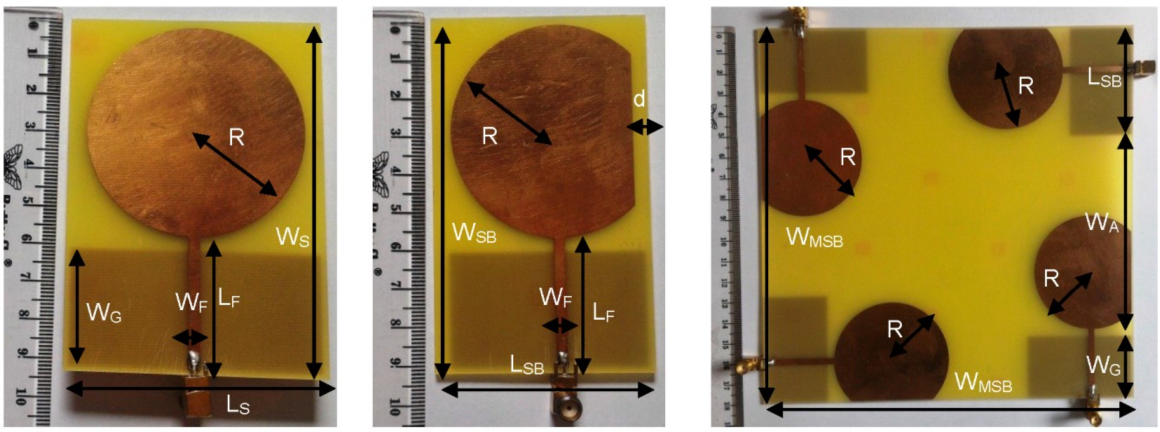
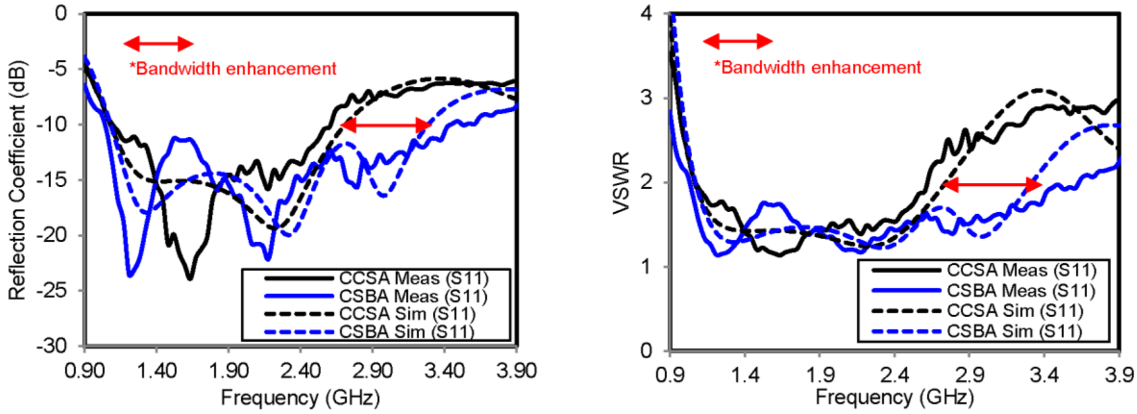


Figure 7. Photograph of (a) conventional circular shape antenna (CCSA) [Model-1], (b) circular shaped beleved antenna (CSBA) [Model-2], (c) MIMO circular shaped beleved antenna (MCSBA) [Model-3]

