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Research Article

Comprehensive Methodology for Advancing MIMO Circular Microstrip Patch Antenna Design with Aperture Coupling and Defected Ground Structure for Ultra-Wideband Applications

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ABSTRACT

This work provides a complete approach for enhancing a design and performance of circular microstrip patch antennas with multiple inputs and outputs (MIMO) for use in Ultra-Wideband (UWB) communication systems. The suggested approach combines Defected Ground Structure (DGS) and Aperture Coupling, two cutting-edge approaches, to provide the best possible antenna performance. Microstrip patch antennas can be excited for MIMO applications using an approach called aperture coupling. This methodology offers a comprehensive method for attaining better performance for UWB applications by addressing the difficulties present in MIMO systems and circular microstrip patch antennas. A microstrip patch antenna with aperture coupled feed line and Defected Ground Structures (DGS) is designed and simulated in this research. This work compares two antenna designs: one without DGS structure and the other with DGS. Antenna efficiency and bandwidth can be increased by manipulating the electromagnetic properties of ground plane through integration of DGS. The paper assesses a combined impact of these design elements on important antenna characteristics, such as diversity gain, return loss, gain, directivity, through in-depth analysis and experimentation. The results of this study make significant contribution to a field of antenna engineering by providing insightful information about intricate details of design required to create high-performance MIMO circular microstrip patch antennas that are specifically suited to the needs of contemporary UWB communication systems. The proposed method achieves 3.52 GHz of bandwidth at 5.68 GHz center frequency for without DGS while 3.57 for with DGS and isolation is 23.

Keywords: Ultra-Wideband (UWB), Defected Ground Structure (DGS), Multiple Inputs and Outputs (MIMO)

INTRODUCTION

Wireless communications have completely changed the way we live today, allowing us to stay connected on the go for everything from social media to accessing information [1]. However, traditional wireless techniques that rely on models often struggle to keep up with the growing demands of new applications, especially when it comes to low-latency networks and complex communication settings [2,3]. Thanks to technological advancements, we can now generate and discover Terahertz (THz) radiation, which opens up exciting possibilities in fields like radio astronomy and medical imaging [4]. That said, rolling out commercial THz systems isn't without its hurdles, such as significant atmospheric interference and high path loss, which means we need powerful transmit and receive antennas [5].As the demand for wireless bandwidth continues to rise, research into massive MIMO technology has gained momentum. This technology is crucial for the next generation of networks because of its impressive spectral and energy efficiency [6]. Microstrip antennas are a popular choice in wireless communications, thanks to their straightforward design, lightweight nature, and cost-effectiveness [7,8]. The THz band shows great potential for secure and high-speed communication, but designing UWB antennas comes with its own set of challenges, particularly regarding bandwidth and gain limitations [9,10]. While conventional printed antennas tend to have narrow bandwidth and low gain, defected ground structures (DGS) provide a smart solution for minimizing mutual coupling and boosting antenna performance [11]. However, we need to be cautious, as DGS can sometimes lead to unwanted backward radiation that needs to be addressed [12].

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Ultra-wideband (UWB) technology is fantastic for high-speed data transmission, offering benefits like low power consumption, high data rates, and resistance to multipath interference, making it perfect for telecommunications and multimedia applications [13-15]. UWB systems do face a few hurdles, like standardization issues, managing interference, and the challenges of antenna design. The use of DGS in MIMO antennas has really boosted their performance by cutting down on mutual coupling, increasing bandwidth, and fine-tuning impedance matching. This makes them a great fit for the next wave of communication systems [16,17]. Studies have indicated that when you pair DGS with fractal and metamaterial designs, you can take antenna performance to the next level, especially for high-frequency applications like 5G and beyond [18]. Innovative DGS setups, such as slot-array structures and complementary split-ring resonators, have successfully minimized interference and enhanced gain characteristics across various fields, from biomedical systems to industrial communications [19-22]. Research in MIMO antenna technology is ongoing, with a focus on discovering new DGS configurations that can deliver even better performance in UWB applications. Techniques like substrate-integrated DGS and photonic bandgap structures are showing promise in cutting down interference and boosting radiation efficiency [23,24]. In the realm of millimeter-wave and sub-6 GHz 5G applications, DGS has improved directivity and gain, which is essential for reliable high-speed data transmission [25]. The push for miniaturized, high-efficiency MIMO antennas with DGS is vital to keep up with the rising demand for compact wireless devices [26].

In the end, incorporating DGS into circular microstrip patch MIMO antennas has been crucial for the progress of UWB communication systems. Looking ahead, research will aim to refine DGS configurations and hybrid design approaches to achieve better performance, less interference, and greater reliability in the next generation of wireless networks [27-30].

OBJECTIVES

- Enhance the design and performance of MIMO circular microstrip patch antennas for use in UWB communication systems.
- Improve antenna performance by combining DGS and aperture coupling techniques to increase diversity gain, bandwidth, and efficiency.
- Optimize the ground plane and coupling slot parameters to increase antenna's gain, isolation, and efficiency.
- This strategy contributes to the development of effective and small antenna configurations by providing an achievable method to implement MIMO systems using circular microstrip patch antennas.
- Examine and verify the effects of aperture coupling and DGS on antenna characteristics like DG, ECC, gain, return loss, and directivity.

The paper is organized as follows. An overview of MIMO circular microstrip patch antenna with aperture coupling and defective ground structure is given in Section 2. Section 3 explains the approach to improving antenna design. Section 4 presents the results of the proposed methodology and compares them with findings of other approaches that are currently in use. Section 5 contains paper's conclusion as well as some suggestions for additional research.

