Frequency Reconfigurable Aperture-Coupled Microstrip Array Antenna Using Periodic Defected Ground Structures

M.A. Aris, M.T. Ali and N.H. Abd Rahman

Abstract In this paper, a design of 2 × 2 frequency reconfigurable microstrip array antenna using Defected Ground Structures (DGS) with aperture-coupled feed line for outdoor mobile applications. Two periodical dumbbell geometries with different dimensions etched on the ground plane. Each dimension of DGS structures etched on the ground plane resonant at two different frequency bands, (7.28–7.73 GHz) and (8.55–9.12 GHz), respectively. The reconfigurability of the antenna is based on the transition modes of switch on the feed line. When the switch is in "OFF" mode, the antenna resonant is at 7.5 GHz and covers 7.28–7.73 GHz frequency band while the antenna resonant is at 8.85 GHz in "ON" mode and covers 8.55–9.13 GHz frequency band. Switching modes for the preliminary prototype are presented in open and short condition of the feed line. The reconfigurable array antenna simulated using Computer Simulation Technology (CST). Results between simulation and measurement provide good agreement of the designed antenna. This new approach offers simple design and small volume of reconfigurable microstrip array antenna for future outdoor mobile applications.

Keywords Defected Ground Structures (DGS) · Reconfigurable antenna · Array · Aperture-coupled

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1 Introduction

Based on its versatility, frequency reconfigurable microstrip antenna has received high attention in order to support wide areas of wireless communication systems. This high demand is supported by numerous reasons, such as able to support more than one wireless standard, minimize cost, simple integration, and good isolation between different wireless frequencies [1]. However, due to low gain, very narrow bandwidth of microstrip circuit design reconfigurable antenna in single element is not significant for outdoor wireless systems. Therefore, in order to generate high directivity better bandwidth, frequency reconfigurable antenna with array structure has been developed by many researchers and finely designed to support multifrequency bands wireless communication systems, for example, Wi-Fi, WLAN, WiMAX, and lately for LTE [2, 3]. Unfortunately, frequency reconfigurable antenna array has limited only for indoor wireless network applications, due to its very complex switching and biasing network [4]. In addition, limited array elements and very complex designs such as back-to-back structure and stacked design [5, 6] also contribute main restriction to design antenna array for long distance wireless communication.

Therefore, this paper proposes a 2 × 2 microstrip frequency reconfigurable antenna array using periodic Defected Ground Structure (DGS) with aperture-coupled feed line method for outdoor mobile applications. The antenna was designed and fabricated on the substrate Rogers RO3006 with permittivity of 6.15 and thickness of 0.64 mm. The aperture-coupled feed line is selected due to its good background, such as it offers independent optimization of the feed line and the radiating element, low interference between feed line and patch element, and better bandwidth [6]. Defected Ground Structure (DGS) method has potential to offer innovative approach in designing frequency reconfigurable microstrip array antenna based on two main characteristics of DGS, slow wave propagation in Pass band and Band Stop [7], where these criteria are able to reject unwanted frequency band and minimize coupling effect for antenna array [8].

In this research, two identical dumbbell Defected Ground Structure shapes have been chosen and optimized to resonate at 7.5 and 8.85 GHz. The antenna was simulated using Computer Simulation Technology (CST). In this design, the switching concept for reconfigurability refers to open and short condition of antenna feed line. Finally, prototype reconfigurable antenna was fabricated and measured to validate its performance.

2 Antenna Design

2.1 Single Element Microstrip Antenna

At the beginning of the experimental analysis, systematical steps have been conducted to achieve the main objective. First step is to design a single element antenna

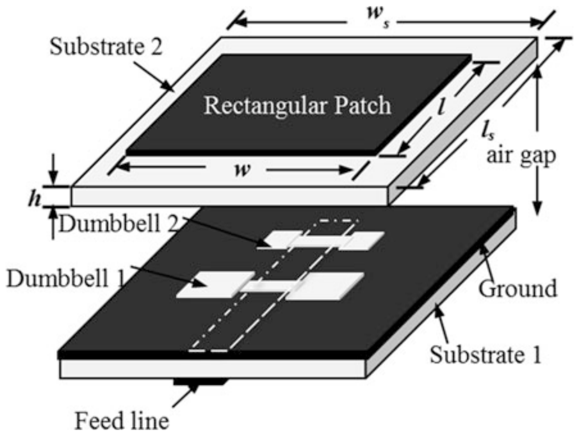

Fig. 1 Diagram of single element for frequency reconfigurable microstrip patch antenna with aperture-coupled feed line and periodic dumbbell DGS structure

