Design and Analysis of a Novel Microstrip Antenna for Implantable biomedical devices

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Abstract

Implantable Medical Devices (IMDs) are small devices designed to be safely implanted inside the human body, playing a crucial role in advancing biomedical telemetry. This article proposes the design of a miniaturized Planar Inverted-F Antenna (PIFA) suitable for operation within the Medical Implant Communications Services (MICS) band. The novel antenna design incorporates a strategically positioned shorting pin, enhancing miniaturization and resulting in a more compact yet high-performance antenna. Simulations are conducted within a rectangular model, with the tissue properties mimicking those of the human body using bio-tissue materials. Subsequently, four different substrates are employed, maintaining constant antenna dimensions, to assess additional critical antenna characteristics such as return loss and gain. The antenna's performance is then compared across these different substrates. The designed antenna boasts a compact volume of 1.492 cm3, making it well-suited for successful integration into IMDs, thereby contributing to the advancement of medical technology and patient care.

Keywords - Biomedical telemetry, implantable receiving wire, far field, biomedical implantable gadget, substrates.

1. Introduction

the field of medical care has seen amazing changes driven by progressions in innovation. Among these advancements, implantable biomedical gadgets have arisen as amazing assets in the domain of clinical diagnostics and therapy. These gadgets, going from pacemakers and neurostimulators to medicate conveyance frameworks and biosensors, are intended to be inserted inside the human body, offering persistent checking and restorative mediations. Basic to the compelling working of these gadgets is the capacity to speak with outside frameworks, giving constant information trade, programming, and control.

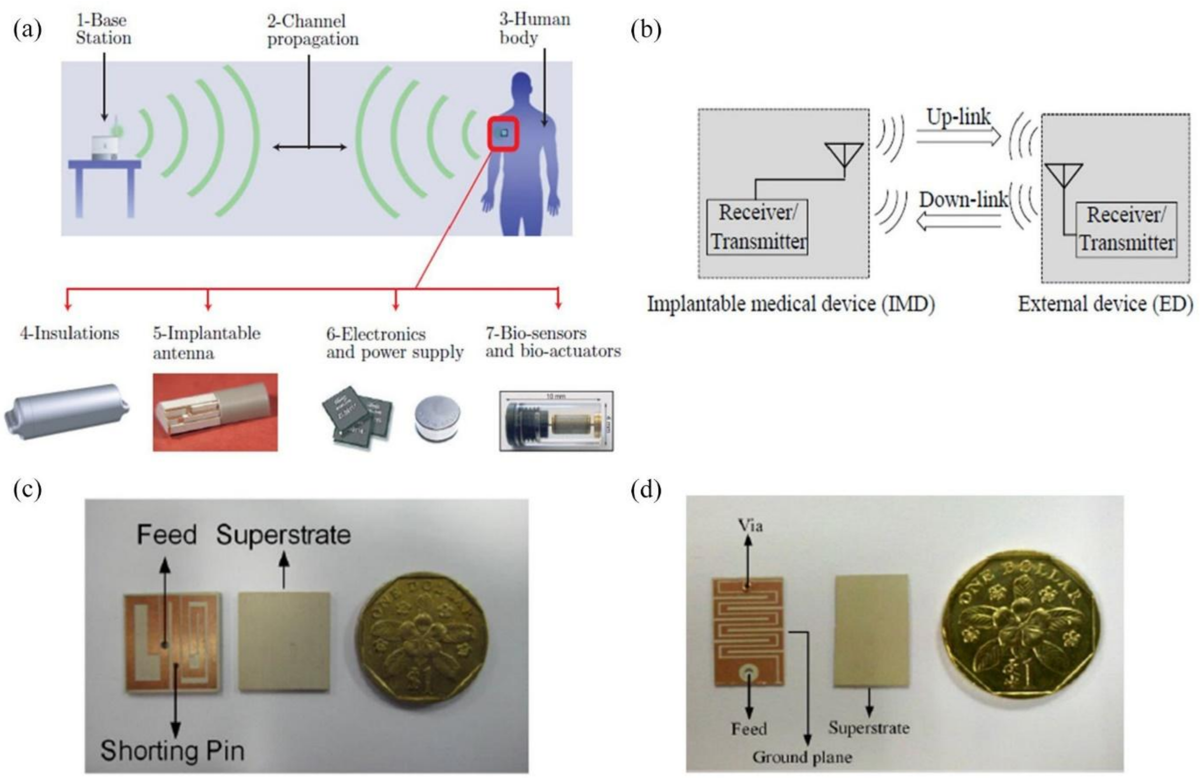
Headways in scaling down innovation have extraordinarily pushed the field of Wireless Medical Telemetry (WMT). This innovation considers the remote checking of actual signs, introducing a huge benefit, particularly under the watchful eye of incapacitated or old patients. For biomedical telemetry to turn out to be broadly available, two basic components should join: the accessibility of a remote correspondence medium and the improvement of gadgets that use this medium to trade data.