METHODS

1. Proposed Methodology

This study presents a novel and innovative approach that significantly improves the performance of MIMO 3x3 circular microstrip patch antenna designed for UWB applications. The aperture coupling feeding technique and the DGS are utilized to their full potential by this methodology. Antenna design has been completely transformed by feeding technique known as aperture coupling. The antenna can have wide impedance bandwidth, low cross-polarization, high gain, and low back radiation due to aperture coupling technique. Additionally, it makes it possible to utilize various substrates for radiating patch and feed line, which can enhance the antenna's performance and effectiveness. The DGS method includes etching holes or imperfections in antenna's ground

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plane, which may result in band gaps or stop bands in frequency response. This can improve suppress undesired harmonics, radiation characteristics, decrease mutual coupling, and boost the antenna's gain and bandwidth. The utilization of Aperture Coupling and DGS in antenna design is a promising approach for achieving optimal performance in contemporary wireless communication systems, as it presents numerous advantages for Ultra-Wideband (UWB) applications. The key benefit of integrating aperture coupling and DGS are reduced mutual coupling in MIMO System, Improved Return Loss and Impedance matching, broadening bandwidth, surface wave suppression, interference mitigation, compact design, and precision in beam steering and directivity. Therefore, small antenna, an efficient, and high-performing for ultra-wideband applications can be produced by combining aperture coupling with DGS.

1.1. Defected Ground Structure

DGS is a process that involves forming a slot or defect in a printed microstrip board's ground plane. DGS is used to adjust the microstrip circuits or antenna's electromagnetic characteristics and current distribution. DGS has the ability to filter or block specific frequencies from radiating from the antenna or from propagating through the microstrip line by creating a stop band or band gap in the frequency response. In addition, DGS can improve the isolation, radiation pattern, bandwidth, gain, impedance matching, and isolation of the microstrip circuit or antenna. The EBG structure, which is periodic pattern with band-stop property, is simplified into the form of DGS. This method creates a band gap in frequency response which is mainly used to increase bandwidth, gain and reduce mutual coupling, unwanted noise of antenna. An energy range in a periodic structure where no waves or vibrations can propagate is known as a band gap in frequency response. It is sometimes referred to as a band gap or a stop band. A system or material with a repeating pattern of units or elements in one or more dimensions is called a periodic structure. A frequency response band gap happens when the incoming waves or vibrations interact with the periodic structure and produce destructive interference, which eliminates the energy of the waves or vibrations. It is possible to regulate or filter the transmission of waves or vibrations in particular frequency ranges by using a band gap in frequency response. The fundamental component of DGS consists of resonant gap or slot in ground metal that is positioned directly beneath transmission line and oriented to provide an effective coupling to the line. An equivalent circuit for DGS is one that is parallel-tuned and connected in series with transmission line. This circuit is depicted in Figure 1. The equivalent values of R, L, and C are established by DGS structure's dimensions and its location in relation to transmission line. The input and output impedances are those of line section.

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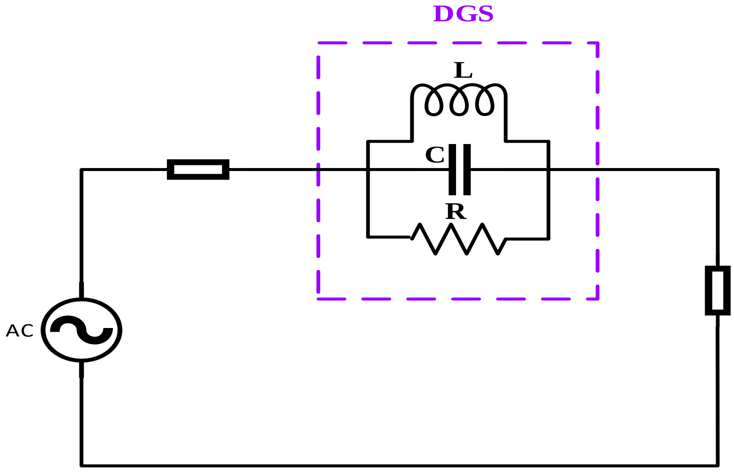

Figure 1. Equivalent Circuit of DGS

DGS is a technique used to reduce microstrip antenna's size. If better performance is desired, a complex shape can occasionally be etched into the ground plane instead of a simple one. Figure 2 illustrates an example of DGS-specific shapes etched onto microstrip circuits' ground plane.