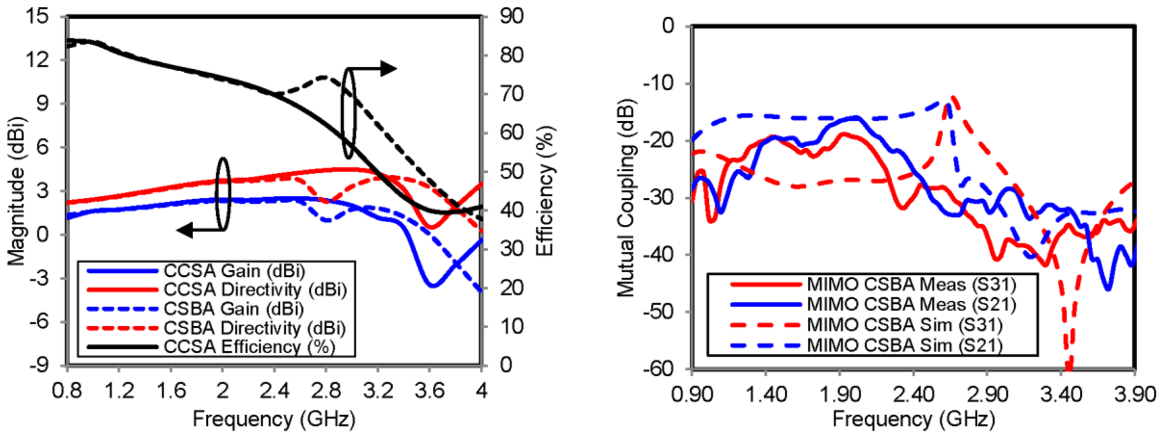
Figure 8(a) shows the comparison between simulated and measured of reflection coefficient of CCSA antenna dan CSBA antenna. The simulated/measured of CCSA antenna [Model-1] achieves lower frequency=1.093 GHz/1.094 GHz, upper frequency=2.719 GHz/2.568 GHz, center frequency=1.906 GHz/1.831 GHz, bandwidth=1.626 GHz/1.474 GHz, and reflection coefficient=-16.39 dB/-15.13 dB with the size of CCSA antenna has 63x90 mm. Furthermore, the simulated/measured of CBSA antenna [Model-2] achieves lower frequency=1.051 GHz/1.090 GHz, upper frequency=3.299 GHz/3.422 GHz, center frequency=2.175 GHz/2.265 GHz, bandwidth=2.248 GHz/2.332 GHz, and reflection coefficient=-17.99 dB/17.37 dB with the size of CSBA antenna has 51.5x90 mm. Moreover, Figure 8(b) shows the comparison between simulated and measured of VSWR. The simulated/measured of CCSA antenna [Model-1] achieves VSWR=1.35/1.42, and the simulated/measured of CSBA antenna [Model-2] achieves VSWR=1.28/1.31. Base on the measurement performance, both antennas can work as expected. However, the comparison result showed that proposed antenna CSBA [Model 2] has wider-bandwidth of 58,2% and smaller-size of 18.2%.



(a) (b)

Figure 8. (a) The comparison between simulated and measured of reflection coefficient; (b) The comparison between simulated and measured of VSWR

Figure 9(a) exhibits the comparison of gain (dBi), directivity (dBi), efficiency (%). The gain of CCSA [Model 1]/CSBA [Model 2] antenna has 1.58 dBi/1.56 dBi, 3.61 dBi/2.29 dBi, 2.44 dBi/2.27 dBi, and 2.47 dBi/2.34 dBi for frequency of 0.95 GHz, 1.85 GHz, 2.35 GHz, and 2.45 GHz, respectively. Furthermore, the directivity of CCSA [Model 1]/CSBA [Model 2] antenna has 2.34 dBi/2.32 dBi, 2.36 dBi/3.54 dBi, 3.99 dBi/3.74 dBi, and 4.09 dBi/3.84 dBi for frequency of 0.95 GHz, 1.85 GHz, 2.35 GHz, and 2.45 GHz, respectively. The efficiency of CCSA [Model 1]/CSBA [Model 2] antenna has 83.99 %/83.92%, 75.12 %/74.92%, 70.10%/71.25%, and 68.95%/70.89% for frequency of 0.95 GHz, 1.85 GHz, 2.35 GHz, and 2.45 GHz, respectively. Moreover, Figure 9(b) shows the comparison between simulated and measured of mutual coupling (S_{21}) and (S_{31}). The simulated/measured of mutual coupling of MIMO-CBSA [Model-3] antenna are -16.15 dB/-26.18 dB and -27.11 dB/-26.41 dB for mutual coupling (S_{21}) and mutual coupling (S_{31}), respectively. The MIMO antenna obtain very good mutual coupling (<-15dB). Moreover, the measured results are in a good agreement with the simulated results.



