Miniaturized Wide Bandwidth MIMO Dielectric Resonator Antenna using Defective Ground Structure for UWB Applications

A Keerthanai Priya[1], B. Bhuvaneswari[2]

[1]PG Student, Department of Electronics and Communication Engineering, Panimalar Engineering, College, Chennai, India
[2]Professor, Department of Electronics and Communication Engineering, Panimalar Engineering, College, Chennai, India

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Abstract - *The current scenario of wireless communication needs compact and wide bandwidth radiators for effective communication. Microstrip Patch Antennas are used widely, as they are low-profile. The efficiency of microstrip antennas is poor because of conductor loss and spurious radiation. To overcome these problems, MIMO Dielectric Resonator Antenna (DRA) with Defective Ground Structure (DGS) is proposed in this paper work. The two element MIMO DRA is made up of Rogers RO4350 with dielectric constant and thickness as 3.5 and 0.76mm respectively and designed at 6.9 GHz. Bandwidth can be enhanced by placing DGS. A stub is placed between two DRA to provide the isolation between the two antennas. The Ultra Wide Band obtained here is 4.692 GHz (5.92-10.62) GHz at a resonant frequency of 6.9 GHz with reflection coefficient of -43 dB without interfering with WLAN frequencies. Three types of design trials were done. The design is carried out in the fact that dielectric material with low dielectric constant will provide more bandwidth. The overall dimension of the compact antenna is about (29×29×2.295) mm^3. The various parameters like reflection coefficient (S_{11} dB), VSWR, directivity, gain are analyzed.*

Key words: DGS (Defected Ground Structure), DRA, MIMO elements, WLAN, Reflection coefficient (S_{11}) dB

1. INTRODUCTION

In current scenario applications, we need compact planar antennas for wireless communications. To accomplish this, microstrip patch antennas of various shapes has been proposed. The major demerit of patch antennas are spurious radiation due to presence of conducting element acting as antenna and it provides only narrow bandwidth [1] and hence it is not suitable for high frequency millimetre wave applications.

To overcome the demerits mentioned above, Dielectric Resonator Antenna (DRA) is proposed. Long ago dielectric materials were used only as resonators, but now it is used as radiators too [2]. To make DRA to radiate the following constraints has to be considered such as type of dielectric material used, dielectric constant, temperature coefficient, Q factor, mode of excitation to make it to work at particular frequency [3].

A huge amount of research work has been carried out in DRA of various shapes. Rectangular DRA provides more flexibility towards design [4]. Rectangular Waveguide Model is used to design and analyze DRA in rectangular shape [5]. Cross polarization level is lower in rectangular DRA. MIMO (Multiple Input Multiple Output) provides more gain when compared to single antenna. In [6], compactness and entire Ultra Wide Band is achieved for the size (29×29×5) mm^3. WLAN band is suppressed using L shaped parasitic stripes. Defective Ground Structures (DGS) is placed in ground plane to improve the bandwidth [7 & 8]. In [9], Z shaped DGS is placed to enhance the bandwidth with frequency range (8 - 12) GHz. Compactness is achieved using meandered structure in the ground plane [10]. Good isolation is achieved by placing DGS in case of MIMO antennas which in turn reduces mutual coupling between the antennas [11]. In [12], a four element MIMO antenna was presented each element has individual ground plane to reduce mutual coupling between the antennas. In [13], by placing the antennas orthogonally and introducing a narrow slit in the ground plane improves the isolation between the antennas. Dielectric material with lower dielectric constant will provide more bandwidth [14].

2. DESIGN OF ANTENNA

Dielectric Resonator Antenna (DRA) is designed using Dielectric Waveguide Model. The design is simple for rectangular DRA and provides more degrees of freedom. The feeding technique used here is microstrip line method. The antenna consists of three layers they are ground, substrate and third layer act as DRA. The ground is normal Perfect Electric Conductor (PEC) with thickness 0.035mm, substrate can be RO4350 or FR4 (design were carried out using both substrates individually) with thickness 0.76mm and 1.57mm respectively.

The antenna is analyzed with DRA made of RO4350 and DRA made of FR4 for three possible designs. For all the three designs, the ground is made defective to enhance the bandwidth. For the first design, the DRA is made up of FR4 material with dielectric constant 4.4 and thickness 1.57mm and substrate is RO4350. The overall dimension of the antenna is (40×29×2.29) mm^3. A stub is placed between the two DRAs which produces isolation and reduces mutual coupling between the two antennas. The ground is defected and hence the bandwidth of about 1.6 GHz is obtained which is centered at 6.9 GHz. For the second design, the same dimension is followed as that of first design, added to that, a rectangular slot is introduced in the ground plane. Due to introduction of slot, bandwidth is increased from 1.6 GHz to 2.6 GHz.

