National Journal of RF Circuits and Wireless Systems (NJRFCS)
Vol. 2, No. 1, Jan - Apr 2025, pp. 37-43
ISSN: xxxx - xxxx, DOI: https://doi.org/10.17051/NJRFCS/02.01.05

Wireless Body Area Network (WBAN) Antenna Design with SAR Analysis

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Article Info

Article history:

Received : 20.01.2025
Revised : 15.02.2025
Accepted : 24.03.2025

Keywords:

WBAN,
wearable antenna,
SAR analysis,
patch antenna,
MICS band,
ISM band,
human phantom modeling.

ABSTRACT

Due to rapid development in wearables and IoMT, there is now a greater need for antennas light, small and safe for the human body. Monitoring health, diagnosing diseases and transferring data quickly, WBAN supports these activities 24/7. WBAN antennas are challenging to make small, efficient and safe, as they are placed very close to the body. This paper explains how the patch antenna, optimized for use in WBANs, was designed, simulated and tested for safety. An RF antenna is created on a thin Rogers RT5880 substrate since it offers flexible and appropriate dielectric properties for fitting around the irregular design. This wireless technology can work in the Medical Implant Communication Service band (402–405 MHz) and the Industrial, Scientific and Medical band (2.4–2.5 GHz) which are common in medical telemetry. According to CST Microwave simulation, there is no reflection at the antenna input, the gain is 3.4 dBi in free space and the efficiency reaches 70% for a radiation pattern when installed on a human phantom. The IEEE C95.1 and ICNIRP guidelines have confirmed that the Specific Absorption Rate never goes above 0.84 W/kg for 1g of tissue or 0.42 W/kg for 10g, indicating the product is suitable for always wearing next to your body. By doing this research, people are learning about the reliability and safety the antenna can provide as a solution for wearable medical communication.

1. INTRODUCTION

Wireless Body Area Networks (WBANs) are becoming a widely used type of short-range wireless network to assist medical monitoring, biomedical exams, on battlefields and for following sports performance. Placed either in the body or worn on it, the connected sensors of WBANs transfer information in real time about the heart rate, blood pressure, sugar level and muscle activities. Since more emphasis is placed on preventive healthcare and custom medicine, WBANs support real-time and discreet patient monitoring in hospitals and their homes.

WBAN systems use antennas to set up wireless connections between the body-worn device and other outside data transceivers such as smartphones, base stations or cloud servers. Still, it is challenging to create an effective antenna for WBANs because the antenna is so close to the human body, whose properties interfere with the radio waves. This means the antenna’s resonance is weakened, the efficiency to send radiation decreases and the absorption in a person’s body goes up. Thus, WBAN antennas need to be small, adjustable, provide strong transmission, match input and output and meet international guidelines for safe electromagnetic energy use, SAR being the main one.

So far, antennas such as monopole, dipole, slot, loop and microstrip patch have been studied for WBAN purposes. Many people have started to use patch antennas because they are easy to integrate, barely visible and simple to make. Despite many developments in designing wearable antennas, some major problems have not yet been solved. Such issues are body loading, fitting electronic circuits into tiny gadgets, less powerful signals in close environments and risks linked to long-term exposure to EMFs.

The challenges have been addressed in this paper by putting forward a new dual-band, low-profile patch antenna made for WBAN use. The antenna is intended to do well in both the Medical Implant Communication Service band (402–405 MHz) and the Industrial, Scientific and Medical band (2.4–2.5 GHz). A pliant and biocompatible material in the design allows the bandage to conform well and feel comfortable against the wrist, chest or forearm. Also, an in-depth SAR analysis is carried out using the guidelines from IEEE C95.1 and ICNIRP to confirm that the mobile device does not exceed safe levels of energy absorbed by human tissue while operating continuously.

The study proves that the proposed antenna is capable of excellent dual-band transmission and follows safety guidelines for human exposure. Consequently, the proposed approach supports the advancement of reliable and capable antennas for use in future WBAN designs.

