Compact Wearable Antenna with Band-Notch Features for Medical Applications

Dr. Somesh Kumar, Yadvendra Prasad Dwivedi, Subhramit Bera
Electrical and Electronics Engineering
Atal Bihari Vajpayee-Indian Institute of Information Technology and Management (ABV-IIITM), Gwalior
Gwalior, India
Email: somesh@iiitm.ac.in, yadvendra@iiitm.ac.in, bee_2023034@iiitm.ac.in

***Abstract*—In this paper, we propose a compact wearable antenna featuring five selective notch bands, utilizing Rogers 5880 as the dielectric substrate with a thickness of 0.508 mm. This slim design enables the antenna to be slightly flexible, making it suitable for wearable applications. The antenna is fed by a microstrip line with an input impedance of 50 Ω. By incorporating various notch structures on the radiating patch, along the feed line, and on the underside of the substrate, five notch bands are achieved. Additional notch bands can be generated by employing an enhanced structure, which introduces two notch bands and integrates side-mounted metal strips to direct current to the notch structures on the substrate's underside. This approach provides efficient space utilization with minimal interference among the notch structures. The proposed antenna has an overall size of 30 × 25 × 0.508 mm^3 and spans the full UWB range from 2.56 to 12.7 GHz, excluding notched bands at 2.58–3.21 GHz, 4.05–4.29 GHz, 5.00–5.64 GHz, 8.60–9.05 GHz, and 9.20–10.32 GHz. Integrated into a physician's chest badge, this antenna could reduce the need for manual card swiping, providing a hygienic solution by lowering the potential for bacterial contamination. Thus, this antenna holds valuable potential in advancing medical technology applications.**

***Index Terms*—Band-notched, medical application, slot, ultra-wideband (UWB) antenna, wireless body-area network (WBAN).**

I. Introduction

With the continuous advancements in science and technology, there is a growing demand for wireless communication systems. Ultra-wideband (UWB) antennas have gained significant interest due to their broad frequency range [1]. However, UWB antennas are highly susceptible to interference, leading to the development of notch antennas to address this challenge. Techniques for creating notch bands in UWB antennas can generally be classified into two approaches. One method involves adding parasitic branches [2]–[4] to introduce current at specific frequencies, which localizes the electromagnetic waves and generates notch bands. Another technique is to etch slots into the radiating patch, ground, or feed line [5]–[8], which causes current to concentrate around the slots, suppressing signal reception at those frequencies.

With the rapid expansion of 5G, additional frequency bands are now allocated for a growing number of applications, thereby increasing interference with UWB antennas. However, most current UWB antennas incorporate only one [9], [10], two [11], [12], or three notch bands [13], [14], limiting their ability to manage multiple interference sources. To enhance communication stability, more notch bands are required to filter out additional unwanted signals. Moreover, compact design is a key feature for microstrip patch antennas. In limited space, additional notch bands demand complex structures, which may result in mutual interference among the notch elements. Thus, a careful design of notch structures is essential to minimize interference across different frequency bands.

Microstrip patch antennas are popular for wearable applications due to their portability and compact form factor [15]. In medical settings, for example, doctors commonly use access cards, which require frequent hand swiping and may contribute to bacterial contamination. Developing a hands-free access method could help address this issue, advancing healthcare technology and improving patient care.

To tackle these challenges, this paper presents a five-band notched UWB antenna designed for integration into a doctor's chest badge. This design features five separate notch bands to mitigate various interference sources. A novel notch structure is introduced to create dual notch bands while minimizing interference within a limited space. Additionally, a unique side-mounted metal structure on the substrate is proposed to facilitate efficient notch band generation. The antenna's low profile makes it flexible and suitable for wearable applications. This paper details the antenna design process, compares per-

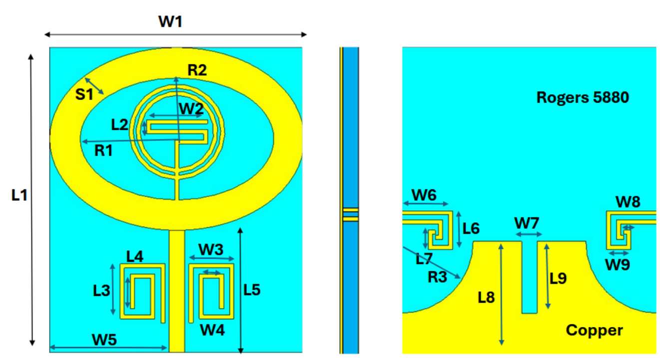

Fig. 1. Geometry of Proposed Antenna

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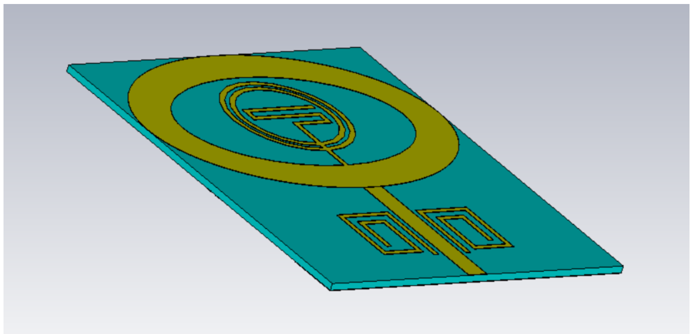