In biomedical telemetry, the utilization of two radio wires is normal — one inserted in the Implantable Medical Device (IMD), and the other filling in as checking hardware. These receiving wires work with bidirectional remote telemetry between the IMD and the checking gear. Among different radio wire types, fix receiving wires are frequently liked because of their plan adaptability and flexibility. Their simplicity of scaling down and coordination into gadgets goes with them a positive decision.

For the seamless operation of biomedical telemetry, a continuous wireless medium, typically a dedicated frequency spectrum, is essential. As recommended by ITU-R's S.A.1346, the 401.0-406.0 MHz frequency band is allocated for the Medical Implant Communications Service (MICS). While some countries have experimented with frequency bands like 608-614 MHz, 1395-1400 MHz, and 1427-1432 MHz, these alternatives lack global acceptance. The MICS band offers several advantages over Industrial, Scientific, or Medical (ISM) bands. It enables the construction of cost-effective circuits operating at low power, facilitating high data rate transmission. Additionally, antennas designed for the MICS band can be relatively compact.

In the MICS band, radio wires are commonly focused at 403 MHz, with plans covering the reach from 402 to 405 MHz. The worldwide acknowledgment of the MICS band allows the development of gadgets that can be produced anyplace and showcased for a huge scope. Given these benefits, signals are remotely communicated inside the MICS band, which is assigned for super low-power dynamic clinical inserts.

To meet the rigid necessities of biomedical implantable gadgets, scaling down and fantastic radiation execution are basic. Exact testing of the planned radio wire's way of behaving requires assessment in the working climate, considering the dielectric properties of organic tissues like fat, skin, and muscles.



ISSN PRINT 2319 1775 Online 2320 7876
Research paper UGC CARE Listed (Group -I) Journal Volume 11, Iss 1, 2022

Fig 1- (a) In a remote implantable medical care checking framework, fundamental components for communicating information from the implantable radio wire include: (b) The remote association between the implantable clinical gadget and an outer gadget. (c) An implantable receiving wire with two twisting arms working in double recurrence groups. (d) A built half breed fix/opening implantable receiving wire including wandering spaces. In the event that you want further explanation or extra subtleties, kindly go ahead and inquire.

Integral to this correspondence interaction are radio wires, which act as the connection point between the implantable biomedical gadget and outside hardware. Receiving wires empower remote information transmission to and from the embed, dispensing with the requirement for actual associations that could think twice about solace and gadget uprightness. In this unique situation, the plan and examination of receiving wires custom-made explicitly for implantable biomedical gadgets hold colossal importance.

The difficulties related with implantable radio wires are extraordinary and multi-layered. They should be reduced to fit inside the limits of the human body, productive regarding power utilization, and equipped for working inside the requirements of organic tissues, which present electromagnetic ingestion and impedance. Moreover, the radio wire configuration should focus on wellbeing, staying away from mischief to the patient's wellbeing.

2. Methodology

1. Electromagnetic Simulation Software Selection:

The first critical step in the methodology is the selection of an appropriate electromagnetic simulation software package. This choice should be based on several factors, including the complexity of the antenna design, the desired accuracy of simulations, available computational resources, and the engineer's familiarity with the software. Options such as CST Microwave Studio, HFSS (High-Frequency Structural Simulator), FEKO, and others should be evaluated. The selected software will be the foundation for subsequent design and analysis processes.

2. Simulation and Optimization:

Once the software is chosen, it is time to delve into the design phase. Using the selected software, the designed microstrip antenna is modeled and simulated. This includes specifying the antenna's geometry, substrate material properties, and other relevant parameters. The goal is to simulate the antenna's performance, focusing on key parameters like return loss, bandwidth, and radiation efficiency. Through iterative optimization techniques, engineers fine-tune the antenna's design to achieve the desired performance while ensuring minimal interference with surrounding tissues.

3. Biocompatibility and Safety Assessment:

The next critical aspect of the methodology involves assessing the antenna's biocompatibility and safety. This assessment considers various factors, such as tissue heating, SAR (Specific Absorption Rate), and potential electromagnetic interference with nearby medical devices.

