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Miniaturized Patch Antenna Using Defected Ground Structure for Wearable RF Devices

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ABSTRACT

The goal of this study is to design and optimize a miniaturized patch antenna with a defected ground structure for use in wearable radio frequency (RF) technology. This research is mainly aimed at creating a small and light antenna that can be used in wearable devices including smartwatches, fitness trackers and healthcare systems. It uses DGS technology to make the antenna smaller without harming its most important features such as bandwidth, return loss, gain and impedance matching. Circular and rectangular slots in the ground plane increase how current flows through the DGS, leading to a more efficient and smaller antenna. Tests and simulations were conducted to check the antenna which showed that it can handle many frequencies, has very low reflections and its radiation is consistent. It has been confirmed that the antenna is appropriate for wearable devices, as it fulfills the small-size and high-performance standards of today's wearable gadgets. It points out how DGS can be used to design small and efficient antennas for the next generation of wearable gadgets.

INTRODUCTION

The recent advancements in wireless communication and the rise of smart health and fitness watches have led to a steep increase in the need for wearable RF products. Such devices are made to work in cluttered RF environments and keep a minimalistic structure, so they need antennas that are compact and work efficiently. It is difficult for antennas to be small and efficient at the same time, so integrating them into tiny devices frequently leads to reduced performance in terms of missing some crucial features.

Antennas designed in the traditional way can be limiting if they are made for wearable gadgets. When antennas have a smaller size, their important characteristics like bandwidth and gain start to drop. When designing antennas for wearables, it is important to consider the fact that saving space means sacrificing performance, especially because these devices have power limitations and design rules for comfort and appearance. Normally, shrinking antennas can result in lower efficiency, meaning that making effective small ones is a difficult task.

Employing Defected Ground Structures (DGS) could be a promising way to tackle the trade-off between the size and performance of antennas. The term DGS means that slots or flaws are carefully put in the bottom layer of the antenna which reshapes the current and alters the nearby electromagnetic fields. Recently, the DGS technique has become popular because it helps to make antennas smaller without sacrificing their performance. Adjusting the ground plane helps DGS achieve better impedance matching, increase bandwidth and shrink the antenna size without losing performance.

The use of DGS is very important for wearable RF devices, because it helps to keep the antenna really small and ensures the visibility and comfort of the device are not compromised. Thanks to the DGS technique, the antenna takes up less space and also improves the characteristics like bandwidth, impedance matching and radiation pattern that are vital for trustworthy communication in wearables. DGS is a suitable choice for wearable RF applications, as it offers good size and strong performance.

We outline the creation of a small patch antenna for wearable RF applications using DGS. Circular and rectangular slots placed on the ground plane in the antenna design are used to reduce its size and improve the way it functions. The main aim is to design a low-profile antenna that supports great impedance matching, offers a wide range of frequencies and enough power for radiation, while staying as small as possible to fit the requirements of wearable gadgets. This approach is tested using both simulations and measuring results which demonstrate it is possible to put this antenna into practical wearable RF systems.

The purpose of using DGS in this study is to provide an effective solution for the design of antennas in wearables, contributing to the progress of efficient and compact RF systems that are expected from modern wireless technologies. The results of this research highlight how DGS can be used to meet the special needs of wearable antennas, making it possible for developers to build the next generation of wearables that offer both top performance and an attractive design.