Fig. 2. 3D View of Proposed Antenna

TABLE I
OPTIMIZED DESIGN PARAMETERS OF THE ANTENNA

W1=25mm	W2=6mm	W3=4.4mm	W4=1.6mm	W5=11.725mm	W6=0.7mm
S1=3mm	W7=1.5mm	W8=0.7mm	W9=2.4mm	L1=30mm	L2=12mm
L3=5.4mm	L4=3.4mm	L5=12mm	L6=3.8mm	L7=1.9mm	L8=11mm
L9=7mm	R1=9.5mm	R2=6mm	R3=7mm		

formance metrics at various stages, and analyzes the formation of each notch band through simulated and experimental results. Finally, we demonstrate the application of this antenna in a wearable format on a doctor's badge and assess its practicality in medical and other badge-based scenarios.

II. Antenna Structure Design

The configuration of the UWB antenna with embedded band-notch structures is illustrated in Fig. 1. The design utilizes a Rogers Duroid 5880 substrate with a relative permittivity of $\varepsilon_r = 2.2$, a loss tangent of $\tan\delta = 0.0009$, and a thickness of 0.508 mm. A rectangular radiating patch with a slot is located on the top surface of the substrate, while the bottom layer features a rectangular ground plane etched with a small rectangular slot and two sector-shaped slots to improve impedance matching.

An S-shaped strip is embedded within the rectangular slot on the radiating patch, connected to the end of the feed line, which has a characteristic impedance of 50 Ω, creating the first notch band. Enclosing the S-shaped strip within two circular rings enhances the notch band characteristics. Additionally, two identical spiral strips are positioned symmetrically along the feed line, forming two additional notch bands.

On the underside of the substrate, two long spiral strips and two short spiral strips, placed on either side, generate the remaining two notch bands. The radiating patch and the long and short spiral strips are linked by two parallel strips on the sides of the substrate, which help achieve optimal isolation among the notch bands. The optimized antenna parameters are listed in Table **??**.

III. Results and Discussion

A. Antenna Five Band-Notched Characteristics Mechanism Analysis

At 2.67 GHz, the current primarily accumulates along the notch strip within the radiating patch. At 4.13 GHz, the current is largely concentrated on the spiral strips located on both sides of the feed line. For the 5.31 GHz notch, the current distribution is focused on the long spiral strips at the bottom of the substrate.

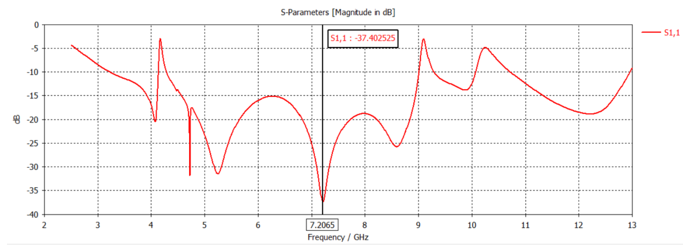

Fig. 3. S11

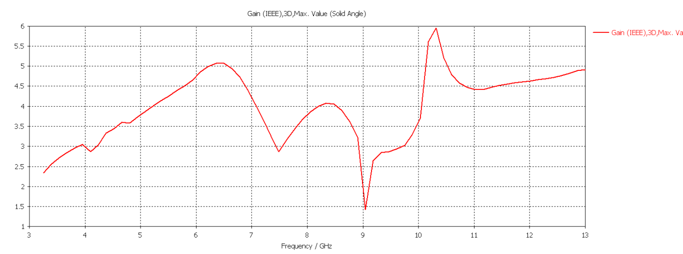

Fig. 4. S11

In the higher frequency range, at 8.95 GHz, the current again centers around the spiral strips on either side of the feed line, while at 9.38 GHz, it is predominantly concentrated on the short spiral strips on the substrate's underside. The spiral strips beside the feed line create two notch bands, thus optimizing substrate space and enabling further miniaturization of the antenna.

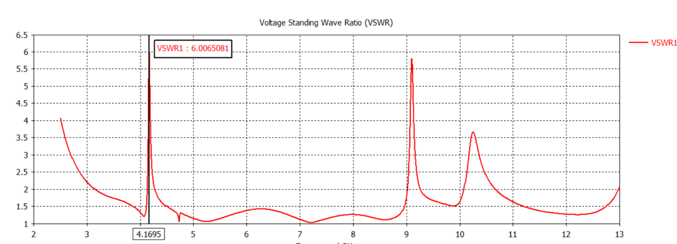

Fig. 5. S11

Furthermore, by integrating a structure along the substrate's side that connects the radiating patch with the bottom spiral strips, we introduce a novel method to channel current directly into the notch structures at the bottom, facilitating the formation of additional notch bands. This approach not only enhances the antenna's band-notch capabilities but also supports its compact design.