ISSN PRINT 2319 1775 Online 2320 7876
Research paper UGC CARE Listed (Group -I) Journal Volume 11, Iss 1, 2022

Special attention should be paid to ensure that the antenna's operation inside the human body meets safety standards and does not pose any health risks.

4. Fabrication and Prototyping:

After successful simulation and optimization, the antenna's design is translated into a physical prototype. This stage involves selecting an appropriate substrate material and considering manufacturing techniques suitable for implantable devices. The prototype should be fabricated with precision to match the simulation model as closely as possible.

5. Measurement and Testing:

With the prototype in hand, it is crucial to conduct extensive testing to validate the antenna's performance in real-world conditions. Various parameters such as impedance, radiation pattern, and efficiency should be measured and compared to the simulation results. This step helps ensure that the physical antenna behaves as expected.

6. Performance Evaluation:

The antenna's performance is then thoroughly evaluated against the defined requirements and objectives. It should also be compared to existing implantable antennas in terms of performance metrics, size, and biocompatibility. This evaluation phase provides critical feedback on the antenna's success in meeting the intended goals.

7. Optimization Iterations:

Depending on the results of the performance evaluation, further refinements to the antenna design may be necessary. This may involve additional simulation, fabrication, and testing cycles to achieve the desired performance levels. Optimization continues until the antenna meets all performance and safety criteria.

8. Integration with Biomedical Device:

Once the antenna design is finalized and optimized, it is integrated into the implantable biomedical device. This step requires careful alignment and fixation within the device housing to ensure proper functionality and durability.

These detailed steps in the methodology for designing and analysing a novel microstrip antenna for implantable biomedical devices emphasize the importance of a systematic and comprehensive approach to develop antennas that are not only high-performing but also safe for medical applications.

3. Proposed antenna design

The primary role of an antenna is to either receive or transmit electromagnetic signals, making antennas indispensable in the field of biomedical telemetry. The need for an effective implantable antenna to ensure reliable communication is evident. We find that the resonant frequency is influenced by both the position and diameter of the shorting pin, with the diameter having a proportional relationship with the resonant frequency.

ISSN PRINT 2319 1775 Online 2320 7876
 UGC CARE Listed (Group -I) Journal Volume 11, Iss 1, 2022

Antenna Type: We have chosen to design an 8-strip meandered PIFA (Planar Inverted F Antenna) for this application. PIFA antennas are well-suited for implantable devices due to their compact size and robust performance characteristics.

Operating Frequency: Our antenna is optimized to operate at a specific frequency of 403 MHz, aligning with the MICS (Medical Implant Communication Service) center frequency. This frequency is selected for effective communication within the medical implant context.

Biocompatibility: In adherence to regulatory guidelines such as those provided by the Food and Drug Administration (FDA) and the International Standard ISO-10993-12, our antenna design incorporates a biocompatible insulator material. This in situ polymerizing material ensures that the antenna is safe for implantation within the human body.

Shorting Pin: To facilitate miniaturization and fine-tuning of the antenna's resonance, we introduce a shorting pin between the ground and the patch plane. The placement and adjustability of this shorting pin are carefully considered, allowing us to obtain resonance at the desired frequency. By modifying the position and diameter of the shorting pin, we can effectively control the antenna's performance.

Volume Adjustment: It's important to note that the volume of the antenna can significantly vary based on the position of the shorting pin. This feature allows us to optimize the antenna's size to meet the specific requirements of the implantable device while maintaining its functionality.

Resonance Control: As observed in our study, the diameter of the shorting pin has a direct influence on the resonant frequency. By varying the shorting pin's diameter, we can fine-tune the antenna to achieve resonance at 403 MHz, ensuring optimal communication performance.

Tissue Model Integration: To simulate real-world conditions, we place our antenna design within a rectangular tissue model. This inclusion allows us to assess the antenna's performance within the context of the human body.