then followed by 2 × 2 array antenna. The initial dimension of the single element rectangular patch antenna length (l) and width (w) is calculated using Eqs. (1)–(4) by considering resonant frequency of 8.2125 GHz. Then, two periodic dumbbell shapes with different sizes etched on the ground layer, exactly located under the single rectangular radiator to control the desired frequencies. The complete design for the single element is shown in Fig. 1; where the rectangular radiating element is placed on top of substrate 2, the ground layer is placed on top of substrate 1. The size of the periodic dumbbell DGS structures was obtained from optimization process so that the antenna will resonate at the two desired frequencies. As shown in Fig. 1, dumbbell 1 (in the middle of the ground layer) resonates at 7.5 GHz, while dumbbell 2 (at the top of dumbbell 1) resonates at 8.85 GHz. The complete dumbbell DGS structures on the ground layer are depicted in Fig. 2a, and feed line with switch concept location is illustrated in Fig. 2b. Meanwhile, the length of the “S_w” is equal to the dimension of proposed PIN diode which will be used as the switch. All dimensions for the designed single element are listed in Table 1.

$$w = \frac{1}{2f_r\sqrt{\mu_o\varepsilon_o}}\sqrt{\frac{2}{\varepsilon_r+1}} \tag{1}$$

$$l = \frac{1}{2f_r\sqrt{\varepsilon_{\text{reff}}}\sqrt{\mu_o\varepsilon_o}} - 2\Delta L \tag{2}$$

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

$$\varepsilon_{\text{reff}} = \frac{\varepsilon_r+1}{2} + \frac{\varepsilon_r-1}{2}\left[1+12\frac{h}{W}\right]^{-1/2} \tag{4}$$

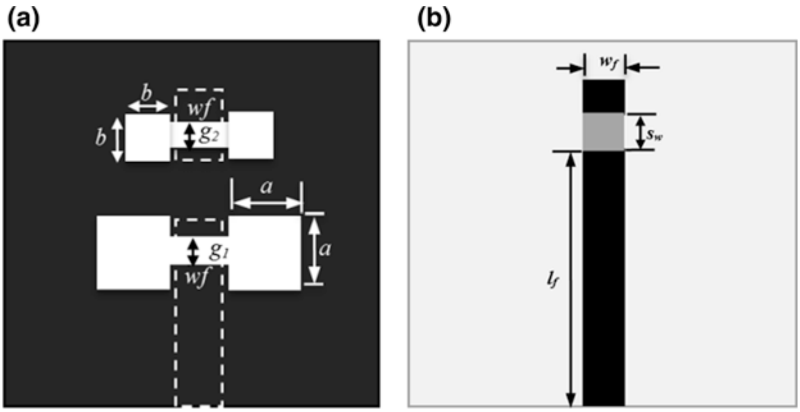

Fig. 2 **a** Periodic dumbbell DGS structures etched on the ground layer and **b** Feed line and position of switch for frequency reconfigurability

Table 1 Dimension of designed antenna

Antenna parameters	Value (mm)
l	9.28
w	10
l_s	15
w_s	15
h	0.64
wf	0.995
a	2.36
b	0.84
g1	0.4
g2	0.25
Air gap	1
s_w	0.9
lf	8.32

2.2 2 × 2 Microstrip Array Antennas

The next step is to design the 2 × 2 microstrip array antenna with the distance of λ/2 between the patch elements and is shown in Fig. 3. A corporate feed network connected to a 50 Ω feed line is used as power divider between antenna elements. The 50 Ω transmission line consists of 70.7 Ω quarter wave transformers with 100 Ω power divider. Meanwhile, four pairs of DGS structures on the ground plane etched with constant dimension as obtained from single element. Dimension of the feed network for 2 × 2 antenna array is depicted in Fig. 4a, b for different resonant frequencies.

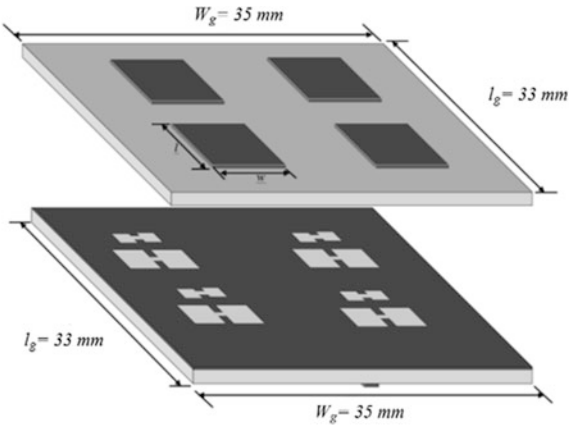

Fig. 3 Top layer with 2 × 2 rectangular patch antenna and four pairs of DGS structure on the ground plane

