Defective Ground Structure Based Dual Port MIMO Antenna Configuration for Future Generation Communication Networks

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Abstract. In this manuscript a defective ground structure based dual port MIMO antenna configuration for future generation communication networks is designed and presented. The MIMO antenna measures 120 × 60 × 0.8 mm^3 in size and is designed using Rogers RT5880 substrate material. The single port antenna is designed and optimized at first. After that, a two-port structure is designed and optimized. The proposed antenna covers frequency from 1.9 GHz to 2.45 GHz. To produce proper resonance, a defective ground structure is introduced into the ground plane. This antenna is self-decoupling, with an isolation of −15 dB between its elements. All MIMO diversity parameters and radiation properties are assessed, in addition to the mutual coupling. The proposed MIMO antenna configuration designed and optimized to offer TARC <− 10 dB, MEG −3 dB, DG ~9.99 dB, ECC <0.02, and gain 3.25 dBi. All assessed MIMO diversity features work reasonably well. The proposed two port MIMO antenna can be used for WLAN and 5G applications.

Keywords: MIMO · Defected ground structure · ECC · DG · 5G · WLAN

1 Introduction

The internet users have increased drastically over the last decade. The need for high-speed communication is multiplying day by day [1, 2]. Wireless technologies are facing new challenges due to excessive data transfer [3, 4]. On the other hand, multichannel fading degrades channel capacity and spectrum efficiency of the antenna system [5]. Conventional systems like single-input single-output (SISO) antenna system fail to bridge the desires of the 5G wireless communication standards [6]. By utilizing cutting-edge radio propagation techniques, multiple antenna structure designs enable excellent data processing and spectrum efficiency. The data traffic generated by extremely demanding applications, including online gaming, cloud services, and live video streaming, to mention a few, is too much for 4G services to handle [7]. A key enabling technology for both current and future communication is the multiple-input multiple-output (MIMO) antenna that uses several antennas to increase data rate, link reliability, spectrum efficiency and throughput to gigabits per second [8].

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Because MIMO technology uses numerous broadcast and receive antennas, and multiplexing methods, it considerably decreases radio propagation concerns. Numerous MIMO antenna designs have been released lately for 5G millimeter-wave applications. Most countries in the world are now implementing 5G technology to meet the demand for handling massive data [9, 10]. Sub-6 GHz antenna deployment is feasible using the current 4G LTE spectrum, makes it an appropriate choice for 5G communication [11]. Isolation is a crucial element for a MIMO antenna and may be enhanced in a number of ways.

To enhance isolation >20 dB between adjacent antenna elements, F-shaped patches with L-shaped slots and decoupling network composed of defective ground structure is utilized in ref [12]. Numerous studies have already been published in the literature in which MIMO antennas are etched with DGS ground planes [13, 14]. A two-port MIMO using simple structure operating between 2.12 and 2.18 GHz has been presented in [15] with isolation level of −15 dB. However, the antenna fractional bandwidth (FBW) is less. An isolation of −22 dB and ECC of 0.004 is achieved using self-decoupled four port MIMO antenna resonates between 3.3–3.6 GHz is given in ref [16]. The reported antenna size is large as compared to other antennas.

Several methods, such as diversity techniques, parasitic elements, neutralization line, and electromagnetic band gap structure (EBG) were utilized previously to minimize mutual coupling. But, the major drawbacks of such techniques are high profile and lower value of gain [17]. Furthermore, the majority of 5G New Radio (NR) research focuses on the frequencies N77, N78, and N79, which span the range of 3.3 to 5.0 GHz [18]. The 1.9 to 2.5 GHz range of frequencies, on the other hand, has gotten less attention.

In this work, a simple, 1 × 2 MIMO antenna made up of patch element is proposed. It achieves good isolation, good gain, low ECC without using any additional structure or matching network. The proposed antenna system resonates at a frequency of 2.25 GHz (center frequency), which occupies the 5G frequency range-1(FR-1), low-band sub-6 GHz. In order to support future wireless applications and attain the required antenna properties, the antenna is designed and simulated. High gain, high efficiency and good diversity performances makes it more suitable for 5G and WLAN applications. This manuscript is ordered as follows. Section 2 presents the single-antenna design. Section 3 deals with MIMO design. The simulated results are discussed in Sect. 4, and the conclusion in Sect. 5 and finally references.

