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Miniaturized Micro Strip Patch Antenna to Achieve Wireless Power Transfer for ISM Applications

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Abstract: This article proposes a miniaturized defective ground structure (DGS)-based microstrip patch that is suitable for usage in a variety of applications, including those in the medical, scientific, and industrial fields. The dimension of a conventional patch antenna at 2.7 GHz on an FR4 substrate consists of 11.01×5.19×0.1575 cm3, where the proposed antenna geometry is set as 5.89×3.06×0.1575 cm3, reducing the overall circuit size by 68.9%. This miniaturized antenna will be easily implementable in wearable devices for healthcare applications. The dimension and shape of the DGS are optimized in such a way as to improve the return loss from -19 dB to -24 dB at the desired frequency. Finally, the transmission coefficient for a conventional and suggested DGS-based antenna has been examined while these antennas are placed in a near-field region.

Keywords: DGS, Wireless Power Transmission, MPA, Antenna Design, Transmission Coefficient

1. INTRODUCTION

Wireless power transfer (WPT) has gained significant attraction to satisfy the growing need for wireless applications, including biomedical, health monitoring, electrical, and wearable sensor technology. In recent years, from watches to cell phones, laptops, watches even electric vehicles are using the wireless power system to be charged. The power is transmitted as an electromagnetic field through microwaves and radio waves. Depending on the range between the sender and the receiver, wireless power transmission is categorised as either near-field or far-field [1]. The near-field WPT is the non-radiative technique: inductive coupling, capacitive coupling, magnetic resonance, and strong magnetic resonant coupling

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[2]. The radiative power transmission method known as the far-field system involves using electromagnetic waves or beams to transmit power [2,3].

Researchers have recently proposed many techniques and built embedded systems for successful wireless power transfer. In [4], the authors presented a self-phasing technology for tissue implants using phase-conjugated operations to achieve continuous near-field wireless power transfer at 4 mm. In this case, the location is not vital to be known. In another work [5], the researchers introduce meta surfaces to achieve radiative power transfer at 2.4 GHz. Here a patch antenna is proposed as a transmitter, and a loop antenna placed under skin tissue is designed to receive the power. A high refractive is applied directly on top of the skin, which improves the WPT system. For biomedical applications, researchers have primarily focused on near-field wireless power transfer. An efficient compact antenna is one of the most important requirements for designing such a WPT system. A detailed radiative far-field system is proposed in [6], where the authors have presented two entirely successful approaches consisting of one rotating conventional patch antenna and another with a Butler matrix-fed antenna array. GRIN lens metamaterial is proposed in [7] to achieve a successful WPT system, where a double-sided s-shaped GRIN metamaterial unit cell is optimized and designed at 2.4 GHz and receives 86% more power. Researchers have focused more on near-field wireless power transfer for biomedical applications as it is non-radiative and will not be a health hazard. One of the essential requirements to build such systems is a compact size efficient antenna. There are several techniques proposed to minimise the antenna's size. In order to decrease the patch antenna's area by a factor of 1/16th times at 2.45 GHz, a metamaterial approach is presented in [8]. To achieve miniaturization, a detailed analysis of different metamaterials structure at three frequency bands is discussed in [9]. However, this popular technique has several disadvantages, such as being costly, tough to fabricate, and design complexity.

Defected ground structure (DGS) has garnered considerable attention lately for providing multiband, miniaturized, larger bandwidth and enhanced performance [10-14]. DGS makes intentional slots in the ground plane to achieve miniaturization and multiband response by controlling the surface current distribution through the slots. To implement this technique, one needs to etch different shapes and sizes of the slots in the bottom surface of a microwave circuit to achieve the targeted antenna. The size, shape, and placement of the DGS need to be optimized precisely and accurately to achieve the best optimum antenna performance. In this publication, we present a small, dipole-generating-slot (DGS) microstrip patch antenna for the application of near-field wireless power transfer.

In this paper, sec II describes the methodology of DGS with the design of DGS-based patch antenna. The result and analysis are presented in sec III by graphical and software designing of antenna. Finally, sec IV summarizes the DGS technique which wireless power transfer may successfully be achieved.