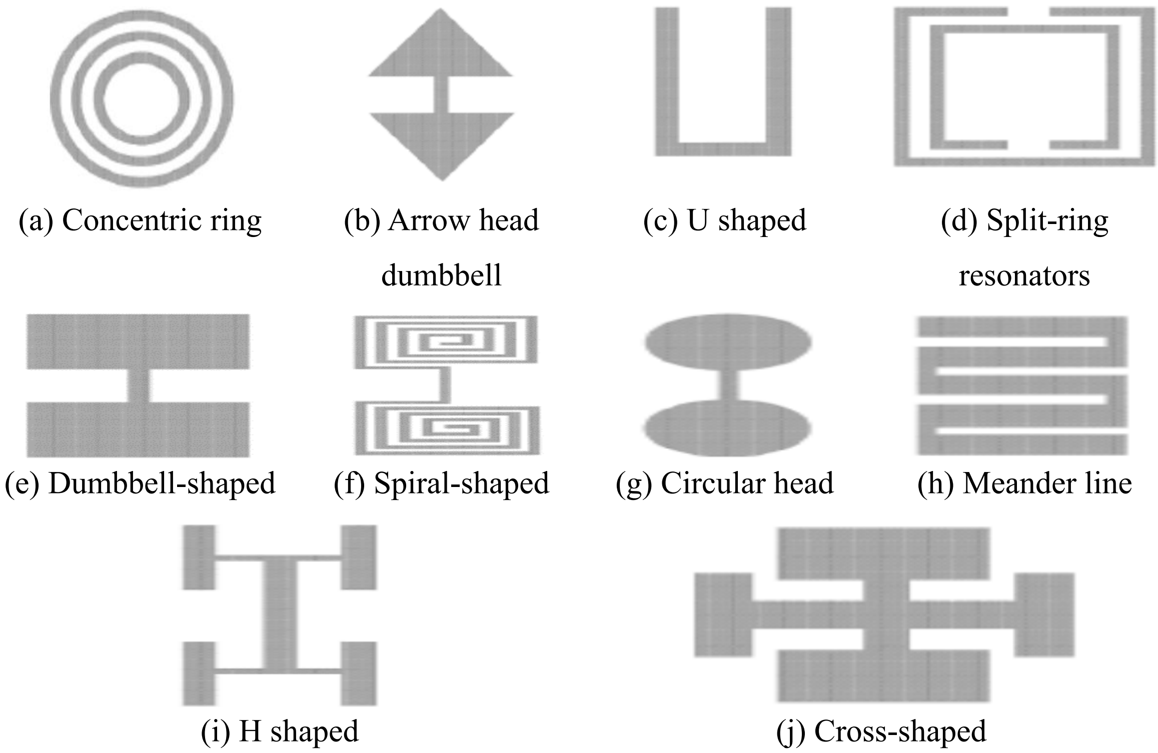

Figure 2. Various shapes of DGS

In this work, H-shaped DGS is applied in microstrip antennas to improve their bandwidth and gain while enhancing their radiation characteristics by suppressing higher mode harmonics, cross-polarization, and mutual coupling between adjacent elements. This type of DGS is preferred in this study because, it has many advantages such as higher degree of compactness is attained and slow wave factor is raised, the stopband also has a better

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bandwidth and return loss level, improved signal integrity, enhance impedance matching, improved isolation in RF Circuits, and enhanced radiation pattern control. The simulated H-shaped DGS is displayed in Figure 3.

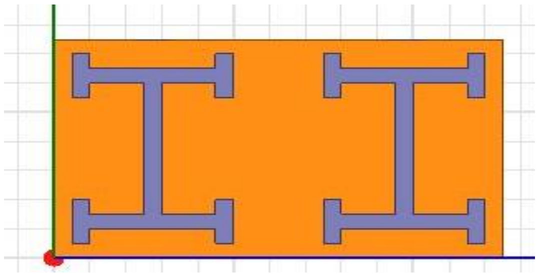

Figure 3. Simulated structure of H-shaped DGS

1.2.Aperture Coupling

The aperture-coupled microstrip patch antenna is very interesting because it enables the feed network (a 50-ohm microstrip transmission line) and the radiating element (a microstrip patch) to be separated by conductive layer. A tiny hole in ground plane allows for electromagnetic coupling of two structures, and a micro-strip antenna is built on separate dielectric slab above it.. Aperture-coupled antenna presents numerous benefits in comparison to traditional direct feed antennas. These include using a different substrate for feed structure and antenna, shielding antenna from spurious feed radiation, and having a large bandwidth. This antenna element is particularly helpful for millimeter-wave phased arrays because of its features. The amount of coupling to patch is calculated through use of micro strip line. The resonant frequency of structure and quantity of undesired radiation reflected back are also affected by aperture's dimensions. The parameter that influences a selection of particular aperture size is determined by impedance of patch at slot. Since simple circuit cannot accurately describe the area near slot, full-wave analysis is the only method that yields meaningful results. But only two variables need to be optimized: the stub length (which is covered next) and the slot length. The slot width has a negligible impact on antenna behavior because of its tiny size.

1.2.1. Antenna Design

The main radiation pattern may be interfered with feed network radiation, so aperture coupled patch antenna's geometry is chosen to minimize this risk. Since the slot is smaller than resonant size and ground plane prevents their direct connection, the resonant patch element is definitely a source of majority radiation. The approximate fields inside cavity formed by patch and magnetic walls surrounding its periphery, if the patch antenna resonates at its dominant mode, are expressed as follows:

$$E_z(x) = \frac{k_0^2}{j\omega\varepsilon_0} cos\left(\frac{\pi x}{a}\right) \qquad (1)$$

$$H_y(x) = \frac{\pi}{a} sin\left(\frac{\pi x}{a}\right) \qquad (2)$$

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The antenna resonant dimension, 'a' is determined by aperture's position on line segment, which yields $k_0 = 2\pi/\lambda_0$. The patch antenna's feedlines and cavity fields will have same coupling coefficient if it has a square shape and $a \times a$ dimensions, meaning that fields inside two cavities must be equal.

The following equations (3) and (4) is provided when examining an infinitely long microstrip line:

$$E_z = e^{-jk} e^{x} \tag{3}$$

$$H_y = \frac{h_{sub}}{WZ_c} e^{-jk} e^{x} \tag{4}$$

Where, Z_c is the line's characteristic impedance of 50Ω, W is the line width, h_{sub} is a feedline substrate thickness, and k denotes line's effective propagation constant. Given this approximation, the fields beneath feedlines grow exponentially with offset to antenna's center; hence, for both feedlines to retain the same fields beneath them, the line width must be the same.

The mathematical expression of electric and magnetic dipole is represented in following equation (5) and (6).

$$C_p = \frac{\frac{2}{3} r_0^3 \varepsilon_{r1} k_0^2}{P_{10}} cos\left(\frac{\pi x_0}{a}\right) \tag{5}$$

$$C_M = \frac{-jk_0 Z_0 \frac{4}{3} r_0^3 \left(\frac{\pi d}{aW}\right)}{P_{10} Z_c} sin\left(\frac{\pi x_0}{a}\right) \tag{6}$$

Where, the coupling factors through electric and magnetic dipole couplings are indicated by symbols C_p and C_M respectively. When the cavities in this microstrip patch antenna have same length, width, and offset with respect to the center x_0, as well as same radius r_0 total power flow (P_{10}), and antenna resonant dimension (a), coupling coefficients between cavity fields are equal.