2 Design and Geometric Consideration

This segment provides the step by step procedure and detailed analysis of the suggested single-antenna architecture. The proposed MIMO antenna single unit element is built using Rogers RT 5880 substrate having a loss tangent of 0.0004 and 2.2 dielectric constant. Figure 1, depicts the proposed single-antenna geometric design. The 3D electromagnetic (EM) simulator computer simulation technology (CST) version 2021 is used for developing and analyzing the design.

The single-antenna unit that is being suggested has dimensions of 60 × 60 × 0.8 mm^3. The substrate consists of an rectangular patch on its top surface and a circular stub connected to the top end and a rectangular stub connected to the bottom corner is fed by

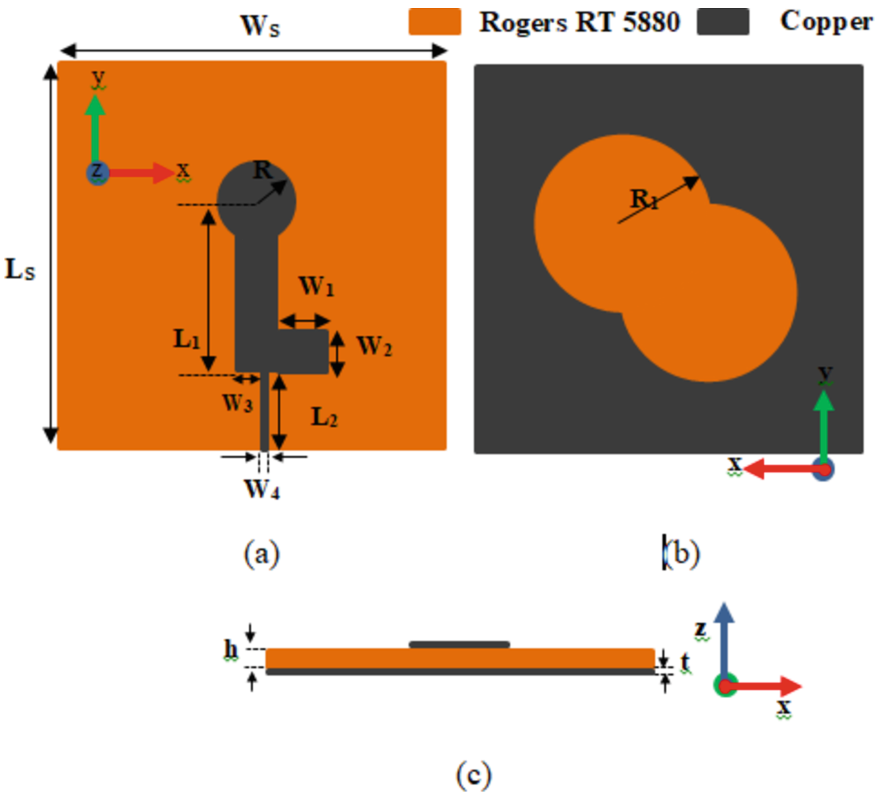


Fig. 1. Structure of the single-antenna unit. (a) top view (b) bottom view (c) front view (All dimensions in mm. W_S - 60, W_1 - 5.5, W_2 - 7, W_3 - 2.5, W_4 – 1, L_S - 60, L_1 - 25, L_2 - 11, R - 5, R_1 - 15, h - 0.8)

a 50 Ω feed. The bottom side of the substrate contains a 0.035 mm thick copper sheet that has been etched with two circular slots with radius R_1 centered at $(-5, 5)_{x, y}$ and $(-5, -5)_{x, y}$ of ground plane which serve as defective ground surface. The recommended two-port MIMO antenna dimensions grow to 120 × 60 × 0.8 mm^3 where the same single-antenna element is mirrored in x-axis direction.

This section examines and discusses the several phases of growth of the designed single-antenna element. Fig. 2, shows the four distinct processes (phase I through IV) in order to reach the final stage of the suggested antenna. A comparative analysis for all four phases in term of reflection coefficient has been done and shown in Fig. 3. Phase - I involves designing a straightforward rectangular radiator using defective ground structure, produces resonance at 3.6 GHz with insertion loss −30 dB. Phase II involves adding a circular stub to the top of the patch, shifts resonance to 3.2 GHz with return loss −12 dB. Similarly, a stub is added at the bottom right corner of the patch to adjust the operating frequency to 2.6 GHz from 3.2 GHz (Phase - III). Lastly, attaching both rectangular and circular stub to the patch offers the desired result (Phase-IV). The impedance bandwidth is 1.9–2.5 GHz and the fractional bandwidth (FBW) is 28%.

