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SIZE MINIATURIZATION AND BANDWIDTH ENHANCEMENT IN MICROSTRIP ANTENNA ON A COUPLE CIRCULAR RINGS DGS

Nabilah Ripin, Nurul Fadzlin Ghazali, Ahmad Asari Sulaiman, Nur Emileen Abd Rashid, Mohamad Fahmi Hussin
Faculty of Electrical Engineering, Universiti Teknologi MARA, Malaysia

Abstract-* Design and fabrication of small microstrip patch antennas for radar application are presented. The new proposed antenna is composed of a rectangular radiating patch on a couple of circular rings defected ground structure (DGS). The circular rings defection on the ground plane offer metamaterial characteristics which were identified using Nicolson-Ross-Weir (NRW) method. An analysis on the radius of the circular rings DGS of the new antenna is provided to achieve 4.75 GHz operating frequency specific for radar application. The rectangular patch antenna without DGS was designed as a reference antenna. The new proposed antenna size is 42% smaller (17.50 x 20.00 x 0.75 mm3) compared to the reference antenna with an acceptable antenna gain. The simulation and measurement results agree well with each other. Both results show that the proposed antenna provides a better impedance matching with a greater improvement in terms of bandwidth with 208 % increment.

Keywords - Miniaturization; bandwidth enhancement; patch antenna; defected ground structure; metamaterial; Nicolson-Ross-Weir method

I. INTRODUCTION

Modern wireless communication systems require the small, lightweight and compact integral elements. In order to fulfill these requirements, the antenna size is needed to be miniaturized for integrating into the new system. Numerous methods have been employed for miniaturization of antenna size. Slot techniques have been proposed to introduce the capacitive or/and inductive loading for size reduction [1]–[4]. However, the proposed method has decreased the impedance bandwidth of the antenna. The effective length of the patch is increased by the left-handed transmission line loading which lower the operating frequency that leads to the reduction in the radiating patch area [5]. Unfortunately, the size of the ground plane did not reduced which make the overall antenna size remain the same.

Metamaterials are also known as Left-Handed Metamaterial (LHM) where the permeability and permittivity were simultaneously negative [6], [7]. The DGS is said to be one of the metamaterial type when it produces negative permeability and permittivity. The DGS is a defection on the ground plane where it disturbs the shield current distribution of the antenna. The disturbance would increase the effective capacitance and inductance which resulting in the slow-wave effect due to equivalent LC components which may reduce the circuit size [8].

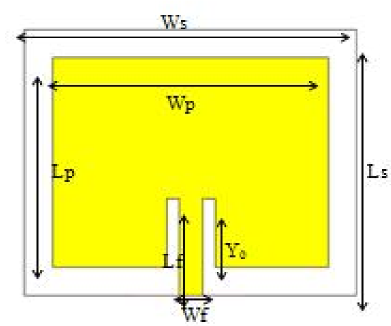
In this letter, we propose a small, lightweight and easy to fabricate microstrip patch antenna on a couple of circular rings DGS in an attempt to miniaturize the antenna size and enhance the impedance bandwidth. In Section II, both antennas were explained in detail including the new structure. The comparison in term of size and configuration of the reference and the new proposed antenna is demonstrated in figure. In Section III, the simulation and measurement results of both antennas were displayed. Section IV delivers a conclusion or summary of the results were presented.

II. ANTENNA DESIGN

The configuration of the reference and the proposed antennas are presented in Section A and Section B, respectively. The rectangular microstrip patch antenna is designed on Rogers 3003 substrate with εr = 3.0 and thickness, h = 0.75mm. Both antennas are designed using CST Microwave Studio software with center frequency of 4.75 GHz.

A. *Reference Antenna*

The layout for the top and bottom views of the reference antenna is shown in Fig. 1 (a) and (b), respectively. The antenna consists of a rectangular radiating patch that is fed by 50Ω microstrip line with a solid ground plane. The width and the length of the overall size of the substrate are Ws = 26.83 mm and Ls = 22.49 mm, respectively. The parameters of the radiating patch are ; Wp = 22.33 mm, Lp = 17.69 mm, Lf = 8.21 mm, Wf = 1.90 mm, Y0 = 5.81 mm.