For the third design, the DRAs are made up of RO4350 material and substrate is made up of FR4 material. This third design is the optimized design, which produces more bandwidth than the previous two designs. The stub is introduced in the ground plane, which reduces mutual coupling between the two antennas. The dimension of the rectangular slot is characterized to get maximum bandwidth from that of second design. The front view and back view of the optimized design is shown below. The optimized dimensions are listed in the table.

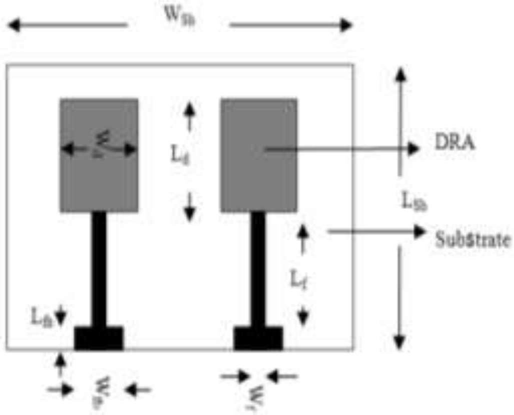

Fig -1: Front view of the optimized design

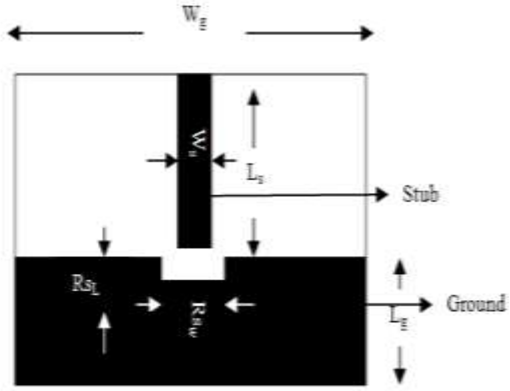

Fig -2: Back view of the optimized design

The Bandwidth obtained from the third design is 4.692 GHz, which is greater than the other two designs. Microstrip feed line is given to excite the antenna. The excitation mode is TE_{101} mode to make the antenna to radiate at 6.9 GHz. Quarter wave transformer is used to match the impedance of feed line to impedance of DRA. The Defective Ground Structure is optimized to get the maximum bandwidth. The reactance like inductance and capacitance of the structure is adjusted to get desired results.

The dimensions of the optimized design are shown in the table

Table -1: Dimension of the optimized antenna

Notation	Description	Dimension (mm)
W_{sb}	Width of the substrate	29
L_{sb}	Length of the substrate	29
W_d	Width of the DRA	9.4
L_d	Length of the DRA	13
W_f	Width of the feed line	1.38
L_f	Length of the feed line	11.5
W_{fb}	Width of the feed	4
L_{fb}	Length of the feed	3.5
Rs_W	Width of the rectangular slot	9
Rs_l	Length of the rectangular slot	4.5
W_g	Width of the ground	29
L_g	Length of the ground	8.5
W_s	Width of the stub	15
L_s	Length of the stub	3.4

3. Results and discussion

This paper is carried out by three designs. The diagram and dimension of optimized design is shown in the figure. The antenna is designed to operate in TE_{101} mode to get resonance at 6.9 GHz, which is specifically preferred for satellite application. Using Dielectric Waveguide Model, the DRA is designed. In first two designs, DRA is made up of FR4 substrate with overall dimension (40×29×2.29) mm^3, which produces bandwidth of about 1.6 and 2.6 GHz respectively, whereas, the third design produces 4.692 GHz of bandwidth. The various parameters like reflection coefficient (S_{11}dB), VSWR (Voltage Standing Wave Ratio), bandwidth, mutual coupling coefficient (S_{12} or S_{21}) dB, directivity (dBi), Gain (dB) are analyzed.