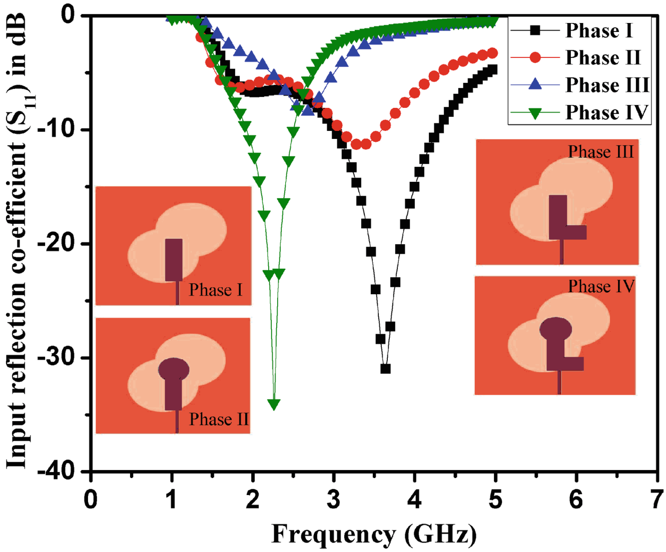


Fig. 2. Evolution stages of designed single-antenna unit

3 MIMO Antenna Design

One benefit of using a MIMO system is that it can boost data rates even when there is interference, multipath fading, and signal fading. A single-element antenna performance may change as a result of electromagnetic wave interaction (mutual coupling) between components in a MIMO antenna. Therefore, one crucial issue that has to be investigated in relation to MIMO antenna systems is mutual coupling. Figure 3, illustrates the 2-element MIMO with antenna-1 and antenna-2 are arranged in mirror configuration. Figure 4, examines simulated transmission and reflection coefficients (S_{21}, S_{12} and S_{11}, S_{22} respectively) as a function of frequency. It is worth mentioning, like single-antenna unit, the proposed multi-antenna is also operating at 2.25 GHz. Isolation of −15 dB is recorded over the entire operating range. The inter-spacing between single-element is 50 mm.

4 Results and Discussions

Figure 5, displays the radiation patterns for port 1 and 2 of the suggested antenna. By applying a matched load termination of 50 Ω on one port and concurrently providing excitation to other ports, one may estimate the radiation pattern. The suggested antenna provides omnidirectional and dipolar radiation patterns in the *E*- and *H*-plane as displayed in Fig. 5(a) and (b), respectively, at the resonance frequency. It also provides a constant radiation pattern *xz* and *yz*-plane. The antenna is highly efficient (96% radiation efficiency) provides peak gain of 3.25 dBi at the resonant frequency.

The MIMO is stimulated through microstrip feed. Figure 6, illustrates the surface current distribution of the antenna for different phase angles (0° and 90°) of the input

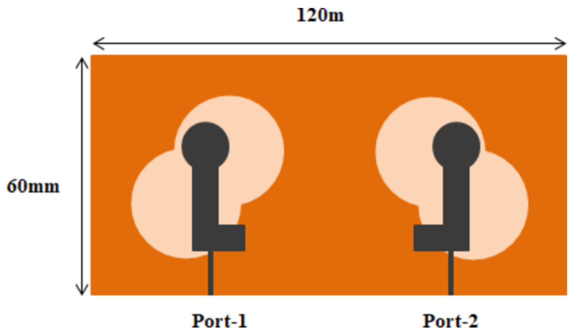


Fig. 3. Two-port Multiple-Input Multiple-Output antenna in mirror configuration

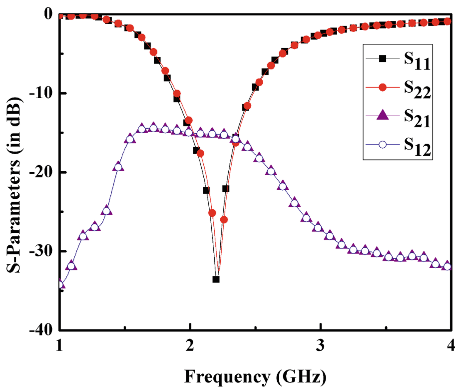


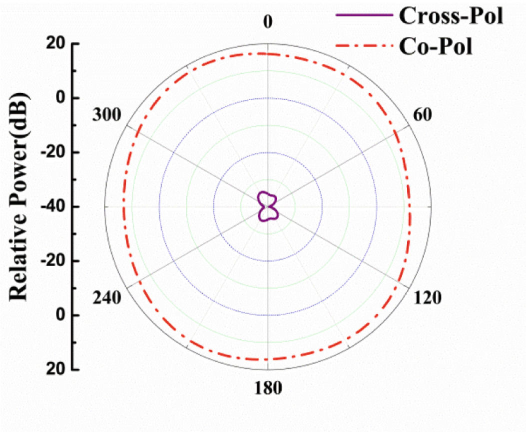
Fig. 4. Multiple-Input Multiple-Output antenna's scattering-parameters

