

## High Directivity of Microstrip Patch Antenna using Metamaterial

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**Abstract:** In this paper, a different Double Negative (DNG) metamaterial is demonstrated to upgrade the performance of Microstrip Patch Antenna (MPA). The scattering parameters are utilized to plan and corroborate the DNG structure. The proposed DNG is then employed as a superstrate of MPA which reduces the surface waves and edge diffracted waves of an antenna and therefore reduces its losses. To analyze the performance a conventional MPA without DNG is also simulated. The outcomes indicate that DNG based MPA has enhanced performance as far as directivity, gain and radiation efficiency of antenna. The directivity is improved from 6.878dBi to 7.184dBi. The effectiveness of an antenna is increased from 72% to 80.42%. Gain of antenna is also enhanced from 5.454dB to 6.237dB. The proposed circular SRR based DNG MPA could be a great competitor for application in wireless communication.

**Keywords:** Double negative metamaterial, rectangular microstrip patch antenna, negative permittivity and permeability, high directivity

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### I. Introduction

A conventional MPA has various provisions in microwave applications however because of its low gain, directivity and efficiency it has restricted applications. A metamaterial is proposed to enhance these essential parameters of MPA. Metamaterials are engineered structures that show certain electromagnetic characteristics which are not discovered in nature. These structures are categorized by negative values for both permittivity and permeability [1]. These materials are likewise considered Double negative materials (DNM) or left handed materials (LHM) [2]-[5]. The idea of metamaterials presence is initially anticipated by Russian Physicist Victor Veselago in 1968 [6] however the exploratory confirmation did not happen until several decades. Diverse methods and structures of DNG metamaterial are proposed to improve the characteristics of MPA [7]-[14]. These DNG material structures are basically used as a superstrate for ordinary MPA [15]-[18]. In this work another sort of DNG metamaterial is proposed, which is comprising of circular split ring resonators (SRR) on one side of the dielectric medium and three circular shape wires on the other side of a medium as a superstrate.

An MPA has various benefits because of its minimal effort, lightweight, simple to create and reconcile with different electronic circuitry [19], [20]. So as to enhance these parameters this paper proposes another DNG metamaterial which is used as a superstrate at a height of 3.36mm starting from ground plane. The outcomes demonstrated that the directivity, gain, return loss have been effectively enhanced. The directivity is improved from 6.878dB to 7.184dB. Gain and radiation proficiency of an antenna is improved by 0.783dB and 8.42% respectively while return loss is reduced to -28.17dB from -16.55dB. All parameters an antenna has been considerably improved due to DNG metamaterial as superstrate of customary MPA.

Simulations are completed utilizing 3D EM Simulator Computer Simulation Technology Microwave Studio (CST-MWS) [21]. MATLAB is used for the verification of Double Negative properties of the proposed DNG structure.

### II. Methodology

In the first stage a conventional rectangular microstrip patch antenna (RMPA) is designed as shown in Fig.1.

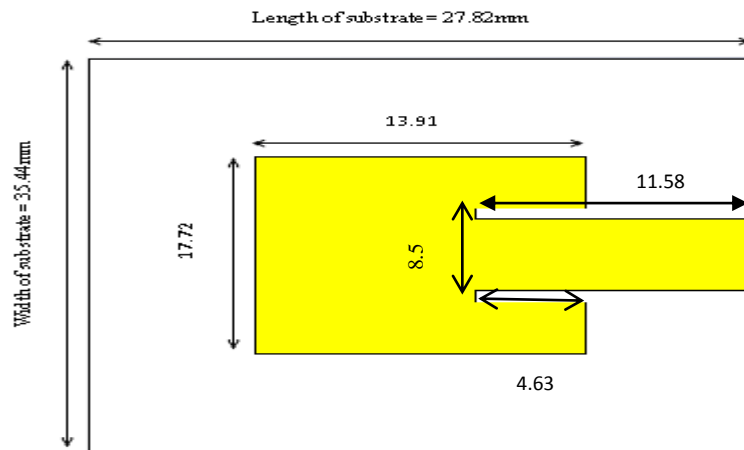


Fig.1: Conventional RMPA (All dimensions are in mm)

Parameters of RMPA are calculated from the given equation in [22].