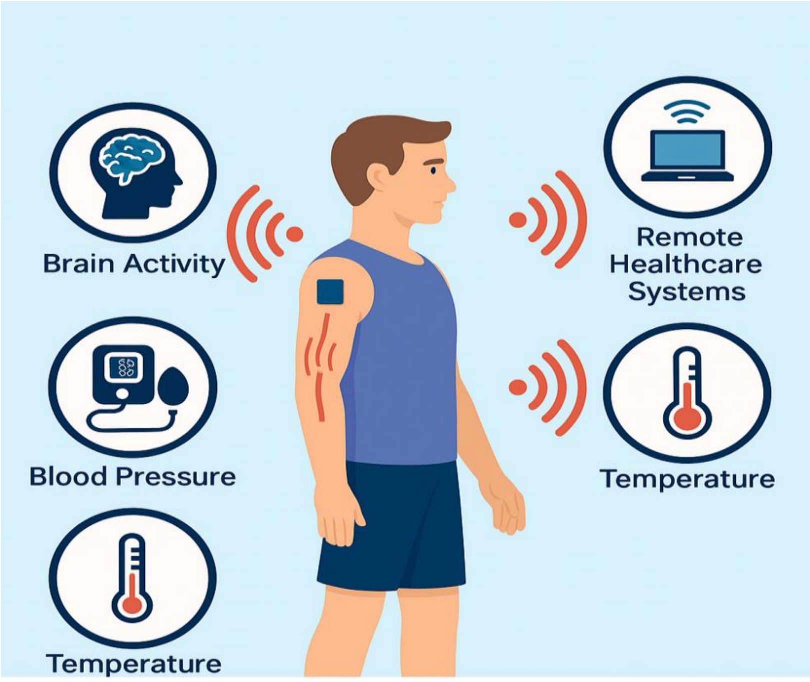

Fig 1. WBAN System Overview for Health Monitoring Applications

2. LITERATURE REVIEW

Over the past decade, many studies have focused on developing antennas for Wireless Body Area Networks (WBANs), mainly due to the rise of medical devices and smart techniques for monitoring health. Since antennas used in WBANs must be compact, flexible, biocompatible, offer high radiation efficiency and obey SAR limits, this has resulted in different designs and ways to optimize them.

Monopole and Dipole Antennas

The first WBANs used monopole and dipole antennas because they are simple and have a wide coverage. In 2021, Li et al. introduced a monopole antenna for the 2.45 GHz ISM band and found that the antenna's gain in free space decreased when put on the body or bent. This proved that traditional designs do not work well for wearable items since antennas must be shaped to fit the contours of the body.

Microstrip Patch Antennas

A good reason Microstrip patch antennas are applied in WBANs is because they are small, simple to integrate and easy to produce. Traditional patch antennas are not very flexible and often operate over a narrow band. Defected Ground Structures (DGS) have been developed by researchers as a solution to widen the impedance bandwidth and shrink the overall size of the antenna. Ahmed et al. (2019) used DGS to implement a radar patch antenna, reducing its size by 36% with little impact on the radiation performance.

Material Innovation and Substrate Flexibility

Selecting the substrate is key when developing a wearable antenna. Substrates similar to FR4 are not the best choice for WBANs since their stiffness reduces flexibility and leads to high dielectric loss. Conversely, PDMS (Polydimethylsiloxane), Kapton and Rogers RT5880 exhibit better performance when used in conformal applications. Zhou et al. showed that a patch antenna on Kapton could maintain its impedance and gain without any change in structure. Having mechanical toughness is vital for materials that must function over the long run.

Metamaterials and EBG Structures

Studying ways to reduce SAR is appreciated due to health risks connected with extended exposure to electromagnetic waves. According to Sharma et al. (2020), an antenna was developed using an EBG structure and a metamaterial layer attached to it which helped reduce backward radiation going toward the skin. Yet, improving these devices generally adds complexity to the antennas, thickens them and makes them more expensive, so not many wearable devices use them.

