An Implantable Wideband Antenna for Monitoring Bone Fracture Healing

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Abstract.

This manuscript presents the creation of a compact wideband implantable antenna with circular polarization that is designed to be used continuously for Bone fracture healing monitoring. Antenna proposed here employs a dual-port looping architecture, offering wideband ranging from 0.15 MHz to4.11 GHz, with resonances at 400 MHz and 3.6 GHz for WBAN and telemetry applications. The dual-port looping architecture in the proposed antenna plays a crucial role in achieving circular polarization (CP) and wideband coverage. This design incorporates two feeding ports arranged in a loop configuration, enabling efficient electromagnetic wave propagation with orthogonal field components. The antenna is made of Rogers Duroid 6010 substrate, for improvement in size reduction to 5 × 5 × 0.324 mm^3. The antenna has return losses of -30 dB at 400 MHz and 3.6 GHz and the gain is -1.46 dB and 0.06 dB at the lower and upper resonant frequencies, respectively. Safety is guaranteed by SAR analysis, where the antenna is positioned in knee bone of a human leg. The circular polarization of the antenna ensures stable transmission of signals in changing environments. Obtained results show good matching impedance and adequate efficiency in radiation, making it suitable for bone healing monitoring in biomedical applications.

Keywords. Implantable antenna, wideband, circularly polarized, bone fracture healing monitoring.

1. INTRODUCTION

Bone fractures healing is considered as a major challenge in healthcare, especially when it comes to tracking the healing process. Conventional techniques like X-rays, CT scans, and MRI yield interval images, which demand regular hospital visits and lack continuous monitoring. This shortcoming has given rise to new wireless implantable antennas that can monitor the bone healing process in real-time, yielding useful information without requiring frequent imaging or clinical visits. The systems offer a long-term, non-invasive way of monitoring the healing of bones. Experiments have proven that implantable antennas can be used to monitor the bone fractures healing, and their applications cover monitoring recovery in bones like the radius, tibia, and phalanges. A detailed study on the various types of implantable antennas with materials used, characteristics, applications and The impact of body fluids and tissues on antenna performance is another critical consideration [1-2]. Researchers have analysed the effects of different body environments on antenna impedance matching and radiation efficiency A compact triple band MIMO antenna with multiple port [3] is presented for wireless endoscopy and is capable of data telemetry with wireless power transfer. A small, circular, dual-band implantable antenna that can be placed on the skin and scalp operating 1.43 GHz and 2.44 GHz frequency bands is discussed in [4]. Several studies have explored innovative antenna designs to optimize their performance in the human body environment. Various antenna geometries, such as meandered conformal designs, loop antennas [5], and fractal-inspired structures [6,7], have been investigated to achieve wideband operation, miniaturization, and improved radiation efficiency. Multi-band and MIMO (Multiple Input Multiple Output) configurations have also been proposed to enhance data transmission reliability, particularly for deep tissue and capsule endoscopy applications [8]. Industrial IoMT application ultra-miniaturized antenna An implantable antenna show multiband operation and improve communication and integration for medical applications [9]. Recent research has proven the successful monitoring of operated fractures, like upper arm fractures, using implantable antennas at operating frequencies such as 402 MHz, highlighting the viability of these technologies in clinical settings [10].

This article introduces the development of a small, Circularly Polarized (CP) antenna for implant in the knee aimed at tracking bone healing of fractures on a continuous basis. The antenna provides wideband performance between 0.15 MHz and 4.11 GHz with resonating frequencies of 400 MHz and 3.6 GHz that are well suited for WBANs and for medical telemetry purposes.

TABLE 1: PROPOSED ANTENNA COMPARISION WITH PREVIOUS WORK

Ref	frequency	Dimensions (mm^3)	BW(MHz)	Gain (dB)	SAR(W/kg)for 1g
[1]	915MHz	7×7×0.254	200	-16.8	8.17
[4]	2.48GHz	25×25×1.28	N/A	N/A	7.3
[7]	2.45GHz	32×30	150	1.68	0.57
[9]	3.23GHz	18×19×0.8	112.23	3.77	1.6
Proposed Antenna	400MHz and 3.6GHz	5×5×0.324	3970 (1500 to 4110)	-1.46, 0.06	8.7 1865.33