Calculation of width

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

Where,

C = Speed of light

$\epsilon_r$  = Dielectric constant of substrate

Effective dielectric constant is calculated from,

$$\epsilon_{eff} = \frac{\epsilon_r + 1}{2} + \frac{\epsilon_r - 1}{2} \left( \frac{1}{\sqrt{1 + \frac{12h}{W}}} \right) \quad (2),$$

The actual length of patch (L),

$$L = L_{eff} - 2\Delta L \quad (3),$$

Where,

$$L_{eff} = \frac{C}{2f_r \sqrt{\epsilon_{eff}}} \quad (4),$$

Calculation of length extension,

$$\frac{\Delta L}{h} = 0.412 \frac{(\epsilon_{eff} + 0.3) \left( \frac{W}{h} + 0.264 \right)}{(\epsilon_{eff} - 0.258) \left( \frac{W}{h} + 0.8 \right)} \quad (5),$$

The calculated parameters of RMPA are given in Table I.

Table I: Parameters of RMPA

Parameters	Dimensions	Units
Dielectric constant ( $\epsilon_r$ ) (FR4)	4.3	-
Thickness (H)	1.0	mm
Operating frequency ( $f_r$ )	5.2	GHz
Length of Patch (L)	13.91	mm
Width of patch (W)	17.72	mm
Cut width	8.5	mm

Cut depth	4.63	mm
Length of microstrip	11.58	mm
Width of microstrip	6.5	mm
Length of substrate & ground	27.82	mm
Width of substrate & ground	35.44	mm

The antenna is modeled and simulated in CST MWS. The S11 graph shows that antenna resonate at 5.2GHz as shown in Fig.2.

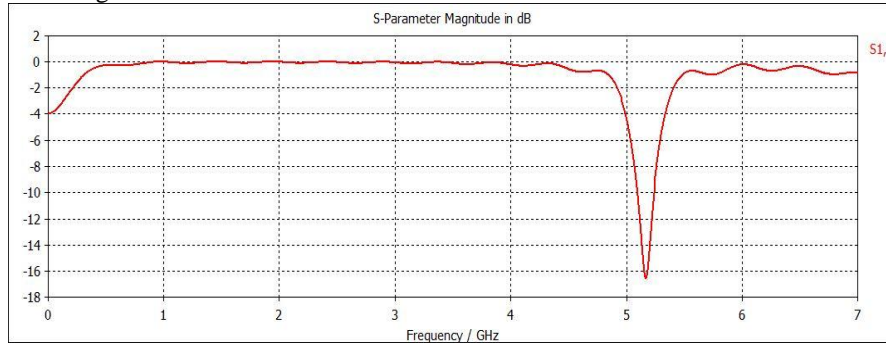


Fig.2: Impedance matching of RMPA

To extract scattering parameters S11 and S21, the proposed design DNG structure is placed between two waveguide ports in CST MWS as shown in Fig.3.

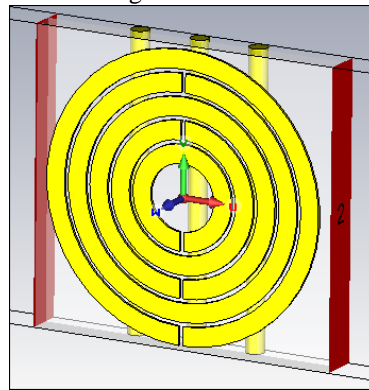


Fig.3: DNG structure between two waveguide ports

The S11 and S21 parameters are then operated to Matlab for the verification of negative permittivity and permeability of DNG structure by direct retrieval technique [23]. The permittivity and permeability parameters are negative in the given frequency band as indicated in Fig.4 and Fig.5 respectively. The equations used in direct retrieval method to find permittivity and permeability is given as:

$$\epsilon = n/z \tag{6},$$

$$\mu = nz \tag{7},$$

$$n = \frac{1}{kd} \cos^{-1} \left[ \frac{1}{2S_{21}} (1 - S_{11}^2 + S_{21}^2) \right] \tag{8},$$

$$z = \sqrt{\frac{(1 + S_{11})^2 - S_{21}^2}{(1 - S_{11})^2 - S_{21}^2}} \tag{9},$$

The dimension of DNG structure is given in Table II.