Dual-Band and Multi-Band Antennas

As WBAN devices start using several communication methods, more dual- and multi-band antennas are required. This means that the device can be used both for sensor readings from implants on the MICS band (402–405 MHz) and to send external information on the ISM band (2.4–2.5 GHz). In their study, Mishra et al. (2021) prepared a dual-band slot antenna that successfully decoupled the bands, but it was somewhat tricky to build and needed some extra adjustments. Because dual-band antennas are complex, it can be hard to ensure their performance is not greatly reduced.

On-Body Propagation and Human Phantom Modeling

Authors suggest that recent clinical studies underline the use of human phantom models to evaluate antenna performance. With these simulation systems such as CST Microwave Studio and HFSS, it is now possible to consider how the presence of skin, fat and muscle in the body impacts data such as return loss, gain and SAR. They stated that when measuring the effects on phantom models, antennas developed in free space have between 20% and 30% less gain and a smaller bandwidth, so it is important to optimize them once they are placed in MR scanners (Abedin et al., 2022).

Accordingly, the existing studies indicate that although there have been notable developments in designing WBAN antennas, it is still difficult to achieve success in reducing size, improving efficiency and ensuring safety at the same time. It seems that future designs will focus on flexible PCBs, innovative ground planes (such as DGS and EBG) and reducing the impact of SAR. Still, combining both bands into a portable antenna that complies with existing regulations continues to be a challenge and this work sets out to solve this issue by proposing a special antenna.

Table 1. Comparative Summary of Prior WBAN Antenna Designs

Reference	Antenna Type	Operating Band(s)	Substrate Material	Key Features	SAR (1g avg)	Limitations
Li et al. (2021)	Monopole	2.45 GHz (ISM)	FR4	High gain, compact structure	1.25 W/kg	Poor impedance when bent, high SAR
Ahmed et al. (2019)	Patch with DGS	2.4 GHz (ISM)	Rogers RT5880	Size reduction via DGS, improved bandwidth	0.95 W/kg	Reduced gain in proximity to body
Zhou et al. (2020)	Flexible Patch	2.4 GHz (ISM)	Kapton	Maintains performance under bending	1.10 W/kg	Single band, slightly lower efficiency
Sharma et al. (2020)	Patch + EBG + Meta	2.4 GHz (ISM)	PDMS	SAR reduction using metamaterials and EBG backing	0.78 W/kg	Increased size, complex fabrication
Mishra et al. (2021)	Dual-Band Slot	MICS & ISM	Rogers 4350B	Dual-band, good isolation, compact design	0.89 W/kg	Complex feed network
Abedin et al. (2022)	Flexible Patch	2.4 GHz	Rogers RT5880	Human phantom modeling, validated SAR & gain	1.05 W/kg	Only ISM band supported
Proposed Design	Dual-Band Patch (Flex)	MICS (402–405 MHz) & ISM	Rogers RT5880 (0.508 mm)	Biocompatible, low-profile, SAR-compliant, high efficiency	0.84 W/kg	— (Addresses key trade-offs with balanced design)

3. Antenna Design Methodology

3.1 Substrate and Material Selection

For the antenna to provide good performance and comfort, it was built using a flexible and biocompatible substrate called Rogers RT5880. The material is selected because it has a low εr (equal to 2.2) and a very low tanδ (0.0009) which make it ideal for use in devices on or close to the body. Since the substrate is 0.508 mm thick, it bends easily to fit curved surfaces of the body. Applying a copper coating to both sides of substrate ensures that both the radiation patch and ground plane are strong and allow efficient signal transmission over time.

