# A Microwave Sensing Antenna System for Hemarthrosis Detection and Monitoring

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*Abstract*—**Hemarthrosis, a genetic bleeding disorder, primarily affects the joints and can lead to significant musculoskeletal damage if not detected early. This project proposes a microwave sensing system designed for the early detection and monitoring of hemarthrosis. The system employs two flexible antennas, positioned around a joint, to monitor changes in the transmission coefficient and reflection coefficient of electromagnetic signals influenced by internal bleeding. The study also explores the use of circular polarization to enhance detection sensitivity. The antennas operate in the ISM medical band at 2.4 GHz. A cylindrical phantom model is used to simulate the human joint, which includes layers of skin, muscle, fat, blood, ligament, and bone.**

*Index Terms*—**Hemarthrosis, Wearable Antenna, Transmission Coefficient, Biomedical Sensing, Circular Polarization.**

## I. Introduction

Hemarthrosis is a genetic bleeding disorder in which people experience internal bleeding in their joints. Around 80–90% of bleeding happens within the musculoskeletal system, particularly in the major synovial joints such as the elbows, knees, and shoulder [1]. As a result of this internal bleeding, the flexor muscle in the joint becomes deformed, leading to an abnormal posture. If hemophilia goes undetected or untreated, it can result in bleeding in the head and brain, potentially causing seizures and paralysis. Failure to diagnose and treat this bleeding in time can be fatal [2]. It's considered a rare genetic disease, affecting approximately one in every 5,000 individuals worldwide [2].

Early detection of hemophilia is crucial. However, the current detection process often relies on patients experiencing severe pain or joint deformities before they receive proper medical evaluation and facilities [2]. They also depend on the family history of hemophilia. Typically, this involves a combination of medical imaging and physical examinations for diagnosis. This highlights a need for improved methods to identify hemophilia at earlier stages, ultimately improving patient outcomes and streamlining the treatment process for patients and healthcare providers.

The wearable antenna is a crucial component in biomedical sensing applications, responsible for transmitting and receiving signals through the human body. Given that the human body is a lossy platform for electromagnetic waves, the design must meet several characteristics. These characteristics include having unidirectional radiation [3], sufficient gain [3], compact size [3], and a low specific absorption rate (SAR) [3]. The earlier reported work has paid more attention to depend on using the reflection coefficient shift than the transmission coefficient for similar disease detection, including effusion. However, these shifts are often too small for reliable detection. For example, [4] reported a frequency shift of approximately 0.0035 GHz with a tumor radius increase of 2 mm.

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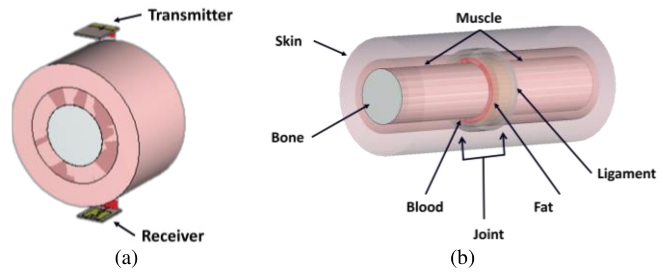



Fig. 1. The proposed measurement setups: (a) system setup, and (b) phantom model of the joint.

This project presents a wearable microwave sensing system for early detection of hemophilia. The use of the transmission coefficient alongside the commonly used reflection coefficient detection methods is adopted in this work using both linearly and circularly polarized antennas. The report is organized as follows: Section II covers the system setup, Section III shows the validation designs for two types of antennas: linear and circular polarized, and discusses the simulation results, Section IV presents a new proposed circularly polarized antenna design, and future work, and Section V discusses MTT-S award impact.

## II. System and measurement setups

The system comprises two antennas positioned around a joint, one functioning as a transmitter and the other as a receiver, as shown in Fig. 1(a). A phantom model is used to mimic the human joint, which consists of layers of skin, muscle, fat, blood, ligament, and bone, as shown in Fig. 1(b). The bleeding is represented as a cylindrical layer surrounding the bone. Increasing the cylinder radius indicates more blood accommodation within the joint. This bleeding leads to a change in the effective dielectric properties of the joint's layer structure. Consequently, the received signal will be altered accordingly. In this work, we considered both linear-linear and circular-circular polarized antennas to study the effect of the received signal on the sensitivity of blood detection.

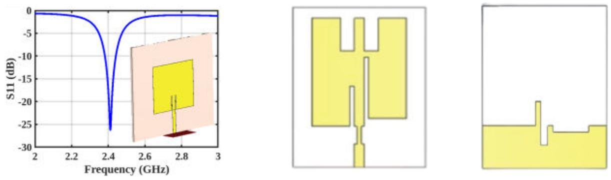
## III. Antenna Designs and simulation results

### A. Antenna Designs

The work validated linear and circular polarized antennas within the proposed setup to investigate polarization effects on detection. A linearly polarized microstrip patch antenna, shown in Fig. 2(a), is designed to resonate at 2.4 GHz in free space. Similarly, a circularly polarized antenna, as proposed in [5] and illustrated in Fig. 2(b), (c), also resonates at the same frequency of 2.4 GHz.