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Ground Structure with Defects

The ground structure with defects (DGS) is designed in such a way as to act as a filter that can reject unwanted frequency responses. It is etched in the ground plane and can be periodic and non-periodic. The performance of antennas can be strengthened by implementing the DGS technique in the bottom surface, such as mutual coupling reduction, multiband response, miniaturization, gain enhancement, reduced front-to-back ratio, improved bandwidth, etc. The size and geometry of the DGS can be changed and optimized to get the optimum required result for targeted applications. A DGS slot can be represented as a parallel inductor and capacitor, which works like a band stop or bandpass filter. In this work, we have proposed an H-shaped DGS-based microstrip patch antenna (MPA) to minimize the overall geometry for wireless power transfer applications in the metallic ground plane that allows for the miniaturization of antennas. The addition of DGS disrupts the current distribution of a microstrip antenna due to the defect geometry engraved into the ground plane. As stated earlier, parallel LC circuits are valuable for modelling DGS because they change the effective inductance and capacitance of the whole circuit. [15]. It interrupts the current distribution and impedance and thus can reduce the size at the desired frequency.

Design of Conventional and Dgs-Based Miniaturized Antenna:

A microstrip patch antenna is constructed on an FR4 substrate (dielectric constant= 4.4, loss tangent = 0.02) where the thickness of the substrate is 0.1575 cm. Each dimension of a conventional antenna presented in detail in Table 1. The antenna is constructed such that it can resonate at 2.7 GHz, the ISM band. In Fig. 2, the return loss is presented, below -10dB, indicating that this patch antenna works fine at 2.7 GHz. Fig. 3 represents the E and H plane of the designed conventional 2.7 GHz patch antenna.

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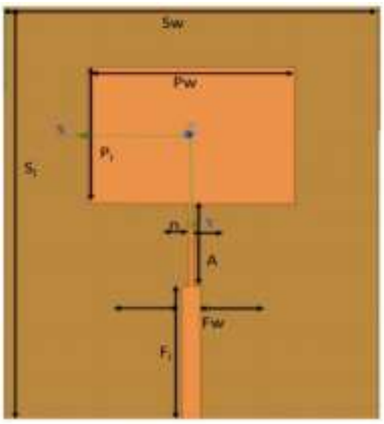

Fig. 1 Conventional 2.8 GHz microstrip patch antenna on an FR4 substrate

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Table 1: Dimension of Conventional 2.7 GHz Patch Antenna

Parameter	Dimension (cm)	Parameter	Dimension (cm)
Substrate length, S_l	11.01	Patch width, P_w	3.26
Substrate width, S_w	5.9	Inset feed width, n	0.072
Patch length, P_l	2.52	Inset feed length, A	1.57
Feedline width, F_w	0.306	Feedline length, F_l	2.446

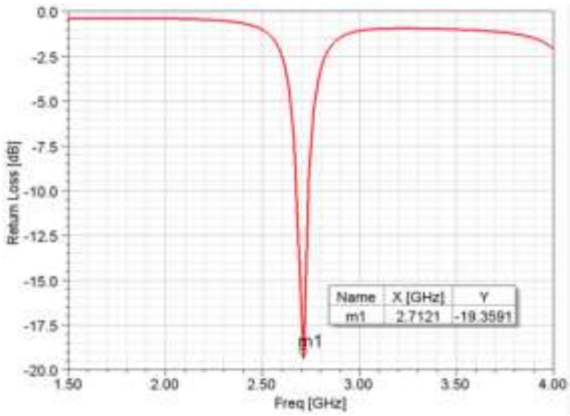

Fig. 2 Return loss of a conventional MPA

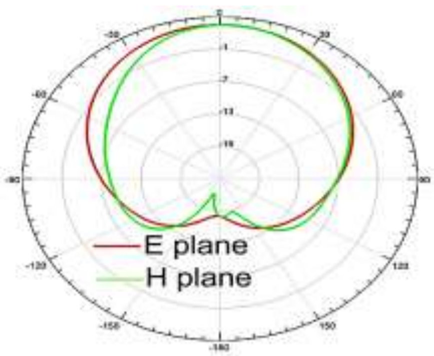

Fig. 3 E and H Plane at 2.7 GHz of the conventional patch antenna

A microstrip patch antenna first designed at an extensive frequency range to achieve the miniaturized behavior. In this instance, a 5.7 GHz patch antenna has been proposed that resonated at the WBAN band. The ground plane is then engraved with an H-shaped groove, which, as shown in Figure 4, modifies the current distribution in the circuit. Thus, the DGS port will modify the impedance acting as a band stop filter for other frequencies except for the desired frequency at 2.7 GHz. To achieve this response, the shape and size of the DGS slot are optimized multiple times. This H-shaped DGS-based microstrip patch antenna which resonates at 2.7 GHz, as shown in Fig. 5. The dimension of the DGS slot and this new patch antenna is described in Table 2. The size of the overall circuit is now 5.89×3.06×0.1575 cm3

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which was earlier 11.01×5.19×0.1575 cm3 for a traditional antenna. As a direct consequence of this, the total area of the DGS-based patch has been cut by 68.9%. Figure 6 illustrates the radiation pattern for the suggested antenna, which does not seem to suffer from a significant performance decrease in comparison to the standard patch antenna.