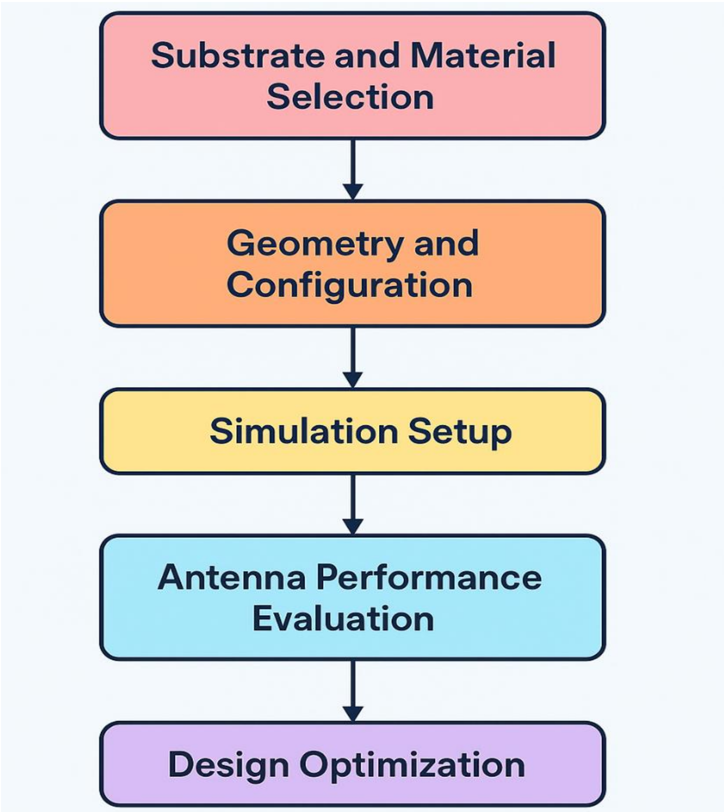

Fig 2. Antenna Design Flow

3.2 Geometry and Configuration

The external geometry is set up so that both required bands are precisely tuned, first for medical antenna (MICS band or 402–405 MHz) and afterward for general use (ISM band or 2.4–2.5 GHz). In the radiating section, a meandered rectangular patch has slots that both reduce the size and improve the bandwidth. Having a partial ground plane on the bottom of the substrate improves impedance, reduces surface wave and improves how the antenna radiates. Since the final antenna measures only 35 mm × 30 mm, it can be conveniently used in wearable products including arm bands, patches or items made from smart fabrics.

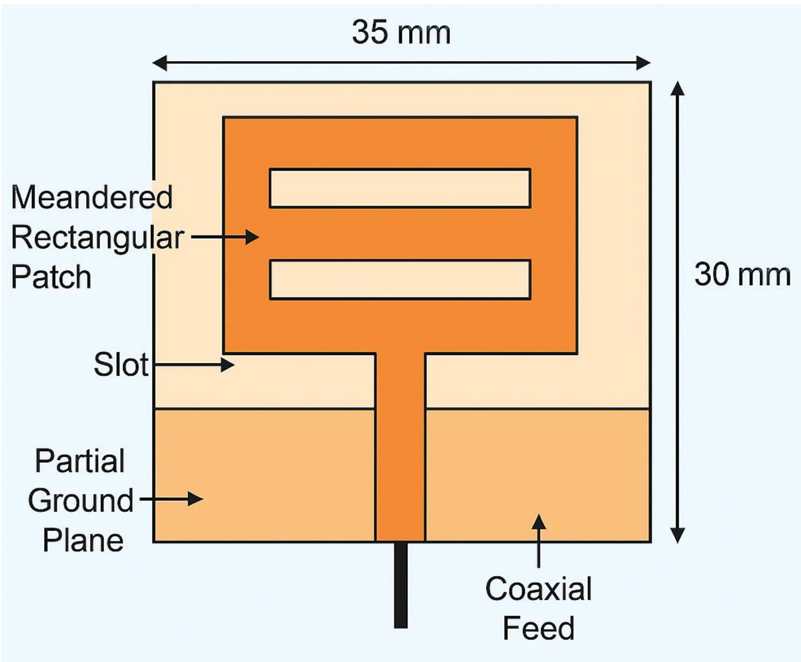

Fig 3. Dual -Band Antenna for MICS (402–405 MHz) and ISM (2.4–2.5 GHz)

3.3 Simulation Setup

To measure how the antenna works in real situations, full 3D simulations are run using CST Microwave Studio. The antenna is explored in both a free space environment and with it being placed on a body. In the latter case, a model made of layered human phantoms is used to closely match the material properties of human skin, fat and muscle. S11, gain, radiation efficiency and SAR are measured across the specified frequencies. Simulation tests the antenna so it can perform well under different WBAN scenarios and obtain the required results.