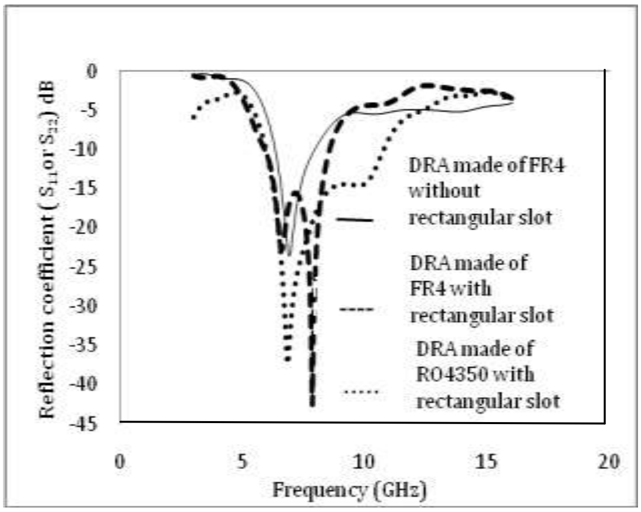

Chart -1: Comparison of Bandwidth for three designs

Using dielectric material with low value of dielectric constant produces more bandwidth. The optimized design in this paper covers Ultra Wide Band (UWB) from (5.9 to 10.6) GHz without interfering with WLAN frequencies. Hence this antenna supports UWB applications. From the graph it is understood that when DRA is made of RO4350 material it produces more bandwidth of about 4.692 GHz (5.96 to 10.6) GHz, which covers UWB without interfering with WLAN frequencies. Using defective ground structure the performance of the antenna is enhanced.

The reflection coefficient obtained for three designs are -24 dB, -22 dB, -41 dB respectively. Among which third design provides least value of reflection coefficient.

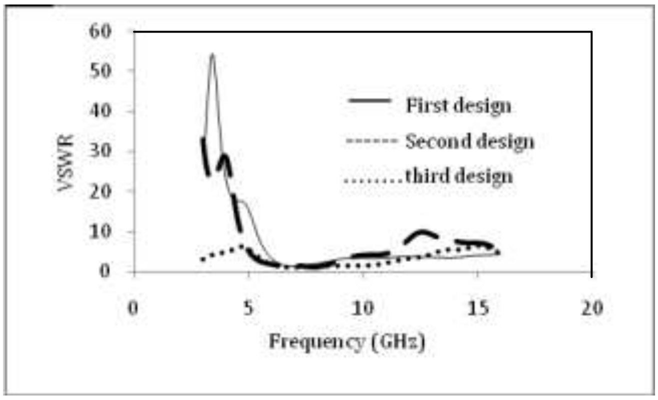

Chart -2: VSWR for three designs

The VSWR for three designs are 1.14, 1.3, and 1.016 respectively. The value of VSWR should be less than or equal to 1. Optimized third design meets this criterion.

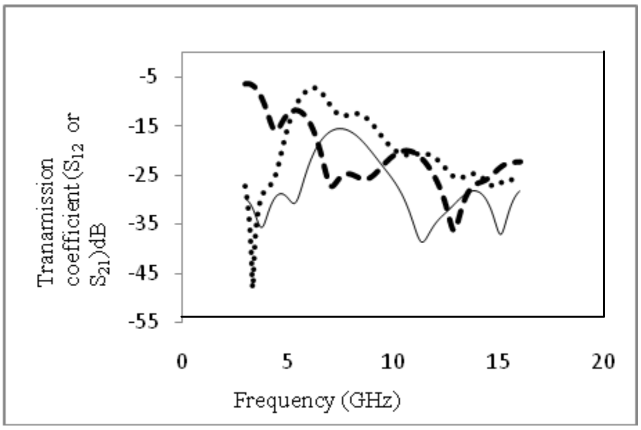

Chart -3: Mutual coupling coefficient for three designs

The fabricated module is shown in the figure,

Fig-3 photograph of fabricated antenna

Mutual coupling is measured at -15 dB. The (S_{12} or S_{21}) dB is -16 dB, -10 dB and -24.1 dB at 6.9 GHz, for first, second and third designs. The third optimized design has value well below -15 dB, which is suitable for MIMO applications.

The directivity is shown in 3D plot for the optimized design. The simulated directivity for three designs is 5.1 dBi, 3.618 dBi, 4.068 dBi respectively. Among which third optimized design has 4.068 dBi.

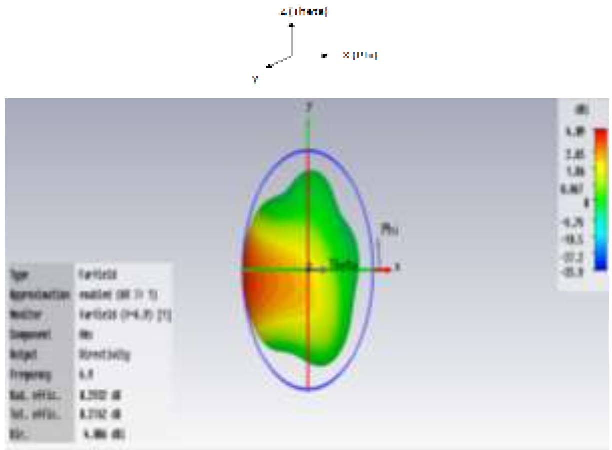

Fig -4: Simulated 3D directivity of optimized design

The gain of three designs is 4.9 dB, 3.4 dB, 4.3 dB. Among which the gain of optimized design is 4.3 dB.