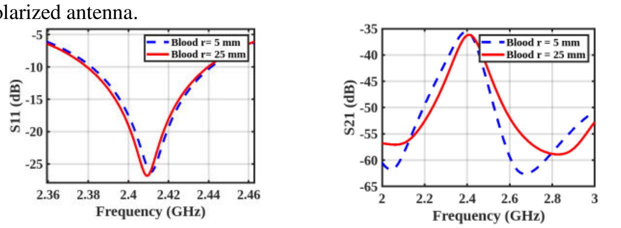
### B. Simulation Results for Linearly Polarized Antenna

Using two of these antennas to construct a linear-linear blood detection system, the reflection and transmission coefficients are calculated at different blood radii, as shown in



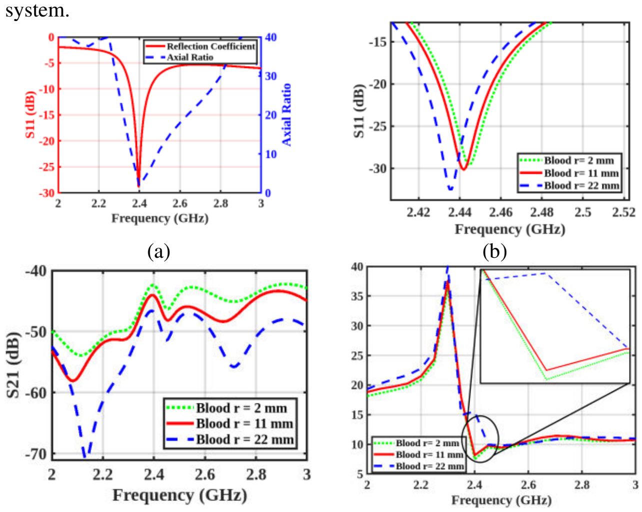

(a) (b) (c)

Fig. 2. The designs used in the validation: (a) linear microstrip antenna and reflection coefficient, (b) front view, and (c) back view of the circularly polarized antenna.




(a) (b)

Fig. 3. Effect of varying the blood radius on the (a) reflection coefficient, and (b) transmission coefficient of the linear-linear antenna detection system.




(a) (b)

(c) (d)

Fig. 4. Performance of the circular-circular blood detection antenna system: (a) reflection coefficient and axial ratio of the single antenna in free-space, (b) reflection coefficient at various blood radii, (c) transmission coefficient at various blood radii, and (d) axial ratio at various blood radii.

Fig. 3. As the blood radius increases, the resonance location of the reflection coefficient shifts towards lower frequencies due to the increase of the effective dielectric permittivity of the medium surrounding the transmitter antenna. A shift of 0.005 GHz is noticed as the radius varies from 5 mm to 25 mm. On the other hand, the transmission coefficient shown in Fig. 3(b) does not clarify a clear variation due to the radius change.

### C. *Simulation Results for Circularly Polarized Antenna*

The simulation results of the circularly polarized antenna are presented in Fig. 4. The antenna operates at 2.4 GHz with overlapping impedance and axial ratio bandwidth. The performance of the circular-circular antenna system is presented in Fig. 4(b)-(d). The reflection coefficient is influenced by an increase in blood radius in a manner like that observed in the linear-linear system. Conversely, the transmission coefficient of the transmitter, plotted against frequency with the blood radius varying from 2 mm to 22 mm, shows a noticeable downward vertical shift as the blood radius increases. This shift enhances the detection process. The presented results show the advantage to use circularly-polarized antennas in the proposed

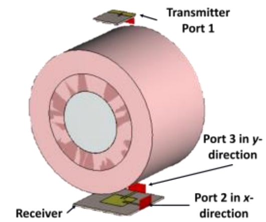
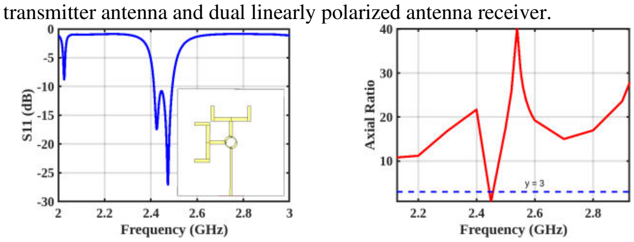



Fig. 5. Proposed blood detection system based on using circularly polarized transmitter antenna and dual linearly polarized antenna receiver.




(a) (b)

Fig. 6. The proposed circularly polarized antenna results: (a) reflection coefficient, and (b) axial ratio.

setup, which provides multiple measurable indicators for early stage hemarthrosis detection. Additionally, the axial ratio gradually shifts towards linear polarization with increasing blood, as shown in Fig. 4(d). This suggests that the model can be customized for patients with a family history of hemarthrosis to evaluate the transition from circular to linear polarization as the blood radius increases. This offers a new method for early detection where two dual-polarized antennas can be used to capture the *x*- and *y*- field components, as shown in Fig. 5. The measured power ratio can be used to determine the axial ratio.

## IV. Implemented Circular Design and Future Work

After realizing the strength of the circular polarization detection method, we suggested a new design of a circularly polarized antenna, as shown in Fig. 6(a). It consists of two arrays of 3-element grid antennas oriented orthogonal to each other. The feeding of the array is achieved via a 90° branch line coupler to guarantee the required 90° phase shift between both arrays. The antenna is optimized in free space at 2.451 GHz for both reflection coefficient and axial ratio levels, as shown in Fig. 6. The next steps involve testing two cases in the setup using the new design: a circular-circular polarized antenna and a circular-dual polarized antenna. Following this, the design will be fabricated for testing on physical models and samples.

## V. The IEEE MTT-S Award Impact

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