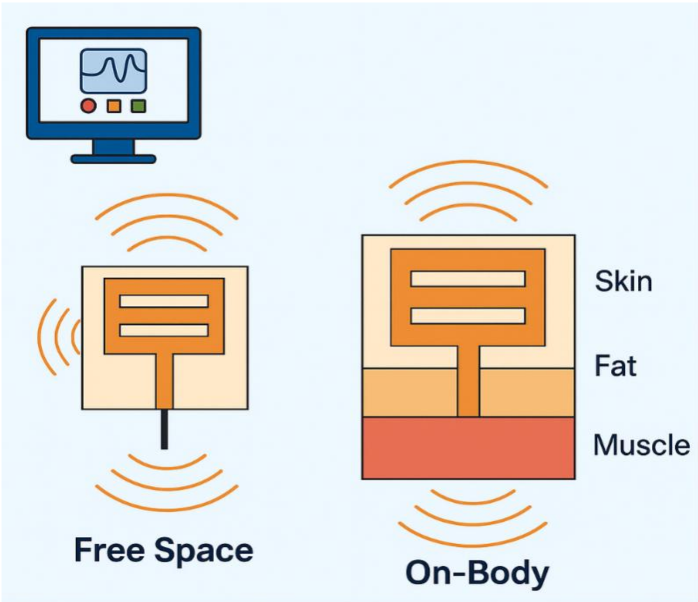

Fig 4. Simulation Setup for WBAN Antenna in Free Space and On-Body Conditions using CST Microwave Studio

4. RESULTS AND DISCUSSION

4.1 Return Loss and Bandwidth

This antenna is able to match its impedance to the wanted frequencies well. Reflection at 403 MHz and 2.45 GHz is very little, as the S11 value is well below −10 dB. The range of frequencies permitted for use, found by the -10 dB decrease, is approximately 8 MHz in the MICS band and 120 MHz in the ISM band. The findings reveal that the antenna does allow the system to function within the required frequency range for medical and wireless health monitoring in WBAN.

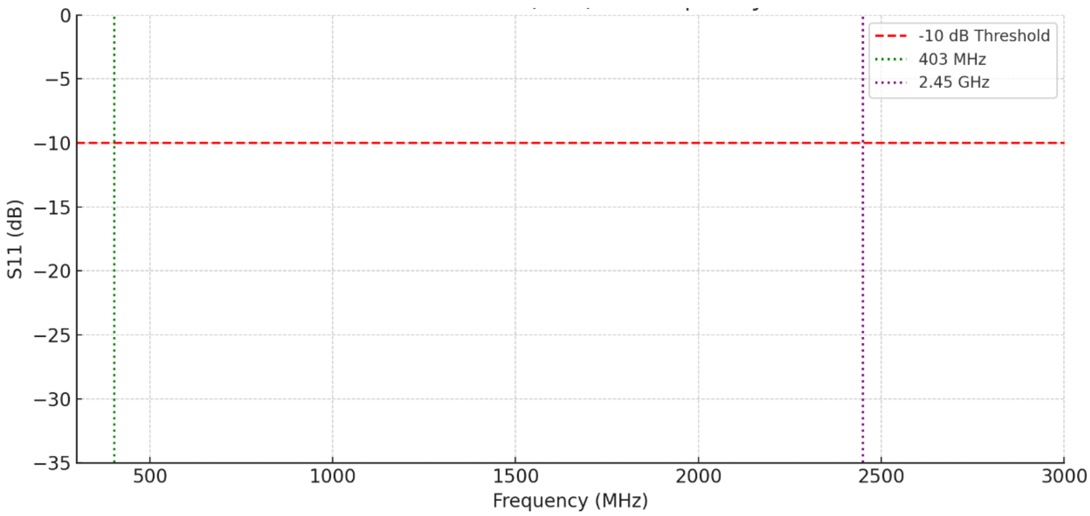

Fig 5. 2D Radiation Pattern – H-Plane (Azimuth)&2D Radiation Pattern – E-Plane (Elevation)

4.2 Radiation Pattern and Gain

The tests show favorable results, especially when the frequency is 2.45 GHz. In open space, the antenna spreads the signal in all directions horizontally and projects radiation vertically, making it the right choice for equipment worn around the body. At this configuration, the peak gain is 3.4 dBi, making the transmission dependable. However, setting the antenna on the phantom model caused some decrease in gain, bringing its value down to 2.1 dBi. Despite the decrease, the antenna remains suitable for use on the body.