1.3. Proposed MIMO Circular Microstrip Patch Antenna with Aperture Coupling and DGS

This antenna is constructed from two dielectric laminates each with dielectric constant of 1.6 mm and dimensions of 15 x 20 x 1.6 mm³. The FR4 substrate is used in both laminates. The ground plane consisting of 0.05 mm thick copper film separates these two dielectric layers. Figure 3 shows the suggested aperture coupled DGS microstrip patch antenna. In this paper, a circular patch is used. The method of cavity model is utilized to compute its radius and mathematical expression is given in following equation (7).

$$a = \frac{F}{\left\{1 + \frac{2h}{\pi \varepsilon_r F}\left(ln\left(\frac{\pi F}{2h}\right) + 1.7726\right)\right\}^{1/2}} \tag{7}$$

Where, h is a height of substrate, ε_r denotes relative permittivity of substrate, and F represents circular patch's resonance frequency.

For a resonant frequency of 10GHz, the radius of the patch is therefore 3.2mm. A micro strip transmission feeding line measuring Lf = 15 mm in length and Wf = 2 mm in width is imprinted on the lower substrate surface. A circular patch is moved y=1.4 mm away from the feed line's top. On the ground plane, a rectangular aperture with dimensions of length Sl = 7.9 mm and width Sw = 1.1 mm is etched. The feed line's stub length, lstub = 2.5 mm, is

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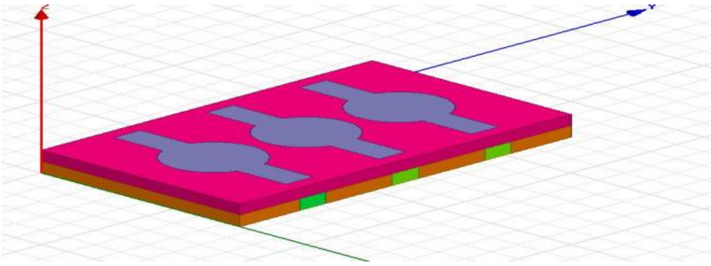
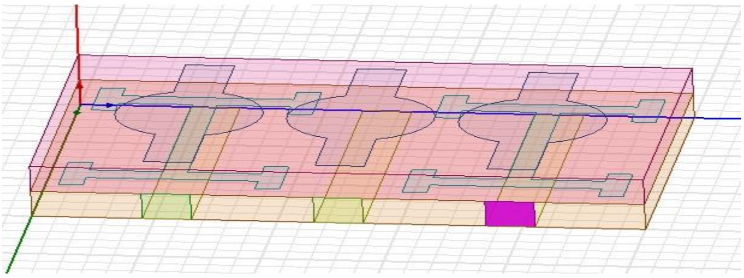
used to adjust the aperture's excess reactance after the slot. The feed and radiating conductor are kept electrically apart by utilizing two dielectric substrates spaced by a ground plane. The ground plane has an aperture through which the patch and feed line are electromagnetically coupled. This antenna design was simulated using HFSS tool.



(a) proposed antenna with DGS



(b) 3-D view of proposed antenna

Figure 4. Structure of proposed aperture coupling with DGS

RESULTS

The proposed MIMO Circular Microstrip Patch Antenna Design with Aperture Coupling and DGS is designed and simulated using High Frequency Structure Simulator (HFSS) software based on some parameters like ECC, return loss, isolation, gain, directivity, and DG. A full-wave 3D electromagnetic simulation program called HFSS is used to design and simulate high-frequency electronic products such as antennas, components, connectors, and interconnects. HFSS increases engineering output, shortens development times, and increases first-pass design success rates. Across a wide range of frequencies, including radio frequency, microwave, and millimeter-wave frequencies, HFSS performs well at simulating and analyzing electromagnetic fields. HFSS is also useful in the study of electromagnetic interference and compatibility, waveguide analysis, and resonator and filter design. Engineers use its capabilities for modeling materials with different electromagnetic properties, exploring parametric studies, and S-parameter analysis. Comparison and evaluation of suggested antenna are conducted with and without DGS.

1.4.Evaluation of 3x3 circular microstrip patch aperture coupled with DGS

The 3 x 3 circular patch antenna fed by aperture coupled without DGS is covered in this section of paper. An antenna with DGS differs from one without in that the latter has a ground plane that has slots or other flaws integrated into it. The primary benefit of DGS, which can decrease antenna size and increase performance, is the slow-wave effect. DGS has been applied in microstrip antennas to improve their radiation characteristics by suppressing harmonics, cross-polarization, and mutual coupling between adjacent elements. It has also been used to increase bandwidth and gain of microstrip antennas. Associated with return loss is the first reflection coefficient, or S11. Figure 5 displays this parameter.