2. Proposed Antenna Design

The suggested implantable antenna features a dual-port with looping architecture designed to achieve circular polarization and wideband performance. The antenna design started with basic patch and slots were inserted to operate at 400 MHz and 3.6 GHz. With an overall size of 5×5×0.324 mm^3, the antenna has slotted radiating patch and ground with 0.035mm thickness. Symmetrical slots with dual port improve bandwidth. The looping structure enhances impedance matching and axial ratio performance, crucial for stable wireless body area network (WBAN) communication. Antenna simulations are carried out using HFSS 2024 with Rogers RO6010 (ε = 10.2) substrate which benefits from low attenuation and miniaturization for efficient signal transmission compared to low dielectric materials like polyethylene and PEEK. Simulation set up was done with sweep frequency range from 0.1GHz to 4GHz covering MICS, ISM and sub 6GHz bands and open radiation boundary at 400MHz.

These structural aspects contribute to the antenna's reliable operation in medical telemetry and bone fracture healing monitoring applications. Figure 2.1. shows different views of wideband implant antenna structure. The antenna adopts a dual-port feeding structure, located at both sides to connect the rectangular strips that constitute a closed-loop configuration. The structure enables accurate control over excitation, allowing for the creation of circular polarization and bandwidth improvement. The feeding mechanism adopted ensures reliable wireless communication irrespective of the orientation of the antenna and thus makes it extremely compatible with implantable devices that have to work within dynamic environments.

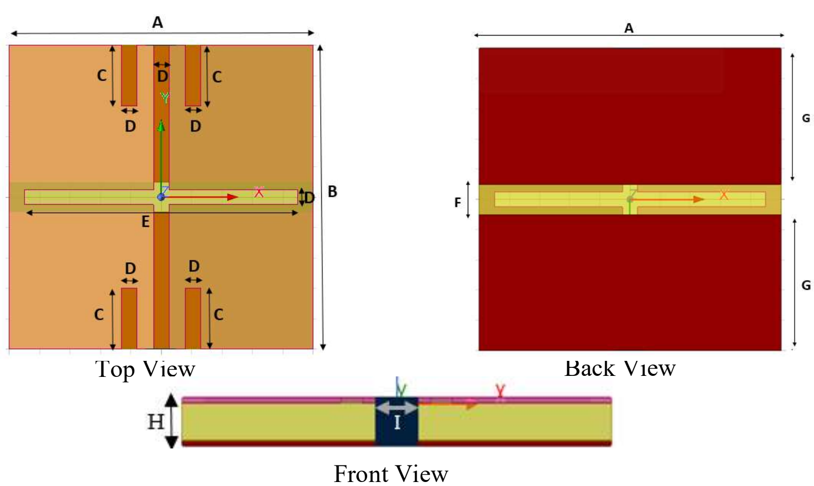


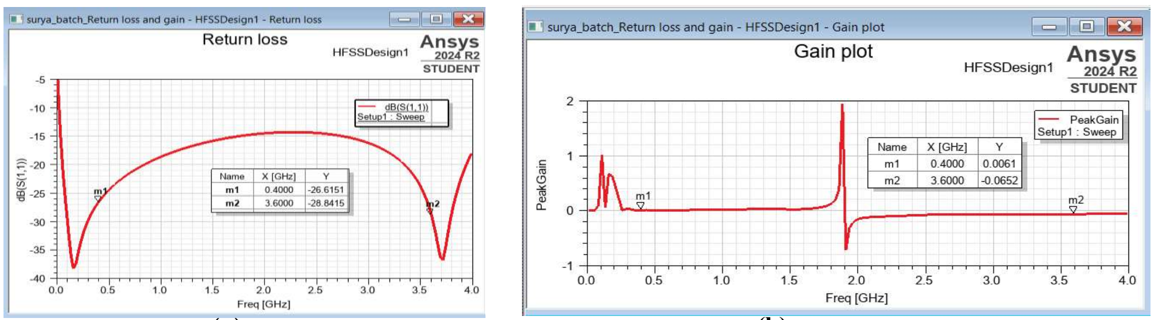
Figure 2.1. Different views of wideband implant antenna structure.