(a)

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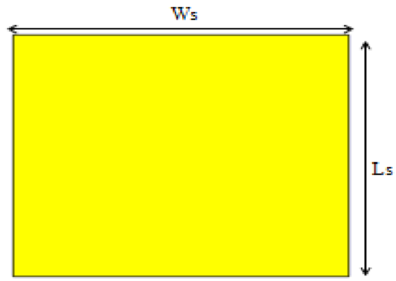


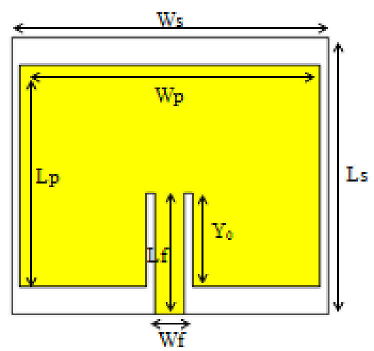
(b)

Fig. 1 Reference antenna; (a) top view (b) bottom view

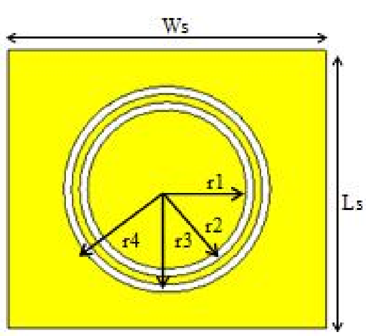
B. *Proposed Antenna*

The geometry of the new proposed metamaterial antenna is demonstrated in Fig. 2. The antenna comprises of a rectangular radiating patch (as shown in Fig. 2 (a)) and a couple of circular rings defected ground plane (as shown in Fig. 2 (b)). Fig. 2 (a) shows the top view of the proposed antenna with Ws = 20 mm, Ls = 17.5 mm, Wp = 19 mm, Lp = 13.94 mm, Lf = 7.68 mm, Wf = 1.9 mm and Y0 = 5.9 mm. The ground plane of the antenna has been defected with couple circular rings shape with r1 = 5.0 mm, r2 = 5.5 mm, r3 = 6.0 mm, and r4 = 6.5 mm.

The circular ring DGS offers metamaterial characteristics with εr = -99.33 and μr = -0.03 which have been verified by Nicolson-Ross-Weir (NRW) method which replicated from [9], [10]. The NRW method is widely used to convert the S-parameters and provides an easiest way to plot the permittivity and permeability values versus frequency.



(a)



(b)

Fig. 2 Proposed antenna; (a) top view (b) bottom view

III. SIMULATION AND MEASUREMENT RESULTS

The simulated reflection coefficient for the reference antenna was compared to the new proposed antenna in a single graph as displayed in Fig. 3. It is observed that the proposed method has enhanced the impedance bandwidth three times wider (enhanced up to 208%) compared to the reference antenna where the fractional bandwidth of the proposed and the reference antenna are 4.74% and 1.54%, respectively. The proposed antenna also produces 25dB better reflection coefficient resulting in a better impedance matching.

Fig. 4 illustrates the measured of reflection coefficient for both antennas which have been measured using the Vector Network Analyzer (VNA). Similar to the simulated result, the measured also shows that the proposed antenna offers a wider impedance bandwidth with 17dB better reflection coefficient. The resonant frequency of the reference antenna shifted from 4.75 GHz to 4.8 GHz while the resonant frequency of the proposed antenna shifted from 4.75 GHz to 4.785 GHz. The center frequency for both antennas are shifted slightly to the higher frequency may due to the corrosion of copper cladding during the fabrication process.

There is a comparison between the simulated and measured of reflection coefficients from the proposed antenna demonstrated in a single graph displayed in Fig. 5. As mentioned earlier, the resonant frequency of the measured result is slightly shifted compared to the simulated result where the simulated frequency is 4.75 GHz while the measured frequency is 4.785 GHz. However, both results produce better impedance bandwidth.