B. Manufacture and Test

The antenna was fabricated and connected to an SMA connector to facilitate subsequent testing of its radiation performance. The design was simulated using CST Studio Suite 2020 to provide a clear demonstration of its performance. The reflection coefficient ($|S_{11}|$) of the antenna, indicating the five notch bands, is shown in Fig. **??**. The bandwidth for $S_{11} < -10$ dB spans from 2.56 to 12.7 GHz, with notch bands centered at 2.58–3.21 GHz, 4.05–4.29 GHz, 5.00–5.64 GHz, 8.60–9.05 GHz, and 9.20–10.32 GHz. These notch bands effectively filter interference from sources such as 4G (2.8 GHz), 5G (4 GHz), WLAN (5.15–5.35 GHz), and X-band satellite communications.

Each notch band achieves a peak $|S_{11}|$ greater than -5 dB, underscoring the antenna's strong interference suppression capabilities. Although some variations are observed, the measured S_{11} values align closely with the simulated results. These minor differences can be attributed to manufacturing imperfections and testing environment inconsistencies, including cable and instrument limitations and environmental factors that prevent ideal testing conditions. The first notch band, in particular, shows some discrepancy from simulation due to its complex structure, which makes it more sensitive to machining accuracy.

The antenna is constructed using Rogers 5880 substrate material with a thickness of just 0.508 mm, which allows for a degree of flexibility [16]. To assess this flexibility, we simulated the radiation characteristics under bending conditions by attaching the antenna to cylinders of various radii: 20, 40, 60, and 80 mm.

IV. Application and Analysis of Antenna

A. Antenna Application Scenario

When attached to a doctor's chest badge, the antenna may experience bending when the badge is lifted, removed, or opened to replace a card. Due to the flexibility demonstrated

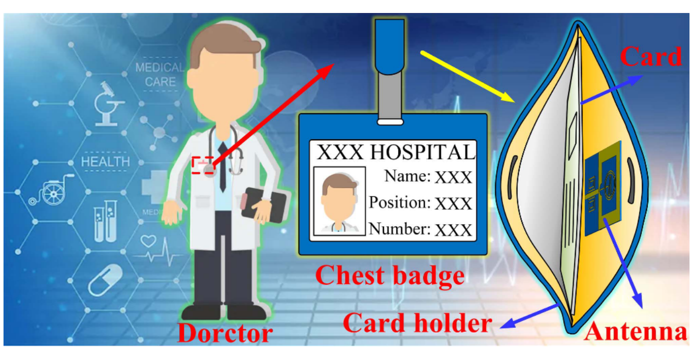

Fig. 6. Application of the proposed antenna.

in previous tests, the proposed antenna is well-suited for this application. The antenna is placed on the internal back side of the badge holder, which preserves the badge's appearance while also protecting the antenna from external friction and reducing the risk of damage.

B. Specific Absorption Rate

To ensure the proposed antenna on the chest badge does not pose radiation risks to the human body, the Specific Absorption Rate (SAR) must be evaluated. The simulated human model comprises four tissue layers: skin, fat, muscle, and bone, with respective thicknesses of 1 mm, 5 mm, 20 mm, and 14 mm, totaling a 40 mm tissue depth. Additionally, a 10 mm air gap is maintained between the antenna and the model to represent the typical separation provided by clothing.

According to safety guidelines, SAR values should remain below 1.6 W/kg per 1 g of tissue as per U.S. standards, and below 2 W/kg per 10 g of tissue according to European standards [17]. We simulated the SAR values at 6, 8, and 11 GHz frequencies.

TABLE II
Comparative Analysis of the Proposed Antenna with Other Antennas

Ref.	**Antenna size (mm^2)**	**Bandwidth (GHz)**	**Number of notch bands**	**Application of the antenna**	**Multiple notch bands in a structure**
[2]	23×28	3.4–12.3	2	Yes	No
[12]	38×40	2.56–12.25	2	No	No
[13]	30×31.2	3.1–12	2	No	No
[14]	35×45	1.2–13	3	No	No
This work	25×30	2.56–12.7	5	Yes	Yes

C. Comparison

The performance parameters of the proposed antenna are compared with those in the existing literature. As shown in Table II, the proposed antenna includes more notch bands than those reported in previous studies. The effective utilization of notch structures is improved by generating multiple notch bands from a single structure. Due to these advantages, the antenna is suitable for use in medical applications.

V. Conclusion

This paper presents a miniaturized wearable antenna with five band-notched characteristics tailored for medical applications. Through a unique design that enables a single structure to generate two notch bands and the addition of metal along the substrate's sides, the antenna achieves a compact size while incorporating multiple notch bands. This design enhances the stability of the communication system by effectively filtering out additional interference signals. The antenna demonstrates a peak gain of 4.76 dBi and an omnidirectional radiation pattern, making it well-suited for wearable applications. By addressing the issue of hand contamination associated with manual card swiping in hospitals, this antenna contributes to advancements in medical technology.

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