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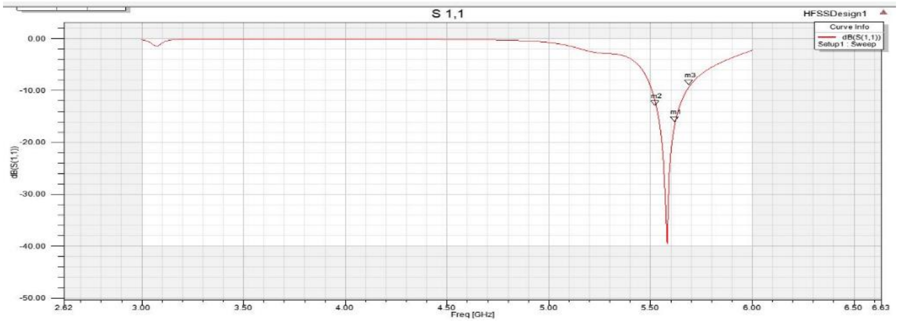

Figure 5. Analysis of S_{11} parameter with DGS

S11 parameter measures the amount of power that the antenna reflects back to source. If an antenna is tuned and matched, S11 should obviously be as small as possible at operating frequency. The 3x3 circular patch antenna with DGS was found to have -39.5 dB return loss. This shows that, at resonant frequency of 5.59 GHz, the antenna effectively matched its input impedance to the transmission line. The return loss value highlights the antenna's resonance and impedance matching capabilities by expressing the amount of power that is actually transferred from source to antenna.

In MIMO antenna system, the coupling between antennas is correlated with S12 and S21 parameters. S12 represents power moved from Port 2 to 1, and S21 represents power moved from Port 1 to 2. The isolation parameters for S12 and S21 with DGS are displayed in Figures 6 and 7 respectively.

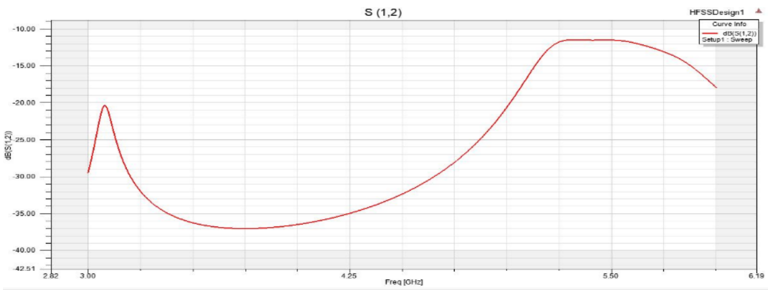

Figure 6. Analysis of S_{12} parameter with DGS

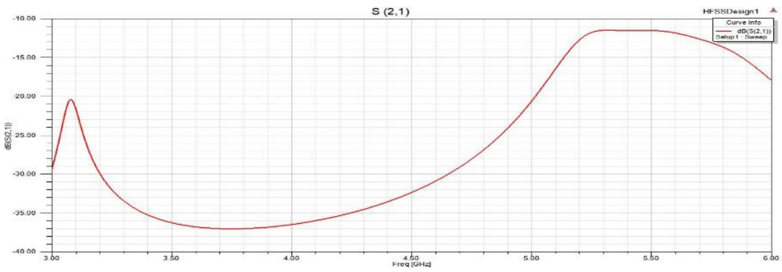

Figure 7. Analysis of S_{21} parameter with DGS

The suggested antenna with DGS, represented by S21 and S12, was found to have an isolation parameter of -11.5 dB. The two elements of the 3x3 array are isolated from one another, according to this value. S13 and S31are typically used to represent power transferred from Port 3 to 1 and from Port 1 to 3. A value of -7.5 dB is found for

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the isolation parameter of the proposed antenna denoted by S13 and S31 with DGS. These features are shown in Figures 8 and 9 .

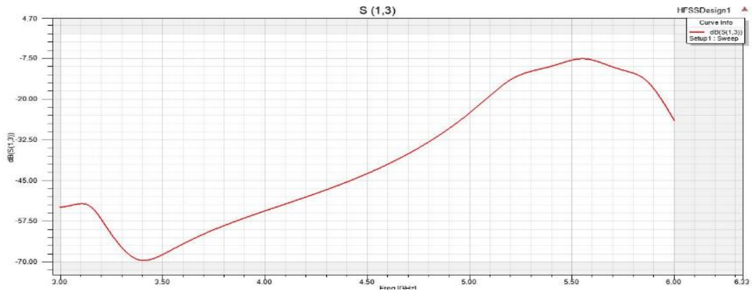

Figure 8. Analysis of S_{13} parameter with DGS

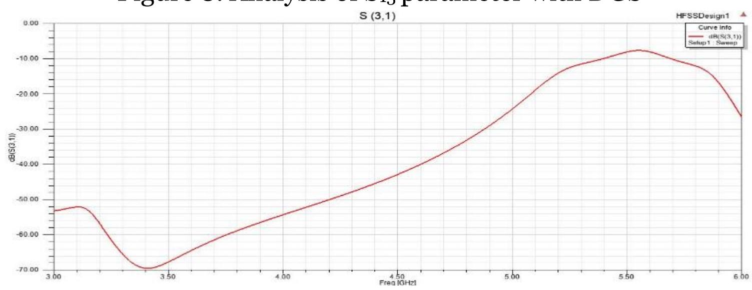

Figure 9. Analysis of S_{31} parameter with DGS

Power transfers from Port 3 to 2 and from Port 2 to 3 are typically represented by S23 and S32, respectively. S23 and S32 in a two-antenna MIMO system are of similar size, but they are phase-opposite. The recommended antenna, represented by S23 and S32 with DGS is found to have an isolation parameter of -10 dB. Figures 10 and 11 shows these characteristics.