Table II: Dimensions of DNG structure

Parameters of DNG	Values	Unit
Length of each wire	14.2	mm
Radius of each wire	0.45	mm
Inner and outer radius of ring 1	2.5 & 1.6	mm
Inner and outer radius of ring 2	3.6 & 2.7	mm
Inner and outer radius of ring 3	4.7 & 3.8	mm
Inner and outer radius of ring 4	5.8 & 4.9	mm
Inner and outer radius of ring 5	6.9 & 6.0	mm
Dielectric of substrate	4.3	-
Thickness of substrate (FR4)	1	mm
Gap of each rings	0.12	mm

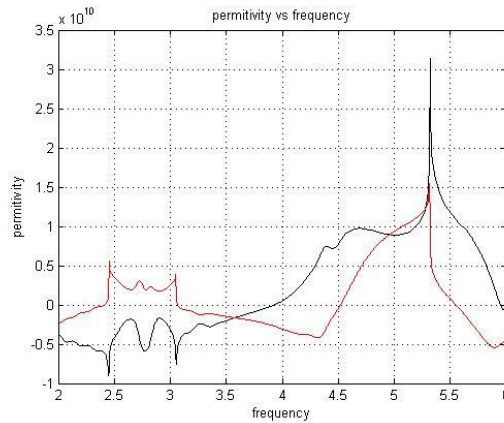


Fig.6: Proposed DNG permittivity vs frequency

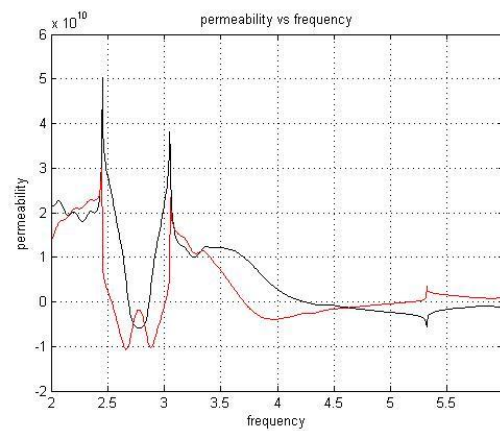


Fig.7: Proposed DNG permeability vs frequency

DNG metamaterial structure is placed as superstrate on RMPA shown in Fig.8 at height of 3.36mm from the ground plane in the final stage of work and compared the results of DNG based antenna with conventional antenna.

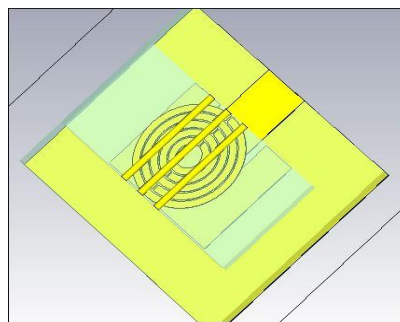


Fig.8: Microstrip patch antenna with DNG superstrate

### III. Results and Discussion

Several parameters like gain, directivity, radiation efficiency and return losses of antenna with transmission line are simulated and compared between conventional MPA and DNG based MPA is discussed below.

#### 3.1 Impedance matching

S11-Parameter of DNG based antenna is shown in Fig.9. It is observed that resonant frequency remain unchanged while impedance matching improved for DNG based MPA.

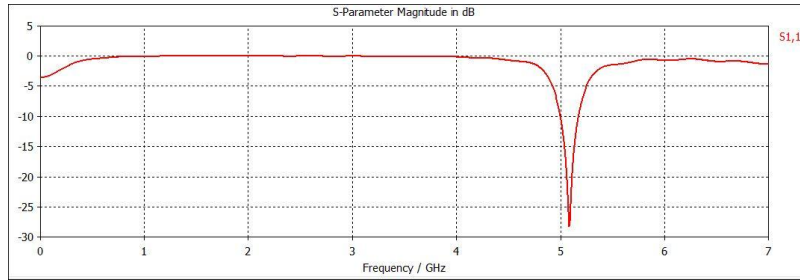


Fig.9: Impedance matching of DNG based RMPA

3.2 Farfield Pattern

Directivity and radiation efficiency of DNG based antenna have been examined and compared for conventional MPA and DNG based MPA. From given Fig.10 and Fig.11 it is evident that directivity of MPA is enhanced from 6.878dbi to 7.184dbi. The improved radiation efficiency due to DNG based MPA is increased by 8.42%.