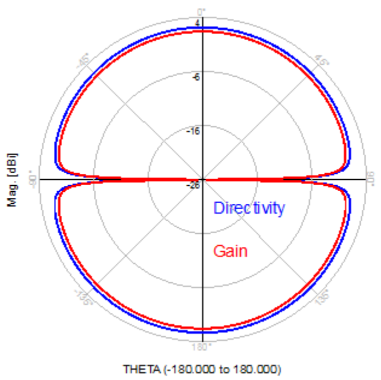
(a) (b)

Figure 9. (a) The comparison gain (dBi), directivity (dBi), Efficiency (%), (b) The comparison between simulated and measured of mutual coupling (S_{21}) and (S_{31})

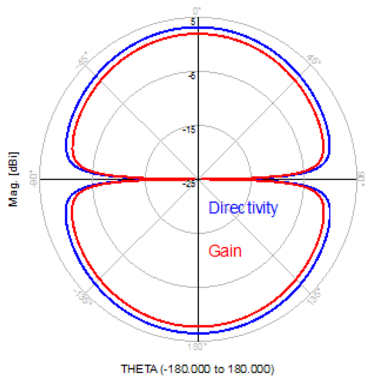
Table 2 summarizes the comparison of simulated and measured data of CCSA [Model-1] antenna, CSBA [Model-2] antenna, and MIMO CBSA [Model-3] antenna, in brief. Moreover, the radiation patterns of the proposed antenna are shown in Figure 10(a)-(h). In conclusion, all of these advantages make it particularly valuable in multistandard antenna applications design such as GSM950, WCDMA1800, LTE2300, and WLAN2400.

Table 2. The Comparison of Simulated and Measured Result of CCSA [Model-1] Antenna, CSBA [Model-2] Antenna, and MIMO CBSA [Model-3] Antenna

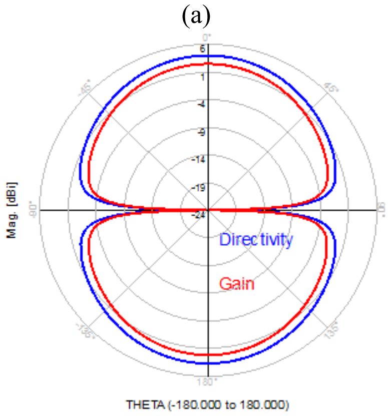
Performace		CCSA [Model-1]		CSBA [Model-2]		MIMO CBSA [Model-3]	
		Simulated	Measured	Simulated	Measured	Simulated	Measured
Lower frequency (GHz)		1.093	1.094	1.051	1.090	1.061	1.095
Upper frequency (GHz)		2.719	2.568	3.299	3.422	3.275	3.417
Center frequency (GHz)		1.906	1.831	2.175	2.265	2.168	2.256
Bandwidth (MHz)		1.626	1.474	2.248	2.332	2.214	2.322
Reflection coefficient (dB)		-16.39	-15.13	-17.99	-17.37	-17.12	-17.25
VSWR		1.35	1.42	1.28	1.31	1.32	1.33
Mutual coupling (S_{21})		NA	NA	NA	NA	-16.15	-26.18
Mutual coupling (S_{31})		NA	NA	NA	NA	-27.11	-26.41
Gain @ f=0.95 GHz (dBi)		1.58	NA	1.56	NA	0.14	NA
Gain @ f=1.85 GHz (dBi)		3.61	NA	2.29	NA	3.90	NA
Gain @ f=2.35 GHz (dBi)		2.44	NA	2.27	NA	4.64	NA
Gain @ f=2.45 GHz (dBi)		2.47	NA	2.34	NA	4.84	NA
Directivity @ f=0.95 GHz (dBi)		2.34	NA	2.32	NA	1.47	NA
Directivity @ f=1.85 GHz (dBi)		2.36	NA	3.54	NA	4.50	NA
Directivity @ f=2.35 GHz (dBi)		3.99	NA	3.74	NA	5.49	NA
Directivity @ f=2.45 GHz (dBi)		4.09	NA	3.84	NA	5.16	NA
Efficiency @ f=0.95 GHz (%)		83.99	NA	83.92	NA	73.74	NA
Efficiency @ f=1.85 GHz (%)		75.12	NA	74.92	NA	87.25	NA
Efficiency @ f=2.35 GHz (%)		70.10	NA	71.25	NA	82.23	NA
Efficiency @ f=2.45 GHz (%)		68.95	NA	70.89	NA	92.82	NA
	W (mm)	63	63	51.5	51.5	190	190
Size	L (mm)	90	90	90	90	190	190
	H (mm)	1.6	1.6	1.6	1.6	1.6	1.6



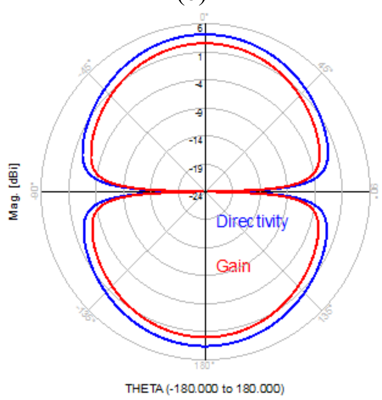
(a)