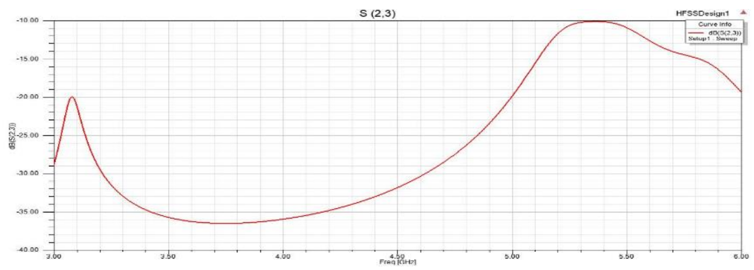

Figure 10. Analysis of S_{23} parameter with DGS

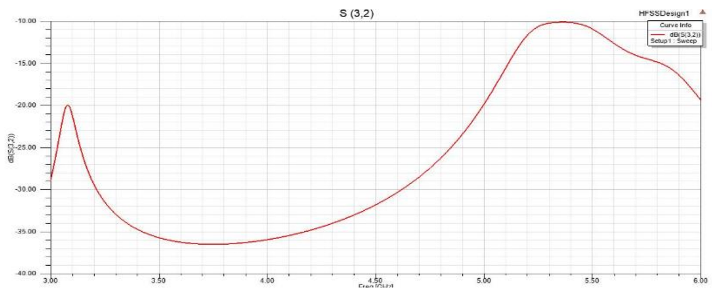

Figure 11. S_{32} parameter of suggested antenna with DGS

According to previously mentioned study, the isolation between S21 and S12 parameters is -11.5 dB, that between the S13 and S31 parameters is -7.5 dB, and that between the S32 and S23 parameters is -10 dB.

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The antenna's capacity to boost signal strength in particular direction is measured by parameter called gain. Gain is essential for increasing UWB reliability and data rate in MIMO systems. The 3-D polar radiation pattern of gain for proposed 3x3 MIMO Circular Microstrip Patch Design with Aperture Coupling antenna with DGS is displayed in Figure 12.

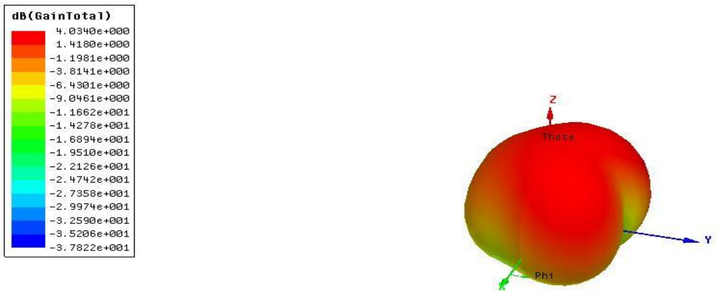

Figure 12. Gain of proposed antenna with DGS

A gain enhancement for MIMO antennas makes use of a metamaterial structure. A circular patch featuring a resonator and complementary elements is utilized to attain elevated gain and minimal mutual coupling. The antenna with DGS has gain of 4.03 dB at resonant frequency of 5.9 GHz according to gain plot.

A more focused radiation pattern from the antenna is suggested by increased directivity. On the other hand, 6.2 dB of directivity was found for recommended DGS antenna. The directivity of this antenna was very high. Figure 13 displays the directivity analysis result of the suggested antenna with DGS.

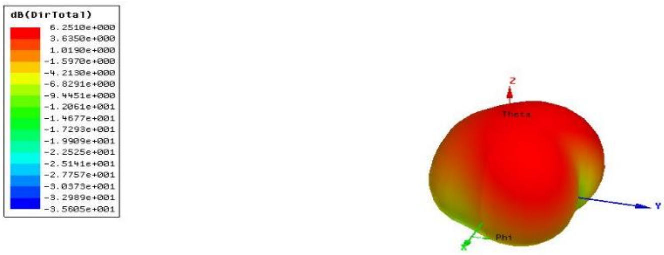

Figure 13. Directivity of proposed antenna with DGS

The polarization diversity and purity of MIMO antenna are reported by ECC. A low ECC value indicates low mutual coupling and high isolation between antenna elements for MIMO performance. The proposed antenna with DGS had an ECC of less than 0.001 both in simulation and measurement over the whole band. Lower ECC values are generally preferred; values of less than 0.5 are thought to be acceptable. Thus, the recommended method achieves better ECC values. Figure 14 shows graphical representation of ECC.

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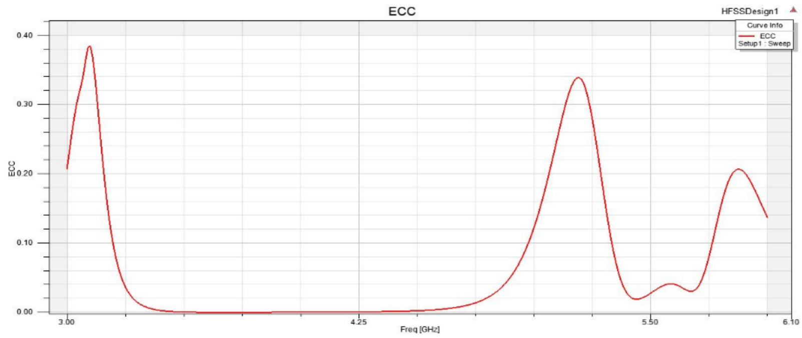

Figure 14. ECC of proposed antenna with DGS

The suggested antenna generated a DG of 10` in the presence of DGS. This suggests that antenna has high degree of directivity and efficiency, which are the factors that determine the DG. Figure 15 shows the proposed antenna's DG plot with DGS.

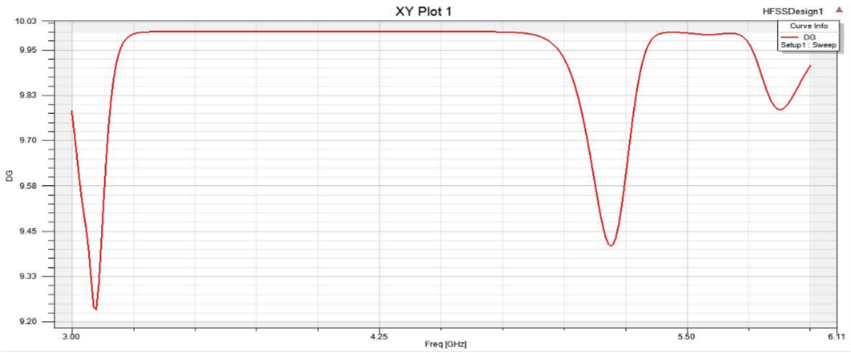

Figure 15. DG of proposed antenna with DGS

From the above analysis, all parameters of proposed antenna with DGS achieved best results when compared to antenna without DGS.