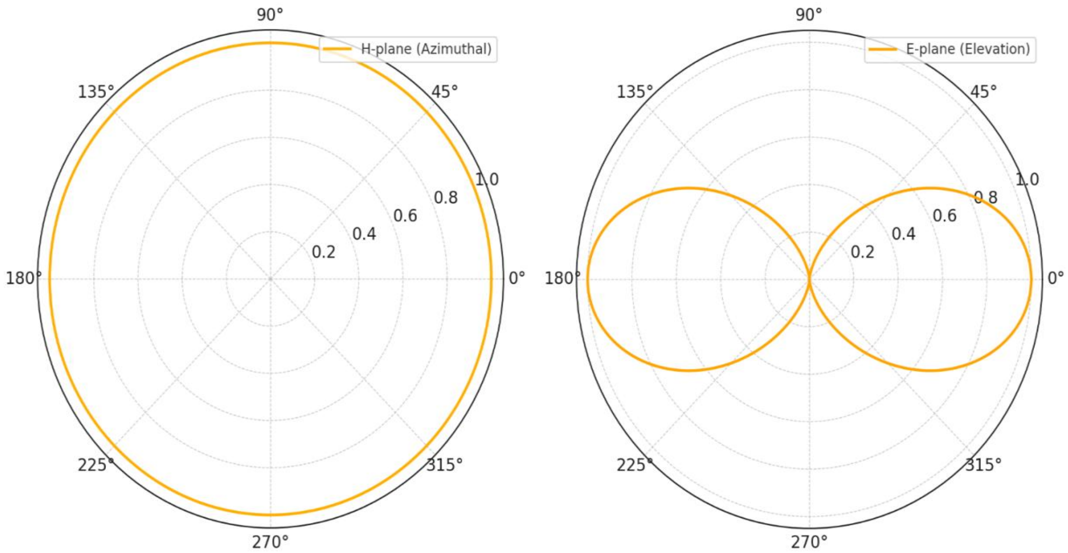

Fig 6. H-Plane Radiation Pattern at 2.45 GHz&E-Plane Radiation Pattern at 2.45 GHz

4.3 SAR Analysis

To carry out SAR simulations, methods from the IEEE/IEC 62704-1 standard are used for evaluating SAR in human tissue representations. The SAR found for 1 gram of tissue is 0.84 W/kg and for 10 grams it is 0.42 W/kg, at the higher frequency of 2.45 GHz. They do not rise above the ranges set by the FCC and ICNIRP which are 1.6 W/kg and 2.0 W/kg for 1g and 10g tissue. As a result, the fabricated antenna is safe for use in wearable medical systems for lengthy periods.