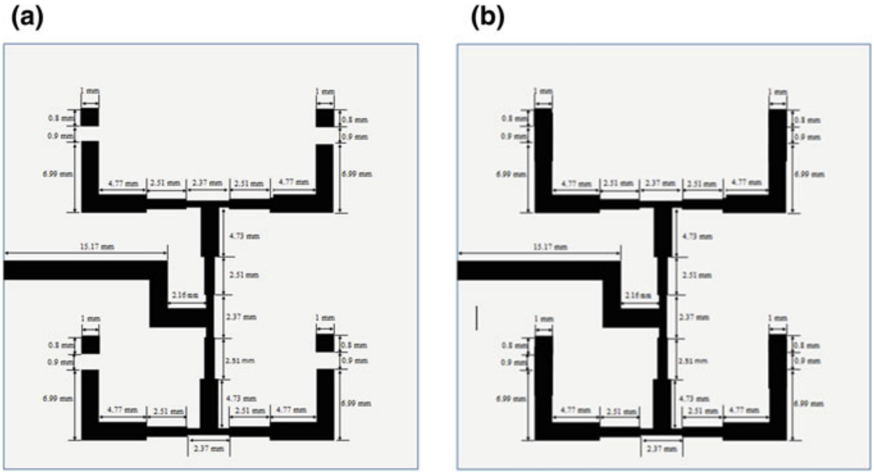

Fig. 4 **a** Feed line with open condition for “OFF” mode and **b** feed line with “ON” mode

3 Simulation and Measurement Results

3.1 Simulation Result Using Computer Simulation Technology (CST) for Single Element

The proposed antenna is simulated using Computer Simulation Technology (CST). Simulation and optimization started with single element antenna. As shown in Fig. 5a, b, two resonant frequencies were obtained from the designed antenna based

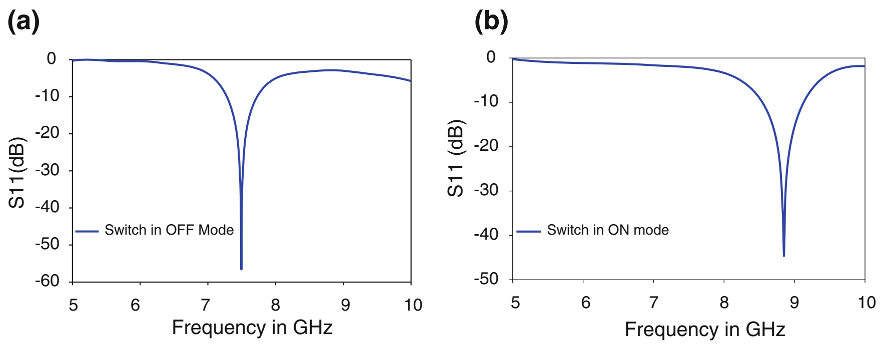

Fig. 5 **a** Simulated result of S11 in "OFF" mode and **b** simulated result of S11 in "ON" mode

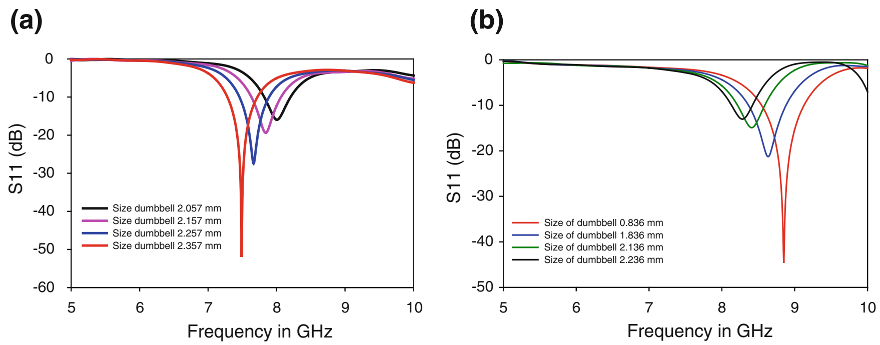

Fig. 6 **a** Parametric analysis in "OFF" and **b** parametric analysis in "ON" mode

on the switch mode and selected DGS's dimension etched on the ground plane. During OFF mode, the antenna operates at 7.5 GHz with S11–56.58 dB, while in ON mode the antenna operates at 8.85 GHz with S11–44.64 dB. The simulated results for S11 indicate a good match obtained from the proposed antenna. Interestingly, the designed antenna could cover very wideband frequency band at two desired frequencies 450 MHz (7.28–7.73 GHz) and 580 MHz (8.55–9.13 GHz), respectively.