DISCUSSION

There are various methods are in practice currently, the proposed method in this study is compared with different models which are currently in practice. Table 1 illustrates the comparison of existing and proposed method.

Table1. Comparison analysis of proposed and existing methods

Ref	Substrate	Return loss (dB)	Isolation	Resonant Frequency (GHz)	Gain (dB)	BW	ECC	DG
[22]	FR4	-24	<20	3.1	-	-	<0.06	>9.6
[24]	FR4	-10	-	2.41	1.43	100 MHz	-	-
[27]	FR4	-	>15	2.57	3.58	2.5 GHz	<0.005	-
[28]	FR4	<-10	>22	5.5	2	2 GHz	<0.01	10
Proposed without DGS	FR4	-11.4	>23	5.68	4.16	3.52 GHz	<0.02	9.8
Proposed with DGS	FR4	-39.5	>23	5.9	4.03	3.57 GHz	<0.001	10

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The proposed MIMO microstrip antenna fed by aperture coupled without and with DGS is simulated and analysed. This evaluation results are compared with various existing methods. The comparison data clearly shows that, the suggested method in this study achieves higher values for all parameters when compared to various methods which are currently in use. Therefore, the proposed method has great performance in all aspects and well suited for UWB.

CONCLUSIONS

This paper offered a new comprehensive approach to enhance design and efficiency of circular microstrip patch antennas recommended for MIMO UWB communication systems. The suggested methodology maximizes antenna performance by combining two cutting-edge techniques: Aperture Coupling and DGS. This research specifically designs and simulates a microstrip patch antenna with DGS and an aperture-coupled feed line. There is a comparative study between two antenna designs: one with DGS and the other without. At resonant frequency of 5.68 GHz, the antenna without DGS showed a return loss of -11.4 dB, indicating successful impedance matching. It also showed a 4.16 dB gain. These metrics were exceeded by the DGS antenna, which achieved an astounding -39.5 dB return loss, 4.03 dB gain at 5.9 GHz, and 6.2 dB directivity. With a simulated and measured Equivalent Circuit Conductance (ECC) of less than 0.001, the suggested antenna with DGS illustrated its stability and performed better overall, functioning throughout the entire band. These results highlight the utility of Defected Ground Structure in circular patch antennas, providing improved radiation patterns, stability, and impedance characteristics for use in Ultra-Wideband (UWB) communication systems. The suggested approach provided 3.52 GHz of bandwidth at 5.68 GHz center frequency in the absence of DGS and 3.57 GHz in the presence of DGS with isolation of 23 GHz.

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REFRENCES

[1] Marques, G., Miranda, N., Kumar Bhoi, A., Garcia-Zapirain, B., Hamrioui, S. and de la Torre Díez, I., 2020. Internet of things and enhanced living environments: measuring and mapping air quality using cyber-physical systems and mobile computing technologies. Sensors, 20(3), p.720, 2020.

[2] Ali, S., Saad, W., Rajatheva, N., Chang, K., Steinbach, D., Sliwa, B., Wietfeld, C., Mei, K., Shiri, H., Zepernick, H.J. and Chu, T.M.C., 6G white paper on machine learning in wireless communication networks.2020, arXiv preprint arXiv:2004.13875.

[3] Manzalini, A., Quantum communications in future networks and services. Quantum Reports, 2020, 2(1), pp.221-232.

[4] Yordanov, P., Priessnitz, T., Kim, M.J., Cristiani, G., Logvenov, G., Keimer, B. and Kaiser, S., 2023. Generation of Terahertz Radiation via the Transverse Thermoelectric Effect. Advanced Materials, 2023, 35(41), p.2305622.

[5] Olson, N.R., Andrews, J.G. and Heath, R. W., Coverage and capacity of terahertz cellular networks with joint transmission. IEEE Transactions on Wireless Communications, 21(11), pp.9865-9878,2022.

[6] Palanisamy, S., Thangaraju, B., Khalaf, O.I., Alotaibi, Y., Alghamdi, S. and Alassery, F., 2021. A novel approach of design and analysis of a hexagonal fractal antenna array (HFAA) for next-generation wireless communication. Energies, 14(19), p.6204, 2021.

[7] AL-Amoudi, M.A., Design and Simulation for Compact Microstrip Resonant Patch Cell Antenna. International Journal of Advances in Engineering and Management (IJAEM), 3(4),2021, pp.191-219.

[8] Khattak, M.A., Khattak, M.I., Owais, S.M., Khattak, A.A. and Sultan, A. Design and analysis of millimeter wave dielectric resonator antenna for 5G wireless communication systems. Progress In Electromagnetics Research C (2020), 98, pp.239-255.

[9] Zhu, S.Y., Li, Y.L., Luk, K.M. and Pang, S.W., 2020. Compact high-gain Si-imprinted THz antenna for ultrahigh speed wireless communications. IEEE Transactions on Antennas and Propagation, 68(8), pp.5945-5954.

[10] Martinez, I., Mao, C.X., Vital, D., Shahariar, H., Werner, D.H., Jur, J.S. and Bhardwaj, S., 2020. Compact, low-profile and robust textile antennas with improved bandwidth for easy garment integration. IEEE Access, 8, pp.77490-77500.