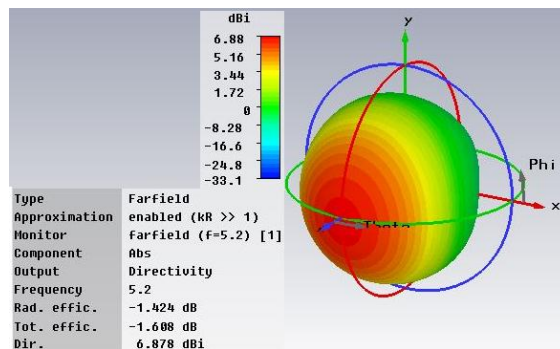


Fig.10: Directivity of RMPA

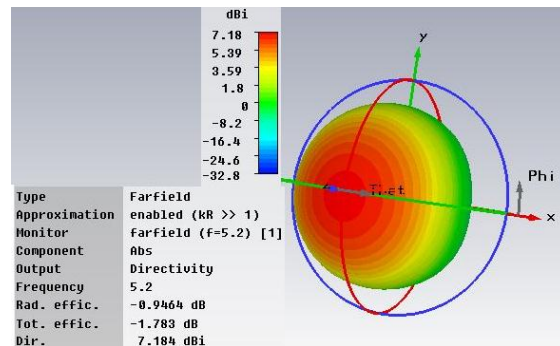


Fig.11: Directivity of DNG based MPA

The gain of DNG based MPA is also improved form 5.454dB to 6.237dB as shown in Fig.12 and Fig.13 respectively.

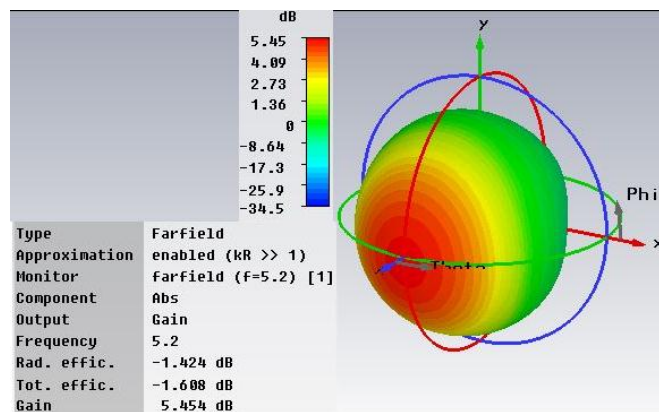


Fig12: Gain of RMPA

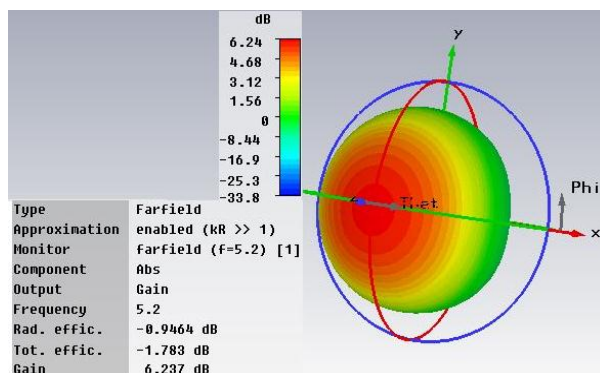


Fig.13: Gain of DNG based MPA

### 3.3 Radiation Efficiency of Antenna

Radiation efficiency of conventional MPA is -1.424dB (72%) but when DNG superstrate is taken into account its radiation efficiency is increased to -0.9464dB which is 80.42%.

## IV. Conclusion

The DNG based MPA usefulness has been completed. The DNG material reduces losses of an antenna which improved its directivity, gain and radiation efficiency. The directivity and gain of DNG based MPA is improved from 5.454dB to 6.237dB and from 6.878dB to 7.18dB respectively. The return loss of an antenna is reduced by 11.62dB. Consequently its radiation efficiency is increased from 72% to 80.42%. The DNG based MPA can be used in advance wireless communication. The overall improvement in performance between conventional MPA and DNG based MPA are summarized in Table III.

Table III: Comparison between Conventional MPA and DNG based MPA

S.No	Parameters	Conventional RMPA	RMPA with superstrate
1	Frequency	5.2GHz	5.2GHz
2	Directivity	6.878dB	7.18dB
3	Radiation efficiency	-1.424dB (62.28%)	-0.9464dB (86.73%)
4	Gain	5.454dB	6.237dB
5	Scattering Parameters (S11)	-16.55 dB	-28.17 dB

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