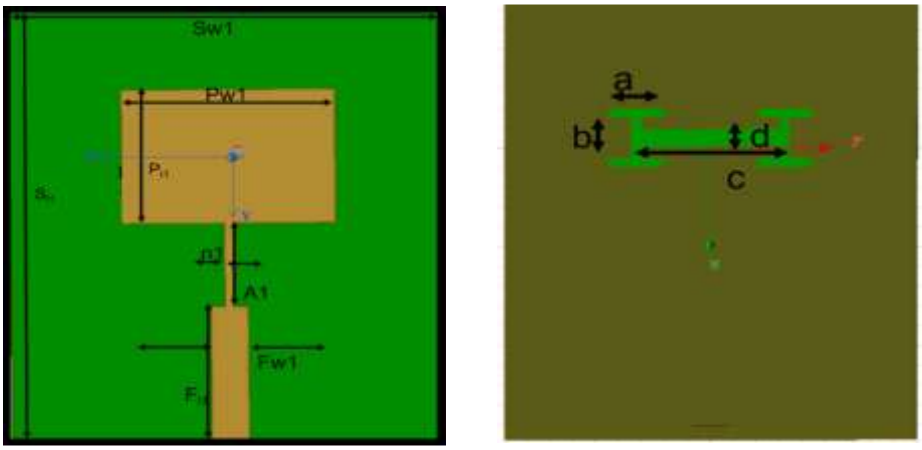

Fig. 4 DGS-based microstrip patch antenna top and ground plane

Table 2: Dimension of the DGS-based microstrip patch antenna

Parameter	Dimension (cm)	Parameter	Dimension (cm)
S_{l1}	5.89	P_{w1}	1.76
S_{w1}	3.6	n1	0.072
P_{l1}	2.52	A1	0.829
F_{w1}	0.0306	F_{l1}	1.317
a	0.45	c	1.2
b	0.4	d	0.2

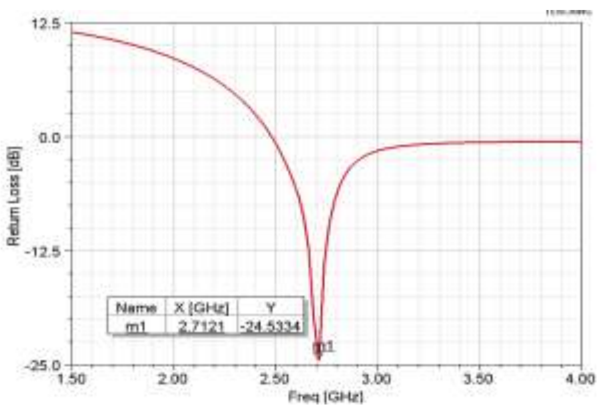

Fig. 5 Return loss for the DGS-based microstrip patch antenn

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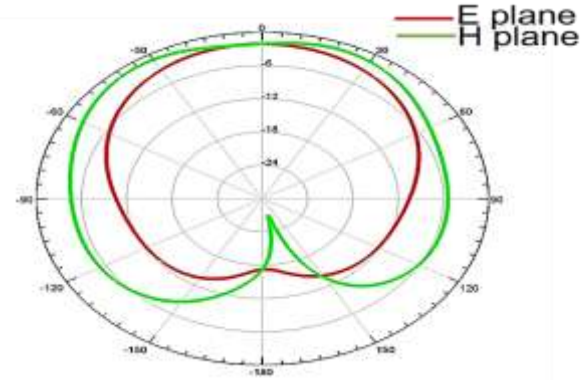

Fig. 6 E and H Plane of the Suggested DGS-based Patch Antenna at 2.7 GHz

To understand how the proposed antenna can be implemented in wireless power transfer, two conventional and two DGS-based patch antennas are placed in their near field region, as shown in Fig. 7. Fig. 8 shows the transmission coefficient for both the cases without and with DGS. It is mentionable how the transmission coefficient has increased with the presence of the microstrip patch antenna. Hence, from equation (1) [16], we can see how much the S21 value impacts to calculate the efficiency of the power transmission. With DGS, the S21 is -5 dB, whereas, without DGS, the value of S21 is around -51 dB. By implementing the DGS, we decreased the size and increased the S21 parameter from -51 dB to -5 dB.