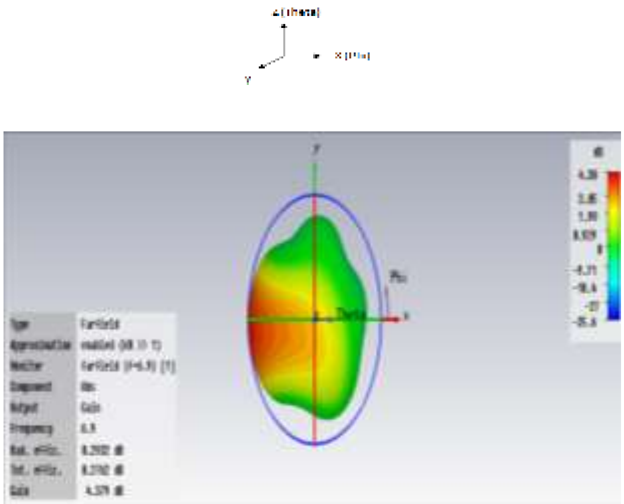

Fig -5: Simulated 3D Gain of optimized design

Figure 9 and 10 shows the surface current distribution at port 1 and port 2 of third design. Based on the surface current distribution we can view how the coupling takes place between the two antennas. Based on that we can make changes in the design and enhance the performance parameters of antenna.

In Fig-6, port 1 is excited and port 2 is terminated and in Fig-7, port 2 is excited and port 1 is terminated.

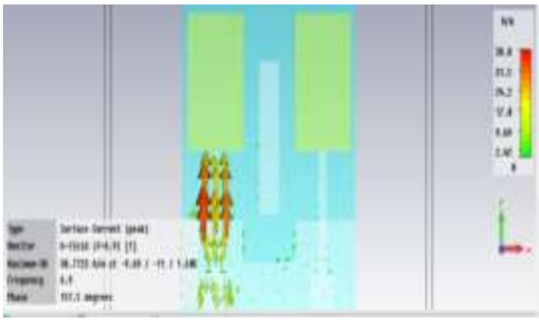

Fig-6: Surface current at port 1

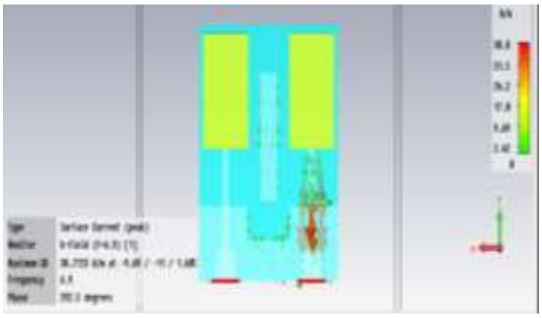

Fig-7: Surface current at port 2

Table-2 Comparison of various parameters of all the three desgns

Design	Size in (mm³)	(S11 or S22) dB @ 6.9 GHZ	(S12 or S21) dB @ 6.9 GHZ	VSWR @ 6.9 GHz	Directivity (dBi)	Gain (dB)	Band Width (GHz)
Design 1	40×29 ×2.3	-24	-16	1.1	5.1	4.9	1.6
Design 2	40×29 ×2.3	-22	-10	1.3	3.61	3.41	2.6
Design 3	29×29 ×2.3	-41	-24.1	1.016	4.08	4.3	4.692

The size of optimized design is less when compared to other two designs hence compactness is also achieved.

4. CONCLUSIONS

In this project, a new compact dielectric resonator antenna is proposed, simulate and fabricated. The overall compact dimension is (29 × 29×2.295) mm³ and a wide bandwidth is obtained for about 4.3 GHz. Since, the dielectric resonator antennas does not contain any conducting material, it does not provide any conduction loss, spurious radiation and it is very suitable for high frequency applications and loss is also less. The design of the antenna is carried out with the fact that material with low dielectric constant will provide more bandwidth. This antenna produces very wide band response and hence supports UWB applications.

The extension of this work can be done by, increasing the bandwidth for higher millimeter wave frequencies and therefore it supports for 5G applications. Dielectric Resonator Antenna is one of the antennas which well supports for high frequency future applications.

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