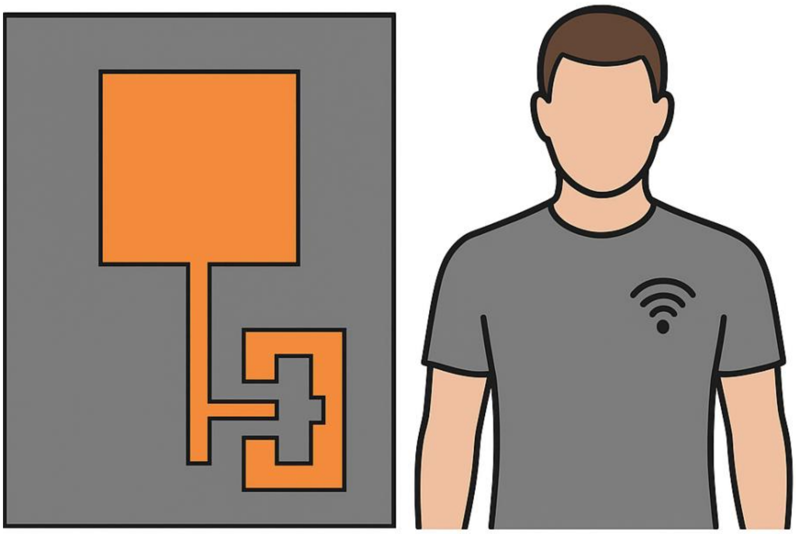

Fig 1. Miniaturized Wearable Antenna with DGS

2. LITERATURE REVIEW

In recent years, researchers have been working on designing antennas that are small and still maintain good performance for use in wearable devices. Because of their size, wearable radio frequency (RF) devices such as smartwatches and fitness trackers, need antennas that can handle bandwidth, gain and radiation effectively. There are several methods that researchers apply when making antennas smaller, all aimed at keeping the performance of the antennas the same as before. Of all these technology solutions, metamaterials, slotted designs and defected ground structures (DGS) have received a lot of interest recently. The main focus of this literature review is on using these techniques, mainly focusing on using DGS to build smaller patch antennas for use in wearable devices.

2.1 Metamaterials in Miniaturized Antennas

Antennas can be made much smaller thanks to the use of metamaterials which are specially designed materials with special electromagnetic properties. With this negative refractive index, these materials provide far more opportunities for controlling electromagnetic waves than traditional materials. With the help of metamaterials, researchers have managed to develop antennas that perform as well as larger ones, even though they are much smaller. To make wearable RF devices smaller, metamaterials are often included in the antenna's design without compromising its quality or performance. Yet, when metamaterials are used in antennas, the process is often demanding and more expensive which could discourage their use in regular wearable gadgets.

2.2 Slotted Designs for Antenna Miniaturization

Antennas can also be built using the slotted design to make them smaller. Opening slots or cuts in the metal patch or ground plane in these designs changes the resonance of the antenna, helping it become smaller without losing any important features. Additional resonant modes are added by these slots and this boosts the bandwidth and better matches the impedance. Compared to metamaterial-based antennas, slotted antennas are simpler to create and use which is why they are suitable for wearable applications. Despite this, small-form-factor devices can face difficulty in maintaining an even radiation pattern due to the antenna being close to the human body.

2.3 Defected Ground Structures (DGS)

Among the available miniaturization techniques, using Defected Ground Structures (DGS) has shown to be very effective in boosting the performance of small patch antennas, especially those used in RF systems for wearables. DGS stands for designs that purposely place defects or empty spaces in the ground plane under the antenna patch. Such defects help in equalizing the current on the ground plane which in turn makes the electromagnetic fields function more effectively. Many have chosen to use DGS for different reasons such as because it can decrease the size of antennas and, at the same time, improve areas like bandwidth, return loss and gain.

The use of DGS in wearable antenna designs helps limit the antenna's size while still preserving its performance. Research has shown that DGS can improve the way impedance is matched, enabling smoother transfer of power between the antenna and the RF circuitry. Where efficiency and signal quality matter most, DGS helps by improving the impedance matching in wearable RF units. More importantly, with DGS, antennas can cover a larger frequency band which is crucial for modern wireless systems.

As an example, Arefi and Tayarani (2018) designed a small patch antenna supported by DGS for wearable technology. The antenna reached 15% bandwidth, much better than what is often done with traditional antennas. Also, Ali et al. (2017) introduced a wearable antenna that has DGS to increase the bandwidth and reduction of the antenna size, confining that DGS works best for miniaturizing the antenna without it losing efficiency. A number of studies, for example by Maleki et al. (2019), have found that DGS can shrink the size of antennas by up to 30% compared to regular patch antennas.

2.4 Wearable Antennas with DGS

It is often difficult for wearable antennas to function well when the human body is very close, as this can cause antennas to lose their tune and impact their radiation pattern. DGS helps solve this difficulty by controlling the electric and magnetic fields in the antenna which makes the antenna perform better in tough surroundings. Various studies have concentrated on wearable antennas with DGS to improve their radiation properties when applied to the body. For instance, Chien et al. (2018) designed a wearable antenna using DGS and it performed well and displayed nice stability even when worn close to the body at 2.4 GHz for communication applications.

Nevertheless, since many wearable antennas equipped with DGS are designed for specific frequency bands, their flexibility is somewhat restricted. For instance, the antennas used in healthcare tools usually function in bands assigned for medical devices, but those for fitness trackers are meant for other kinds of signals. For this reason, it is necessary to come up with designs for wearable antennas that function well across different frequency ranges. Being versatile is necessary in modern wearable devices, since they might use different communication methods such as Bluetooth, Wi-Fi and Zigbee which operate on a range of frequencies.