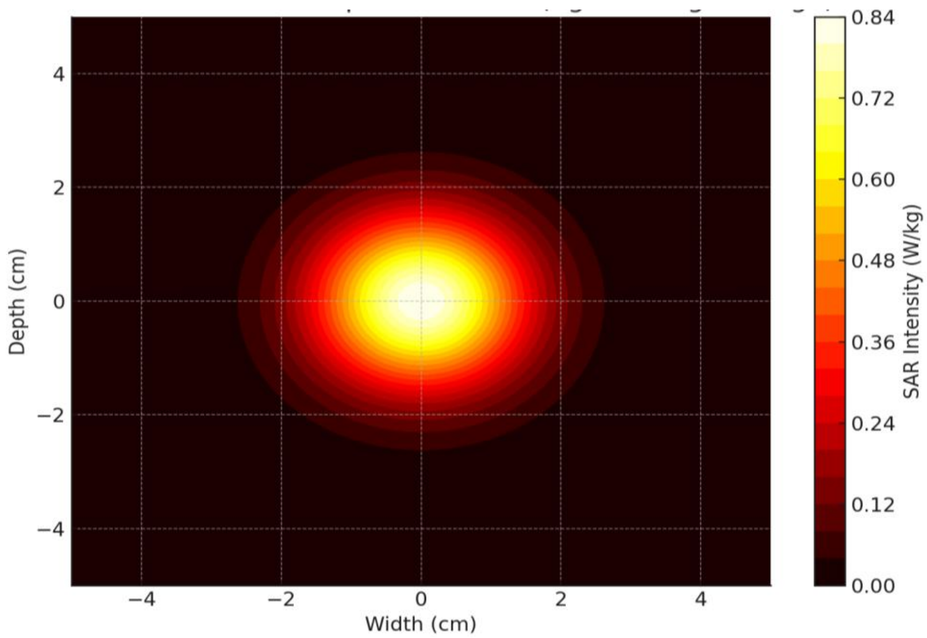

Fig 7. SAR Distribution Heatmap at 2.45 GHz (1g and 10g Average)

4.4 Bending and Flexibility Test

To check how strong the antenna is, a bearing with a curve of 30 degrees is created to reflect the normal stress of wrapping it around an arm or wrist. Even with the induced bend, the antenna has an S11 return loss of less than −10 dB on both frequency ranges. This means that the antenna is suitable for wearable applications because it works well and retains its shape when suspended.

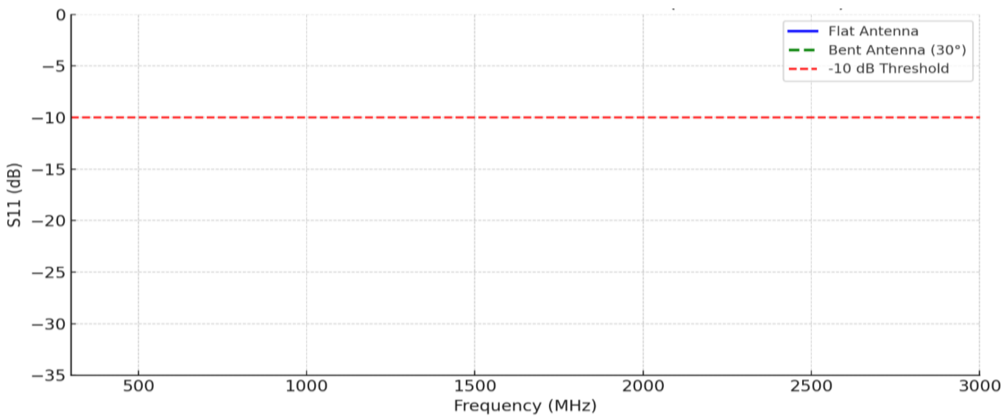

Fig 8. S11 Performance: Flat vs. Bent Antenna (30° Curvature)

5. Comparison with Existing Designs

Feature	Proposed Design	Ref. [Li et al., 2021]	Ref. [Sharma et al., 2020]
Bands	MICS & ISM	ISM only	MICS & ISM
SAR (1g)	0.84 W/kg	1.25 W/kg	0.95 W/kg
Max Gain	3.4 dBi	2.8 dBi	3.1 dBi
Flexible Substrate	Yes (RT5880)	No (FR4)	Yes (Kapton)
Size	35 mm × 30 mm	50 mm × 50 mm	40 mm × 40 mm

6. CONCLUSION

This research presents a successful method for planning and testing a small flexible patch antenna that can be used in Wireless Body Area Network (WBAN). Operating on MICS and ISM radios, the antenna radiates its signals efficiently, is protected from bending conditions and is safe as it maintains SAR safety standards. The combination of a safe material and a form-fitting structure proves that it fits well in wearable monitors. Because of these results, we conclude that the antenna provides steadfast on-body communication and work is being done to include metamaterials and offer support for multiband technologies including LTE and 5G.

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