$$\eta = |S_{21}|^2[(1 - |s_{11}|^2)(1 - |S_{22}|^2)]^{0.5} \quad (1)$$

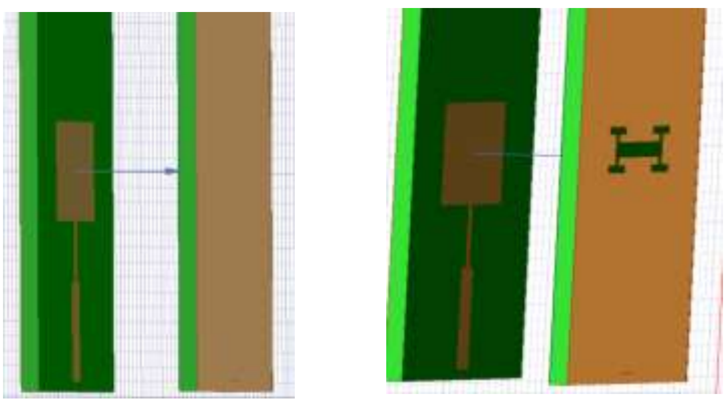

Fig. 7 Two Antennas without and with DGS placed in Near Field Region.

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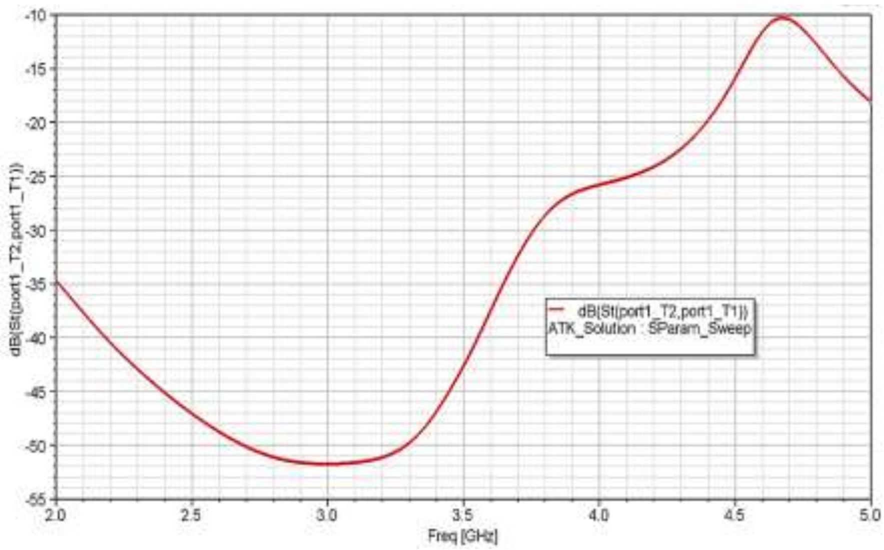

Fig. 7 S Parameters for Two Conventional Patch Antennas when Placed in Near-field Region.

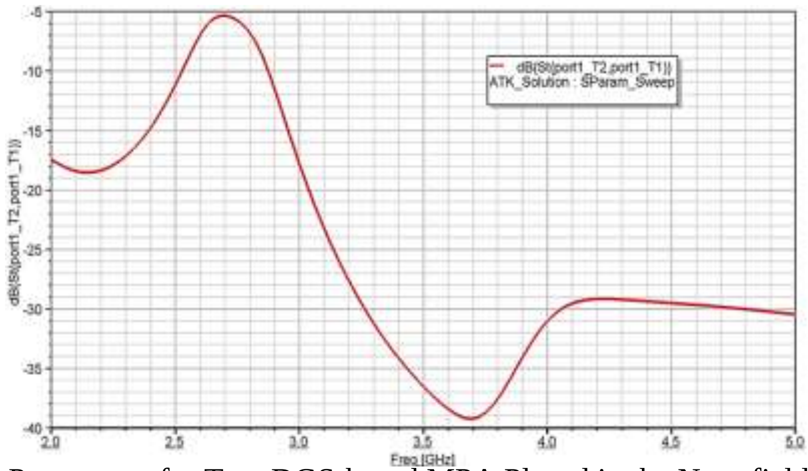

Fig. 8 S Parameters for Two DGS-based MPA Placed in the Near-field Region.

2. CONCLUSION

A DGS-based compact-sized microstrip patch antenna is proposed with a size reduction of 68.9% considering the resonance of the initial antenna at 5.2 GHz which finally shifted to 2.7 GHz, where the reflection coefficient is -24.53 dB. In order to attain miniaturisation, the ground plane has an H-shaped DGS etched onto it which also helps to increase the transmission coefficient in the near-field region from -51 dB to -5 dB. So it is comparable to this DGS-based patch antenna which is capable of carrying out near-field wireless power transmission.

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