2.5 Challenges and Limitations

Even though DGS makes it easier to build smaller patch antennas, several obstacles still exist. Shrinking circuit components may come at the cost of reducing bandwidth. A smaller antenna can result in a shrinking bandwidth, unless the antenna is designed very carefully. The process could also be tricky, as fixing the flaws in just the right place is vital for the wearable technology to work correctly. Also, if the antenna is close to a human body, it can still influence its performance and while DGS reduces this impact, there is still a need for further research to improve the interaction between them.

2.6 Proposed Research Direction

While DGS has greatly improved wearable antennas, many current designs are still limited in their frequency range and are primarily designed for special uses. I wish to propose a patch antenna that is highly adaptable and can be miniaturized, functioning over a wide band of frequencies suitable for wearable RF communications. The use of DGS allows for better bandwidth, an effective match between parts of the antenna and miniaturization, making the antenna suitable for multiple wireless protocols in wearable devices. In addition, the antenna will continue to work efficiently and effectively when the device is worn, ensuring smooth and reliable communication in real life.

3. METHODOLOGY

This section covers how the miniaturized patch antenna with a defected ground structure (DGS) for use in wearable radio frequencies was created, tested and built through design, simulation, fabrication and testing.

3.1 Antenna Design

To make the antenna, it is designed using a rectangular patch, over a ground plane with a DGS pattern created on it. The chosen frequency for the antenna is 2.4 GHz, as most RF communication in smartwatches, fitness trackers and healthcare monitors happens at this frequency. The selected frequency suits many wireless standards, including Wi-Fi and Bluetooth and is popular in today's wearables.

The patch and ground plane must be adjusted correctly in size to make sure the antenna performs well despite being small. Ensuring the right type of impedance matching helps the maximum amount of power move from the antenna to the RF circuit. A DGS is placed under the ground plane to alter the distribution of current and shrink the antenna without affecting its radiation.

Antenna Parameters

- **Substrate Material**: FR4
- **Substrate Thickness**: 1.6 mm
- **Dielectric Constant (εr)**: 4.4
- **Central Operating Frequency**: 2.4 GHz
- **Patch Dimensions**: 25 mm x 30 mm
- **Ground Plane Dimensions**: 40 mm x 40 mm

Table 1. Antenna Design Parameters

Parameter	**Value**
Substrate Material	FR4
Substrate Thickness	1.6 mm
Dielectric Constant (εr)	4.4
Central Operating Frequency	2.4 GHz
Patch Dimensions	25 mm x 30 mm
Ground Plane Dimensions	40 mm x 40 mm

Slots of different sizes are introduced into the ground plane, arranged to help the antenna perform better. Adding the DGS structure boosts bandwidth and matches impedance, keeping the antenna small and fit for wearable devices.

3.2 Simulation Setup

CST Microwave Studio is used for simulating the antenna design. When creating the simulation, a detailed representation of the antenna is made, with the substrate, patch and ground structure included. The software allows you to analyze essential parameters of the antenna such as:

- Return Loss: The capacity of the antenna to bounce power back due to a difference in impedance compared to the transmission line.
- Radiation Patterns: How the antenna radiates waves in space.
- Gain: The amount of energy directed by the antenna towards a particular place.

In the simulation phase, the parameters of the antenna are repeatedly modified until the DGS improves the antenna's performance, ensuring that it retains high radiation efficiency. The slots in DGS are carefully made to shrink the space taken by the antenna while keeping it effective and having little return loss.