excitation signal. In this case, port-1 is excited via feed line and port-2 is connected with matched load. At phase 0° of the excitation signal the coupling between the single–antenna is slightly present and less at 90° (see Fig. 6a and b). Consequently, it is evident that there is good isolation (less than −15 dB) between the antenna elements.

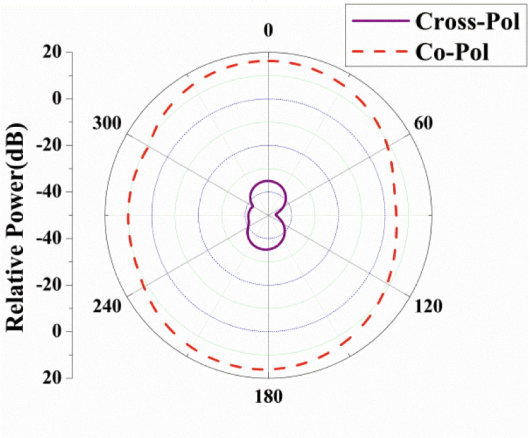
To understand the MIMO antenna multi-channel propagation performance and each port's independence, a number of diversity performance metrics are examined, analyzed, and computed, including the channel capacity loss (CCL), envelope correlation coefficient (ECC), total active reflection coefficients (TARC), mean effective gain (MEG), and diversity gain (DG).

For MIMO antenna systems, one of the most important essential metrics is ECC. The ECC for the recommended MIMO antenna is plotted in Fig. 7. The recommended antenna ECC is 0.02, which is within the acceptable range, is clearly visible. Equation (1) provides the accurate way of calculating the ECC [19],

$$\rho = \frac{\left|\iint_{4\pi} d\Omega F_1(\theta, \phi)^* . F_2(\theta, \phi)\right|^2}{\iint_{4\pi} d\Omega |F_1(\theta, \phi)|^2 . \iint_{4\pi} d\Omega |F_2(\theta, \phi)|^2} \tag{1}$$



(a)



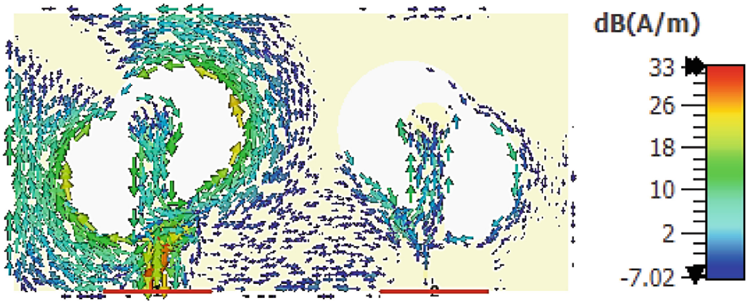
(b)

Fig. 5. Radiation pattern for designed Multiple-Input Multiple-Output antenna at (a) *xz*-plane (b) *yz*-plane

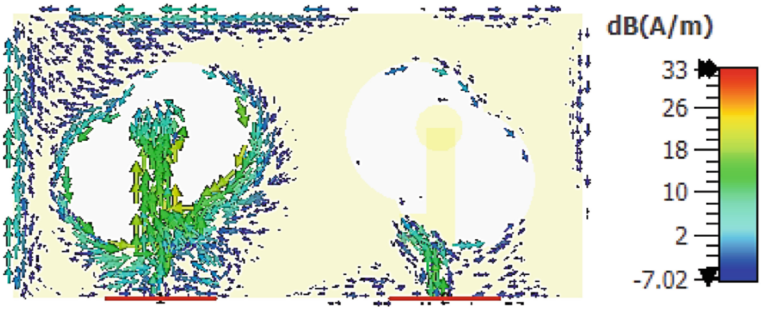
Another crucial MIMO metric that illustrates the power losses during transmission is diversity gain. An antenna may provide a diversity gain of around 9.99 dB at the center frequency and >9.9 dB at the operating bandwidth, as shown in Fig. 8. The ideal DG value is 10 dB, although the recommended antenna provides a value that is near to that. Equation (2) may be used to compute the DG based on the ECC value [19].

$$DG = 10 \times \sqrt{1 - |\rho|^2} \tag{2}$$

TARC is an additional metric that has to be taken into account when choosing the best multiport antenna design. It shows how much mean power is reflected relative to the overall amount of incident power.