[11] Firdausi, A., Wahyudi, I.M.D. and Alaydrus, M., 2021. Designing Franklin's Microstrip Antenna with Defected Ground Structure at MMwave Frequency. J. Commun., 16(12), pp.559-565.

[12] Luo, S., Li, Y., Xia, Y., Yang, G., Sun, L. and Zhao, L., 2019. Mutual coupling reduction of a dual-band antenna array using dual-frequency metamaterial structure. The Applied Computational Electromagnetics Society Journal (ACES), pp.403-410.
[13] Castro, C., Elschner, R., Merkle, T., Schubert, C. and Freund, R., 2020. Experimental demonstrations of high-capacity THz-wireless transmission systems for beyond 5G. IEEE Communications Magazine, 58(11), pp.41-47.
[14] Fellah, R., Azzaz, M.S., Tanougast, C. and Kaibou, R., 2021. Design of a simple and low cost chaotic signal generation circuit for UWB applications. The European Physical Journal Special Topics, 230(18-20), pp.3439-3447.
[15] Jabbar, A., Abbasi, Q.H., Anjum, N., Kalsoom, T., Ramzan, N., Ahmed, S., Rafi-ul-Shan, P.M., Falade, O.P., Imran, M.A. and Ur Rehman, M., 2022. Millimeter-wave smart antenna solutions for URLLC in industry 4.0 and beyond. Sensors, 22(7), p.2688.
[16] Gao, D., Cao, Z.X., Fu, S.D., Quan, X. and Chen, P., 2020. A novel slot-array defected ground structure for decoupling microstrip antenna array. IEEE Transactions on Antennas and Propagation, 68(10), pp.7027-7038.
[17] Khalid, M., Iffat Naqvi, S., Hussain, N., Rahman, M., Fawad, Mirjavadi, S.S., Khan, M.J. and Amin, Y., 2020. 4-Port MIMO antenna with defected ground structure for 5G millimeter wave applications. Electronics, 9(1), p.71.
[18] Kaur, A. and Malik, P.K., 2021. Multiband elliptical patch fractal and defected ground structures microstrip patch antenna for wireless applications. Progr Electromagnet Res B 91: 157–173.
[19] Ullah, S., Ruan, C., Haq, T.U. and Zhang, X., 2019. High performance THz patch antenna using photonic band gap and defected ground structure. Journal of Electromagnetic Waves and Applications, 33(15), pp.1943-1954.Tang, D., Han, C., Deng, Z., Qian, H.J. and Luo, X., 2020. Substrate-integrated defected ground structure for single-and dual-band bandpass filters with wide stopband and low radiation loss. IEEE Transactions on Microwave Theory and Techniques, 69(1), pp.659-670.
[20] Tang, D., Han, C., Deng, Z., Qian, H.J. and Luo, X., 2020. Substrate-integrated defected ground structure for single-and dual-band bandpass filters with wide stopband and low radiation loss. IEEE Transactions on Microwave Theory and Techniques, 69(1), pp.659-670.
[21] Bohra, H., Ghosh, A. and Bhaskar, A., 2021. Design and analysis of spurious harmonics suppressed microstrip ultrawide band filter using modified defected ground structure techniques. Wireless Personal Communications, 121(1), pp.361-380.
[22] Wang, E., Wang, W., Tan, X., Wu, Y., Gao, J. and Liu, Y., 2020. A UWB MIMO slot antenna using defected ground structures for high isolation. International Journal of RF and Microwave Computer-Aided Engineering, 30(5), p.e22155.
[23] Islam, M.S., Ibrahimy, M.I., Motakabber, S.M.A., Hossain, A.Z. and Azam, S.K., 2019. Microstrip patch antenna with defected ground structure for biomedical application. Bulletin of Electrical Engineering and Informatics, 8(2), pp.586-595.
[24] Mishra, G.P. and Mangaraj, B.B., 2020. Highly compact microstrip patch design based on improved capacitive Minkowski fractal defected ground structure. AEU-International Journal of Electronics and Communications, 115, p.153049.
[25] Rahman, M.M., Islam, M.S., Wong, H.Y., Alam, T. and Islam, M.T., 2019. Performance analysis of a defected ground-structured antenna loaded with stub-slot for 5G communication. Sensors, 19(11), p.2634.
[26] Paragya, D. and Siswono, H., 2020. 3.5 GHz rectangular patch microstrip antenna with defected ground structure for 5G. ELKOMIKA: Jurnal Teknik Energi Elektrik, Teknik Telekomunikasi, & Teknik Elektronika, 8(1), p.31.
[27] Tang, X., Yao, Z., Li, Y., Zong, W., Liu, G. and Shan, F., 2021. A high performance UWB MIMO antenna with defected ground structure and U-shape branches. International Journal of RF and Microwave Computer-Aided Engineering, 31(2), p.e22270.
[28] Pannu, P. and Sharma, D.K., 2020. A low-profile quad-port UWB MIMO antenna using defected ground structure with dual notch-band behavior. International Journal of RF and Microwave Computer-Aided Engineering, 30(9), p.e22288.
[29] Sabaawi, A.M., Muttair, K.S., Al-Ani, O.A. and Sultan, Q.H., 2022. Dual-Band MIMO Antenna with Defected Ground Structure for Sub-6 GHz 5G Applications. Progress in Electromagnetics Research C, 122, pp.57-66.
[30] Sohi, A.K. and Kaur, A., 2021. Triple band-stop characteristics from an aperture coupled modified Pythagorean tree fractal-based UWB-MIMO antenna integrated with complementary hexagonal spiral defected ground structure. AEU-International Journal of Electronics and Communications, 137, p.153805.