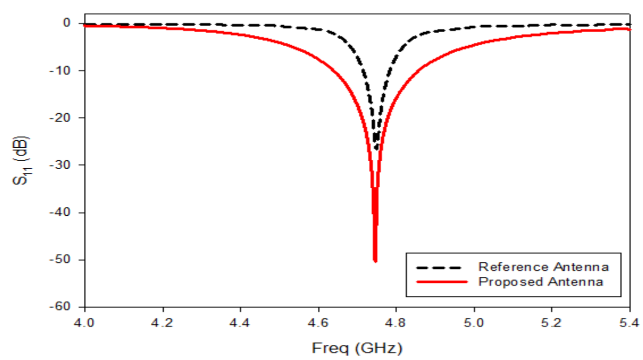


Fig. 3 Simulated reflection coefficient of the reference and the proposed antenna

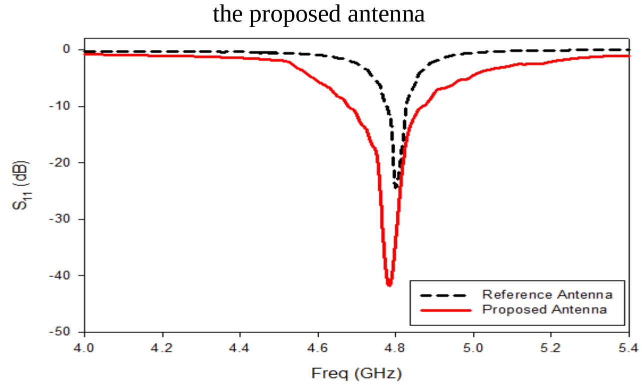


Fig. 4 Measured reflection coefficient of the reference and the proposed antenna

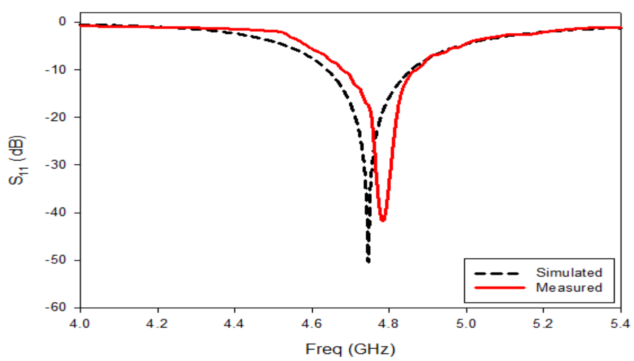
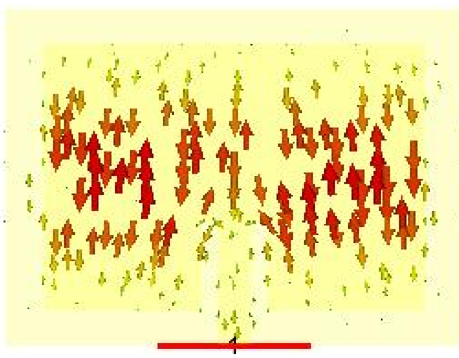
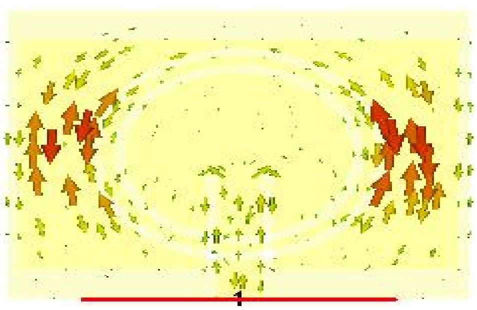


Fig. 5 Simulated and measured reflection coefficient of the proposed antenna

Fig. 6 illustrates the surface current distribution of both reference and the new proposed antenna. Fig. 6 (a) shows the current is predominantly concentrated in the middle of the radiating patch while Fig. 6 (b) shows the current of the new proposed antenna is distributed on the radiating patch mostly concentrated around the couple circular rings DGS.