(a)



(b)

Fig. 6. Current distribution plot at (a) 0° (b) 90° for designed Multiple-Input Multiple-Output antenna

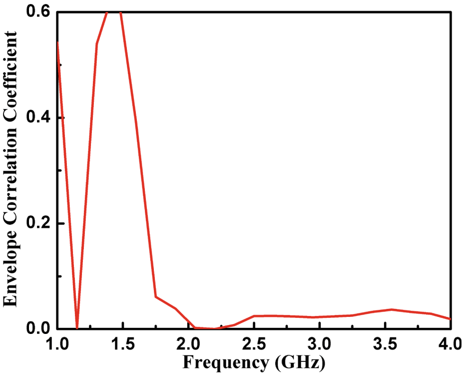


Fig. 7. Envelope correlation coefficient curve for designed Multiple-Input Multiple-Output antenna.

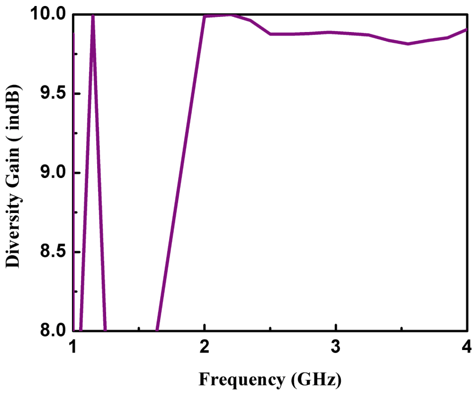


Fig. 8. Diversity gain curve for designed Multiple-Input Multiple-Output antenna configuration.

The expression for calculating the TARC [20] is given in the Eq. (3),

$$\text{TARC (dB)} = \frac{\sqrt{\sum_{j}^{M}|b_j|^2}}{\sqrt{\sum_{j}^{M}|a_j|^2}} \tag{3}$$

Estimated TARC of this MIMO antenna is −10 dB is within the allowable range.

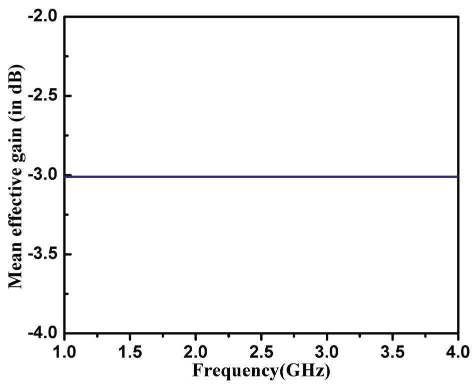


Fig. 9. Mean effective gain curve for designed Multiple-Input Multiple-Output antenna configuration

Mean effective gain is a useful tool for determining the wireless system power reception in a fading environment (MEG). Practically, values that are equal to or less than −3 dBi is acceptable. MEG of −3 dBi is provided at the operational region by the proposed MIMO antenna. Equations (4) may be utilized to determine the mean received signal strength of every of the MIMO [19],

$$MEG = 0.5\left[1 - \sum_{j=1}^{m} |S_{ij}|^2\right] \tag{4}$$

Figure 9, displays the estimated MEG values of the designed multi-port antenna. Finally, the channel capacity loss (CCL) <0.4 bits/sec/Hz has been calculated [19], which is also desirable for the suggested MIMO antenna.

5 Conclusion

In this paper a dual port MIMO antenna configuration for future wireless communication using defected ground structure is designed and presented. This paper presents a self-decoupling MIMO antenna that is straightforward. The main objective of the designed antenna is to cover the 1.9–2.5 GHz frequency range. Once the intended outcomes are obtained with a single- antenna unit, antenna diversity is created by placing the 1 × 2 antennas in mirror orientation. The performance of the MIMO antenna is evaluated using a variety of metrics, such as ECC, TARC, CCL, DG and MEG. The antenna meets the criteria of the specified applications with a gain of 3.25 dBi. Devices utilized in 5G and Wireless LAN applications are strongly applicable to the reported findings in the suggested antenna.

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