(b)



(c)



(d)

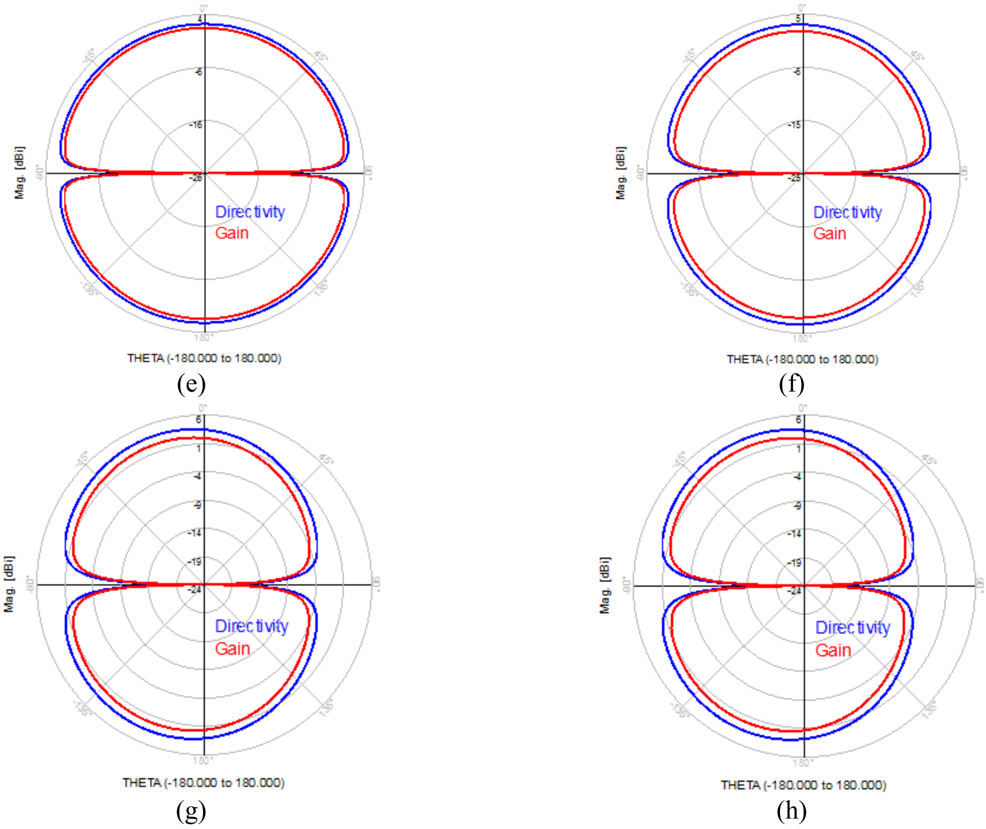


Figure 10. Gain and directivity of CCSA at frequency (a) f=0.95 GHz, (b) f=1.85 GHz, (c) f=2.35 GHz, (d) f=2.45 GHz. Gain and directivity of CSBA at frequency (e) f=0.95 GHz, (f) f=1.85 GHz, (g) f=2.35 GHz, (h) f=2.45 GHz

4. CONCLUSION

In order to reduce the antena size and enhance the bandwidth of antena, this paper was proposed the beleved half-cut microstrip structure. Moreover, this research was investigated conventional circular shape antenna (CCSA), circular shaped beleved antenna (CSBA), and MIMO circular shaped beleved antenna (MIMO-CBSA) as Model 1, Model 2, and Model 3, respectively. This antenna was fabricated on FR4 substrate with er=4.4, thickness h=1.6 mm, and tan d=0.0265. The numerical simulation has been conducted using Advanced Design System (ADS). The measured result showed that proposed antenna CSBA [Model 2] has wider-bandwidth of 58,2% and smaller-size of 18.2% compared to CCSA [Model 1] antenna. Then, after CSBA [Model 2] structure was applied to MIMO 2×2 [Model 3], the MIMO antenna obtain very good mutual coupling (<-15dB). Moreover, the measured results are good agreement with the simulated results. In conclusion, all of these advantages make it particularly valuable in multistandard antenna applications design such as GSM950, WCDMA1800, LTE2300, and WLAN2400.

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