TABLE 2: PROPOSED ANTENNA DIEMENSIONS

Antenna Parameters	A	B	C	D	E	F	G	H	I
Dimensions (mm)	5	5	1	0.25	4.5	0.5	2.25	0.324	0.5

3. Results And Performance

Return loss plays a vital role in determining how successfully an antenna transmits signals without undesired reflections. A smaller return loss means that more power is successfully radiated, resulting in better overall performance. In this design, the antenna has return losses of -30.00 dB at 400 MHz and at 3.6 GHz respectively and wide bandwidth ranging from 0.15GHz to 4.11GHz. These findings enable effective power transfer, making the antenna suitable for medical applications such as bone fracture repair monitoring. The following Figure 3.1(a &b) depicts the return loss performance and gain at various frequencies. Antenna gain is a highly critical parameter that describes the radiating efficiency in one direction. It is an indicator of how well the antenna transforms power fed into it to energy radiated. For the suggested design, the gain is -1.46 dB at 400 MHz and 0.06 dB at 3.6 GHz. Even though negative gain at the lower frequency is expected due to the compact size and implantable nature of the antenna, it is still sufficient to maintain signal transmission uniformly within the human body. Reduced return loss indicates better radiation with good efficiency thereby making it appropriate for stable and reliable wireless communication in biomedical



(a) (b)

Figure 3.1. Antenna performance (a) Return loss (b) Gain

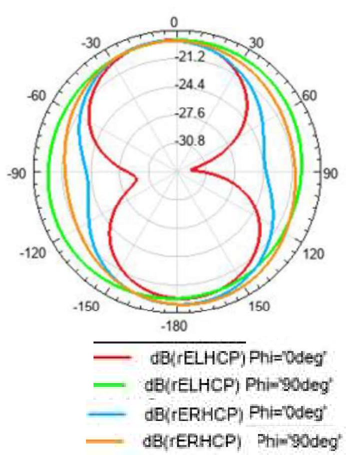
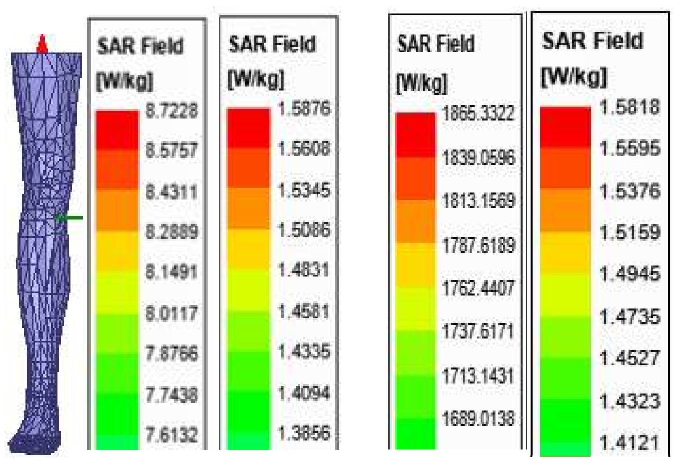


Figure 3.2. Patterns (3.6 GHz)



1W 184mW 1W 0.848mW

400MH **3.6GHz**

Figure 3.3. SAR results

applications. Circular polarization having energy radiated in all directions, thus the movement of legs does not affect the performance. The very minor positive gain at 3.6 GHz ensures higher frequency radiation efficiency. Figure 3.2 shows patterns of the proposed dual-port antenna at 3.6 GHz. The Specific Absorption Rate(SAR) indicates rate of radiated signal by body.In this simulation, the antenna was placed within a layered tissue model, considering the varying dielectric properties and thicknesses of the tissue layers. SAR values were calculated for two frequencies, 400 MHz and 3.6 GHz, based on the watts provided in the study. According to the regulatory standards set by the FCC is 1.6 W/kg for 1 gram of body tissue. The calculated SAR values for both frequencies were assessed against the safety limits to ensure compliance with human safety standards. Figure 3.3 gives the SAR analysis on simulation.

4. Conclusion

A wideband two port CP implantable antenna was designed for healing permanent bone fracture monitoring. The CP wide band operates between 0.15 MHz to 4.11 GHz with resonance at 400 MHz and 3.6 GHz with antenna cross section of 5 mm × 5 mm on Roger 6010 substrate with height 0.324mm. The antenna demonstrates S_{11} of -30.00 dB at 400 MHz and 3.6 GHz having gains of -1.46 dB at 400 MHz & 0.06 dB at 3.6 GHz. Safety certification is ensured by SAR analysis, in which the antenna is placed inside the leg phantom. The antenna's circular polarization ensures reliable signal transmission under dynamic conditions. The antenna can position on edges and sides of the bone. It will not affect that much in signal transmission due to wide bandwidth. Future work will include fabrication and experimental validation of antenna and focus on performance improvement in gain.

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