The functionality of DGS structure in producing two desired frequencies is validated through parametric analysis. The analysis is carried out on the gap junction for each DGS shape specified at 0.4 mm with the length of gap follows the width of feed line. The parametric analysis was focused mainly on the effect of varying the square arm of dumbbell structure. Figure 6a shows that decreasing the size of the square arm of the bottom dumbbell will significantly increase the frequency, while Fig. 6b indicates vice versa.

3.2 Simulation Result Using Computer Simulation Technology (CST) for 2 × 2 Array Antenna

Similarly 2 × 2 array is simulated using Computer Simulation Technology (CST) and is fabricated with different modes “OFF” and “ON.” To confirm the antenna is workable in desired band, simulated and fabricated results are compared and are shown in Fig. 7a in “OFF” mode, while Fig. 7b illustrates the comparison in “ON” mode. During “OFF” mode, the resonant frequency occurs at 7.39 GHz

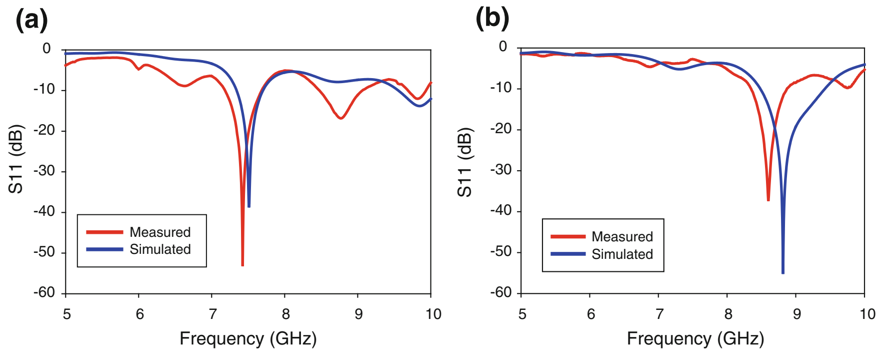

Fig. 7 **a** Simulated and fabricated results in “OFF” mode and **b** fabricate results in “ON” mode

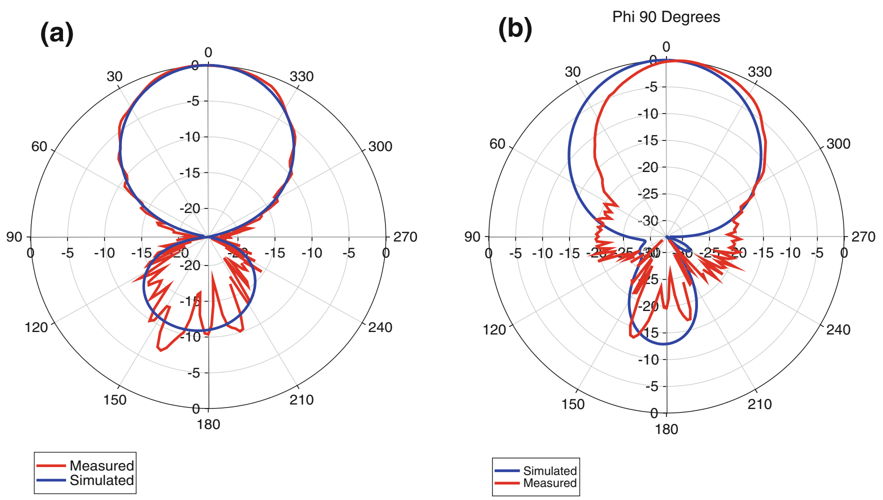

Fig. 8 **a** Simulated and measured radiation pattern in “OFF” mode and **b** simulated and measured radiation pattern in “ON” mode

with S11–53.20 dB; this result shifts 150 MHz from simulated result. In "ON" mode the fabricated antenna resonate at 8.75 GHz with S11–37.41 dB where shift 100 MHz from simulated result. However, the fabricated antenna still works in expected bandwidth to support meteorology and radiolocation applications. Figure 8a, b shows the comparison results between simulated and measured in normalized form for radiation pattern in "OFF" and "ON" modes, respectively.

The performance of the 2 × 2 antenna array antenna is summarized in Table 2. Figure 9 illustrates the fabricated 2 × 2 antenna array. Referring to Table 2, the efficiency and gain directivity of fabricated antenna slightly decrease compared to simulated results.