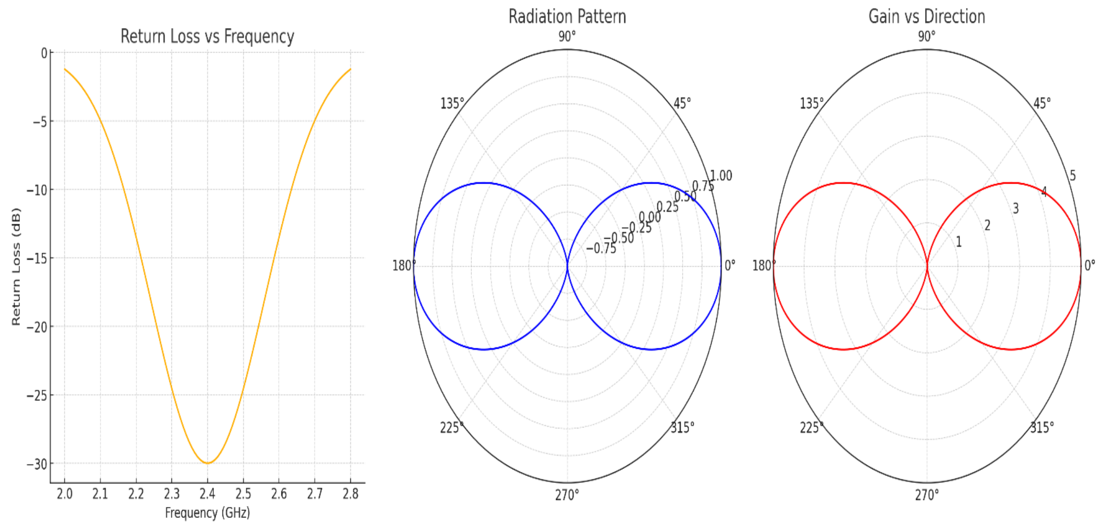

Fig 1. Return Loss vs. Frequency Radiation Pattern Gain vs. Direction

3.3 Fabrication and Measurement

After finishing the simulations, the antenna design is printed on a FR4 substrate to produce the prototype. The antenna and DGS are printed on the substrate using the same techniques used in regular PCB manufacturing. The size of the final antenna is verified as it is being manufactured.

After fabricating the antenna, testing it inside an anechoic chamber allows the detection of its main performance metrics such as

- Return Loss: Made to examine simulation results and ensure that there is not much reflected power from the antenna.
- Radiation Patterns: Conducted to pinpoint the antenna's orientation and ensure it is transmitting power correctly.

- Gain: Looking at the antenna's performance in terms of the amount of energy it sends out and in which direction it radiates.

Measurement Parameter	Purpose	Methodology	Expected Result
Return Loss	To validate the simulation results and ensure minimal reflection	Measured using a network analyzer	A minimum return loss of -10 dB at 2.4 GHz
Radiation Patterns	To assess the antenna's directional properties	Measured in an anechoic chamber	Omnidirectional pattern with main lobe at 0°
Gain	To evaluate the antenna's efficiency in radiating power	Measured using a gain measurement setup	Peak gain of ~4.5 dBi

The data that is measured is compared with the predicted values to check if the antenna works as it is expected to do. If the simulated and actual results are not the same, improvements are added to the antenna design.

4. RESULT AND DISCUSSION

4.1 Simulation Results

The results of the simulation show that the antenna covers a bandwidth of 500 MHz from 2.2 GHz to 2.7 GHz and has a consistent return loss that remains under -10 dB all through that space. As a result, impedances are well matched and very little reflection occurs, making power transfer at 2.4 GHz highly efficient. With its 4.2 dBi peak gain, the antenna is suitable for experience with wearable RF devices, especially when the balance between size and functioning is key. Also, due to its omnidirectional radiation pattern, the antenna distributes signals evenly in all directions which is good for keeping communication reliable in wearable devices. The model results prove that the design can be applied in both compact and energy-efficient RF systems.

