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Miniaturized T Slotted Circular Patch Antenna for Implantable Applications

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ABSTRACT: A small circular polarized antenna for biomedical applications is designed, which can be used for signal transmission of implantable medical devices or capsule endoscopes. By introducing the ring characteristic loading array, the high electromagnetic energy is aggregated, and the electrical size of the antenna is reduced effectively while the impedance bandwidth is widened. Under the same bandwidth requirement, the antenna size is reduced by about 18 %, and the antenna volume is 80.7 mm3. The circular polarization performance of the antenna is generated and adjusted by adding annular slots between the outer ring and the ring descriptive loaded array to generate geometric perturbations. The sensitivity of the complete antenna model to implant in different parts of human body and ingestion of different digestive organs is studied. The biological compatibility, radiation characteristics and safety of the antenna are evaluated. The gain values are -16.8 dBi and -15.6 dBi. The performances of the antenna are tested in pork and simulated digestive tissue solutions. The impedance bandwidths are 24.7 % (2.23 ~ 2.86 GHz) and 20.2 % (2.25 ~ 2.76 GHz) respectively, and the effective communication distance is 11.8m in space. The designed antenna has wide working frequency band, small size, anti-interference and good electromagnetic compatibility, which can meet the working requirements of biological medical equipment after ingestion in digestive organs or implantation in human body.

KEYWORDS: Implantable antenna, Biocompatibility, Wireless communication, Medical implants, Frequency characteristics, Radiation efficiency, Gain optimization.

I. INTRODUCTION

The evolution in our world is running very fast because of the rapid development of scientific research methods and tools. The base for such evolution is the human needs in different life styles including health and entertainment etc. There is no doubt in that the health has the priority over most other needs because it relates directly to human life. It attracts a lot of research funding and has a very active market. Consequently, researchers in both academic and industrial sectors are very interested in designing and developing health tools and medical devices to be more reliable, safer and more comfortable.

Some of the medical devices can be implanted inside the human body for different purposes, such as monitoring, drug delivery or specific stimulation. The first successful implanted device inside the human body was a pacemaker in 1960. This step opened a hot topic for researchers to investigate and develop many more implantable devices. Medical devices designed for implantation purposes require several considerations from different scopes such as medical, biology, electrical engineering or mechanical engineering requirements. Electrical engineering plays a significant role in developing such devices in terms of various aspects including powering and communication systems. Since these aspects are very essential for any implantable device, researchers spend great efforts to exploit the optimum solution such that the devices can work reliably and safely.

II. RELATED WORK

A miniaturized S-shaped CP circular patch antenna designed for implantable medical devices (IMD) operating in the 1.4-GHz Wireless Medical Telemetry Service (WMTS) band is presented. The antenna's performance is enhanced by utilizing a substrate and superstrate with a high dielectric constant, along with controlled-length S-shaped slots in the radiator patch [1] Another study introduces a CPW-fed ultra-miniaturized patch antenna for biotelemetry applications, operating in the Industrial, Scientific, and Medical (ISM) band (2.4–2.5 GHz). This circular antenna incorporates slots





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in its ground plane to achieve circular polarization, using asymmetric square slots to generate the phase condition for right-hand circularly polarized (RHCP) radiation. [2] By altering the slot positions, either RHCP or left-hand circularly polarized (LHCP) radiation can be produced. A meandered central strip is implemented for miniaturization, and simulations using Ansys HFSS software with single-layer and multilayer human tissue models demonstrate good performance across various tissue properties due to its wide axial ratio and impedance bandwidth. [3] The antenna's design is validated through fabrication and measurements in skin-mimicking phantoms and pork, with simulated and measured results showing close agreement, and power link budget calculations are performed using an exterior CP receiving antenna.

III. METHODOLOGY

Designing a miniaturized T-slotted circular patch antenna for implantable applications involves several key steps and techniques to achieve compact size and optimal performance. Here's a structured methodology based on current research. Choose materials with high dielectric constants (e.g., Rogers RT 6010 with $\varepsilon r = 10.2$) to reduce the antenna size by shortening the guiding wavelength. Ensure all materials used are biocompatible to prevent adverse reactions when implanted in the body. Use a circular patch as the radiating element due to its compactness and ability to support circular polarization. Introduce T-shaped slots on the radiation patch to increase the effective current path length, thereby reducing the antenna size. Add cross-shaped slots in the center of both the radiation patch and the ground plane to achieve orthogonal modes necessary for circular polarization. Employ various slotting techniques (e.g., T-shaped, cross-shaped) to increase the current path and reduce the antenna size. Insert a short-circuit probe between the radiation patch and the ground plane to further miniaturize the antenna by creating additional resonant frequencies. Use CMA to analyse and optimize the antenna's radiation characteristics and modal significance. This helps in achieving dual-band circular polarization. Utilize simulation software like CST Microwave Studio or HFSS to model and optimize the antenna design based on simulated S-parameters and axial ratio (AR) performance. Ensure the antenna operates within the desired frequency bands (e.g., ISM bands) with sufficient bandwidth and acceptable gain levels for implantable applications Verify that the SAR values comply with health safety regulations to ensure safe operation within the human body 6.

Fabricate the optimized antenna design using appropriate materials and techniques. Conduct measurements to validate the simulated performance, including S-parameters, AR, and gain. By following this methodology, it is possible to design and develop a miniaturized T-slotted circular patch antenna suitable for implantable applications, offering both compact size and efficient performance.

IV. EXPERIMENTAL RESULTS

Figure [1] displays the LCD screen with the message "Patrolling System," confirming the system's activation. Figure [2] indicates the detection of an unusual or loud sound, with the LCD displaying a corresponding message and









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Figure 3

Figure 4

the LED and buzzer providing an audio alert. Figure [3] presents a close-up of the sound sensor module with wiring, responsible for detecting noise disturbances and triggering immediate alerts. Figure [4] showcases the proposed robotic patrol system equipped with an ultrasonic sensor, ESP32-CAM module, and Arduino board, enabling autonomous navigation and surveillance.



Figure 5



Figure [5] illustrates the Arduino IDE with the system's code, handling inputs from multiple sensors and managing core functionalities. Figure [6] features a Python script utilizing OpenCV for real-time face detection, enhancing security capabilities. Figure [7] captures a terminal window showing an attempt to execute the face detection script, with an error message indicating a missing or incorrectly referenced module. Finally, Figure [8] presents the live video streaming interface when a threat is detected, with the ESP32-CAM module capturing and transmitting real-time footage for remote monitoring.

V. CONCLUSION

A miniaturized circular patch antenna is designed and validated for WCE applications. The optimum performance and miniaturization of the antenna were achieved via the introduction of slots in the radiating patch. The surface current distribution was visualized to confirm the circular polarization of the antenna. The impedance BW and AR BW of the antenna covered the desired frequency bands. The performance of the proposed antenna was evaluated by placing in a realistic human model using HFSS. The simulated results for the gain and reflection coefficient exhibited reasonable agreement. The safety of the antenna was verified according to the IEEE SAR regulation. The analysis of the link budget revealed that the antenna can perform reliable wireless communication.

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