Table 2 Performance of proposed antenna array

	Switch modes			
	Simulated		Measured	
	OFF	ON	OFF	ON
Center frequency (GHz)	7.5	8.85	7.39	8.75
Efficiency (%)	91.88	91.92	79.62	94.62
Directivity (dBi)	9.62	11.1	7.92	10.49
Bandwidth (MHz)	446.5	573.15	439.479	492.847
S11 (dB)	−38.77	−55.23	−53.20	−37.41

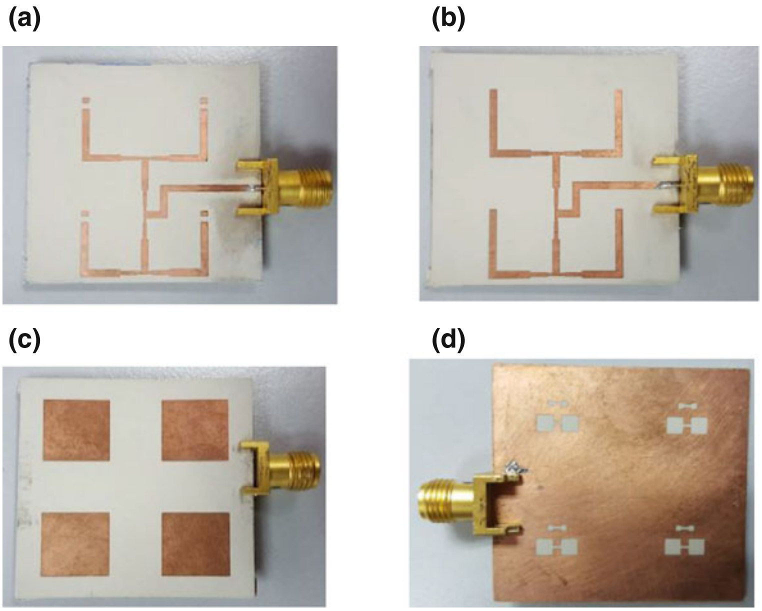

Fig. 9 **a** Feed line network in "OFF" mode for fabricated antenna, **b** feed line network in "ON" mode for fabricated antenna, **c** rectangular patch fabricated antenna, and **d** ground plane with DGS structures

From simulation and fabrication process, large back lobe from the proposed antenna requires additional technique to reduce it, and we noticed that this lobe size is contributed by DGS structure. Meanwhile, the shifted frequency obtained from fabricated antenna and deterioration of efficiency and directivity possibly comes from fabrication errors.

4 Conclusions

From the research, microstrip antenna using DGS structure provides simple structure for microstrip antenna, mainly in designing reconfigurable antenna array, and by varying the size of the DGS shape the desired resonant frequencies are better generated. In addition, the switching concept proposed at the feed line is offering lesser number of reconfiguration switching systems. However, the numbers of switches are significant with the increment of radiator elements.

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References

1. Christodoulou CG, Tawk Y, Lane SA, Erwin SR (2012) Reconfigurable antennas for wireless and space applications. Proc IEEE 100(7):2250–2261
2. Qin PY, Jay Guo Y, Ding C (2013) A dual-band polarization reconfigurable antenna for WLAN systems. IEEE Trans Antennas Propag
3. Li Z, Ahmed E, Eltawil AM, Member S, Cetiner BA (2015) A beam-steering reconfigurable antenna for WLAN applications. IEEE Trans Antennas Propag 63(1):24–32
4. Costantine J, Tawk Y, Christodoulou CG, Lyke JC, Member S, De Flaviis F, Besoli AG, Barbin SE (2012) Analyzing the complexity and reliability of switch-frequency-reconfigurable antennas using graph models. IEEE Trans Antennas Propag 60(2):811–820
5. Ramli N, Ali MT, Yusof AL, Ya'Acob N (2013) Frequency reconfigurable stacked patch microstrip antenna (FRSPMA) for LTE and WiMAX applications. In: 2013 international conference computing, management and telecommunications ComManTel 2013, pp 55–59
6. Ali MT, Salleh MKM, Rusli MHM (2014) Reconfigurable gap-coupled back-to-back truncated rhombus-like slotted patch antenna with steerable beams, pp 338–342
7. Arya AK, Kartikeyan MV, Patnaik A (2010) Defected ground structure in the perspective of microstrip antennas: a review. Frequenz
8. Woo DJ, Lee JW, Lee TK (2008) Multi-band rejection DGS with improved slow-wave effect. In: Proceedings of 38th European Microwave Conference EuMC 2008, vol 1, Oct, pp 1342–1345