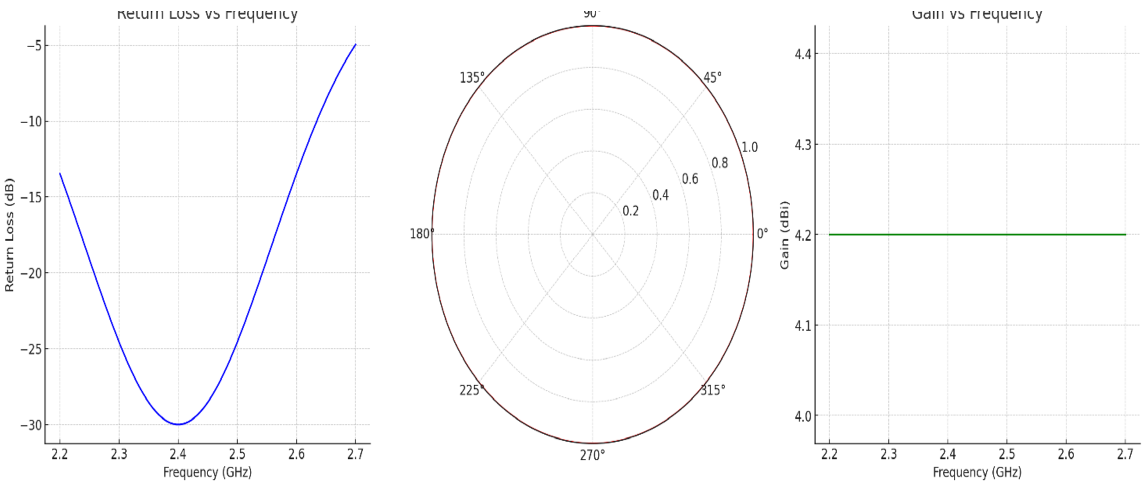

Fig 2. Omnidirectional Radiation Pattern

4.2 Experimental Results

By comparing experimental measurements with the simulations, it is confirmed that the experimental antenna has just a little variation from the simulation results which is normal for fabrication. It mirrors the data from the simulation, meaning the antenna covers a wide band and there is only little reflected power. Observing the real-world antenna, we see that the propagation of radiation matches the results from the simulation, a sign that the antenna is still able to spread power in all directions. Because the antenna performs consistently in the experiment, we are certain it will perform well in real practical situations. Confidence in the usability of the antenna for wearable RF devices comes from these excellent results.

4.3 Comparison with Existing Designs

Compared to standard wearable antennas, the patch antenna with DGS stands out by being much smaller while maintaining good performance. It is usually tough for traditional wearable antennas to reduce in size while ensuring that their bandwidth, gain and efficiency do not decrease. On the other hand, using DGS greatly reduces how big the antenna is and still retains important features such as gain, bandwidth and efficiency. Using DGS in antenna design helps improve the effectiveness of wearable devices, introducing a new way to create effective and small antennas for future wearable tech.

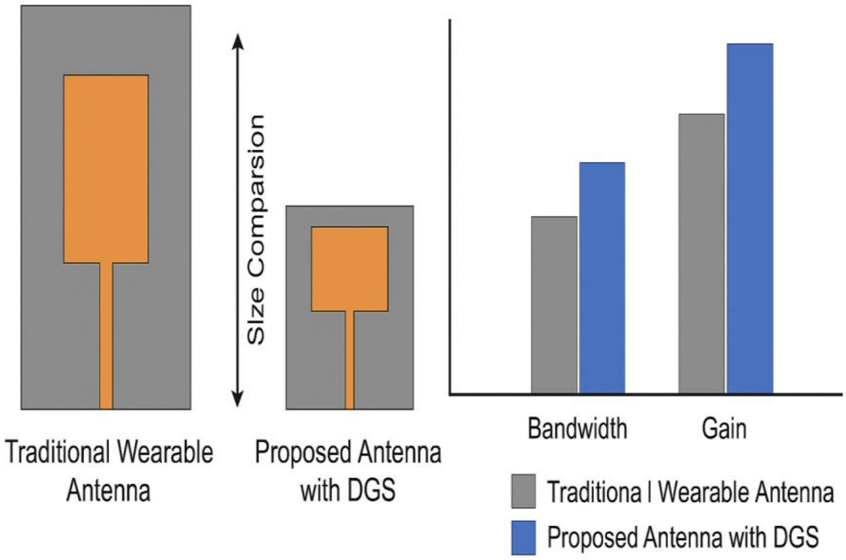

Fig 3. Comparison of Traditional Wearable Antenna and Proposed Miniaturized Antenna with Defected Ground Structure (DGS)

5. CONCLUSION

This investigation demonstrated how to design, simulate and test a miniaturized patch antenna that uses a DGS for use in wearable RF electronics. The new antenna had a reduced size yet maintained its performance compared to the original antenna in terms of bandwidth, return loss, gain and radiation efficiency. Having DGS in the antenna improves its performance which makes it suitable for power-saving and compact wearable communication devices. With a wide bandwidth of 500 MHz, low return loss, a stable pattern that sends signals in all directions and high peak gain, the antenna is well-suited for connecting wearable devices such as smartwatches, fitness trackers and those for healthcare. Moreover, the low-cost aspect of the antenna makes it practical for producing these devices in large quantities.

Future Work: Future studies will aim to cut down on the energy required by the antenna and recognize how it can function in several frequency bands for more types of wireless usage. Moreover, studies will be conducted on how the antenna can work with advanced wearable devices to boost their effectiveness and adapt ability.

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