(a)



(b)

Fig. 6 Surface current distribution; (a) reference antenna (b) proposed antenna

The radiation pattern of both antennas is plotted in Fig. 7. It is observed that the radiation patterns of both antennas are similar in term of the main lobe directivity. Even though the back lobe is arising in the proposed antenna plot due to the enhancement in the impedance bandwidth, the antenna gain of 2.32 dB is acceptable for radar application as referred to [11] and [12].

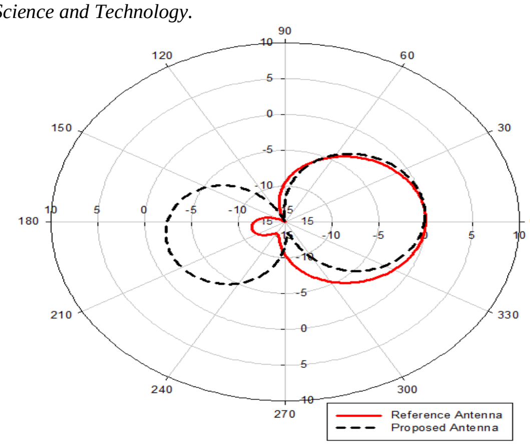


Fig. 7 Plot of radiation pattern for both antennas

The fabricated of the reference and proposed antennas are shown in Fig. 8 (a) and (b), respectively. Both antennas are fabricated on the same material Rogers RO3003 substrate with dielectric constant, εr = 3.0 and thicknesses, h = 0.75 mm. It obviously shows that the proposed antenna in Fig. 8 (b) is much smaller compared to the reference antenna in Fig. 8 (a).

(a)

(b)

Fig. 8 Fabricated antennas; (a) reference (b) proposed structure

The size comparison for both antennas is tabulated in table I. It is shown that the proposed antenna is 42 % smaller compared to the reference antenna which operates in the same operating frequency.

TABLE 1 SIZE COMPARISON BETWEEN THE REFERENCE AND PROPOSED ANTENNA

Type	**Size (mm)**	**Miniaturization Percentage**
Reference antenna	22.49 x 26.83	42%
Proposed antenna	17.50 x 20.00	

A detail parametric study of reflection coefficient, S_{11} for various values of the DGS radii are presented in Fig. 9. The relationship between the radii and the circular rings DGS is according to the formula below:

$$r1 = 6.5 \quad (1)$$

$$r2 = r1 + a \quad (2)$$

$$r3 = r2 + a \quad (3)$$

$$r4 = r3 + a \quad (4)$$

The best performance of the antenna can be obtained at a = 0.5 mm as displayed in Fig. 9 where the center frequency is at 4.75 GHz with better reflection coefficient (S_{11} = -50.34 dB) compared to other values of a.

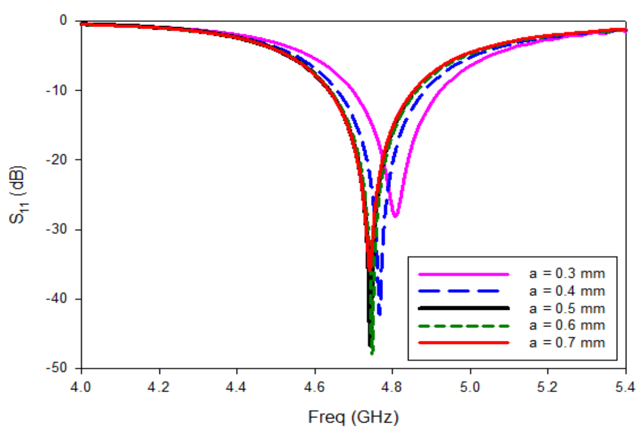


Fig. 9 Simulated reflection coefficient from few different values of DGS radii

IV. CONCLUSIONS

The new proposed antenna has a small size of patch due to a unique approach of applying a couple rings defected ground structure (DGS). The antenna has features of metamaterial characteristic from the couple circular rings DGS on the ground plane. The metamaterial characteristics (with negative values of permittivity and permeability) were verified using Nicolson-Ross-Weir method. The couple circular rings DGS makes the proposed antenna to be able to reduce the antenna size up to 42 % and enhancing the impedance bandwidth up to 208 % compared to the reference antenna.

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