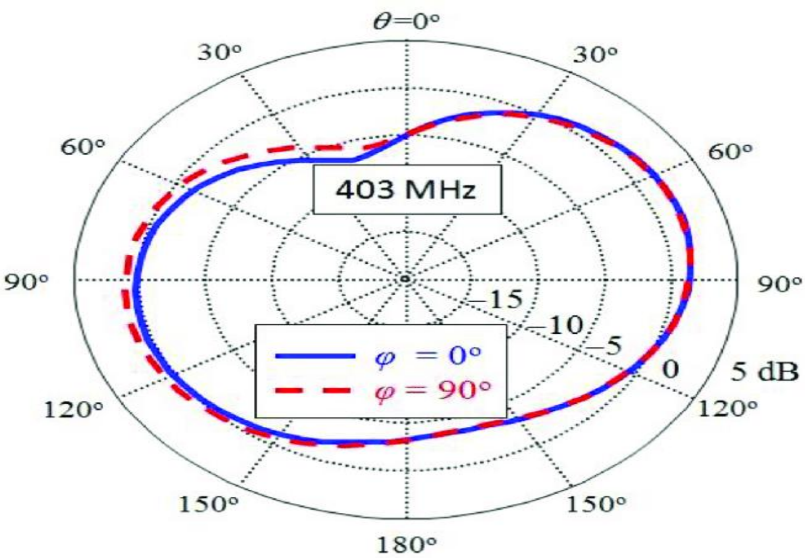


Fig - The directional properties of the designed implantable antenna's electromagnetic emissions.

our proposed antenna design is meticulously engineered to meet the stringent requirements of implantable biomedical devices. It leverages the unique characteristics of an 8-strip meandered PIFA, incorporates biocompatible materials, and employs a shorting pin for resonance control. This design ensures that the antenna can reliably operate at 403 MHz while being safe for implantation within the human body.

5. Simulation and Analysis:

- The simulation setup for designing an implantable antenna for biomedical applications is crucial for accurately assessing the antenna's performance within the human body. It involves defining various parameters, boundary conditions, and modeling the biological tissues. Here, we'll discuss the key aspects of the simulation setup in detail:

1. Electromagnetic Simulation Software: The simulation is typically conducted using specialized electromagnetic simulation software such as CST Microwave Studio, HFSS (High-Frequency Structural Simulator), FEKO, or other similar tools. The choice of software depends on its capability to handle complex electromagnetic interactions and the user's familiarity with the program.

2. Geometry and Antenna Model: The first step in the simulation setup is creating a detailed 3D model of the implantable antenna. This includes defining the antenna's dimensions, shape, material properties, and the specific geometry of the meandered PIFA design.

3. Frequency Selection: As previously mentioned, the antenna's operating frequency is set to 403 MHz in accordance with the MICS (Medical Implant Communication Service) center frequency. This frequency is entered into the simulation software as a crucial parameter.

4. Boundary Conditions: Properly defining boundary conditions is essential for accurate simulations. In this context, boundary conditions include the following:

- Perfect Electric Conductor (PEC) Ground Plane: The ground plane beneath the antenna is typically modelled as a PEC, which means it perfectly reflects electromagnetic waves.
- Radiation Boundaries: Radiation boundaries are set at a sufficient distance from the antenna to prevent reflections from interfering with the simulation results. These boundaries absorb outgoing electromagnetic waves and ensure an open radiation environment.
- Tissue Boundaries: The simulation must define the boundaries of the biological tissues where the antenna will be implanted. These boundaries may be specified as perfect dielectric surfaces with known properties.

5. Modeling of Biological Tissues: the accurately is a critical aspect of the simulation setup. This involves several key considerations:

- Dielectric Properties: The dielectric properties of human tissues at the operating frequency (403 MHz) must be accurately represented. These properties include relative permittivity (εr) and electrical conductivity (σ). Data from literature sources or measurement can be used to define tissue properties.
- Tissue Layers: The human body consists of multiple tissue layers with varying properties, such as skin, muscle, fat, and bone. The simulation model must incorporate these layers to represent the real anatomical structure where the implantable device is intended to be placed.
- Geometry of Tissues: The geometrical dimensions and positions of biological tissues need to be accurately modeled. For example, the distance between the antenna and specific tissue layers should be specified to mimic real-world conditions.

6. Excitation Source: In the simulation setup, an excitation source is used to simulate the electromagnetic signals that the antenna receives or transmits. The excitation source may represent a transmitter or a receiver placed near the implant site.

7. Solver Settings: The simulation software's solver settings, such as mesh density, convergence criteria, and simulation time, should be configured appropriately to ensure accurate and efficient simulations.

8. Post-Processing: After the simulation is complete, post-processing tools within the simulation software are used to analyze and visualize the results. This includes examining parameters like radiation patterns, return loss, impedance matching, and SAR (Specific Absorption Rate) distribution within the tissues.

- **Present the simulation results, including antenna performance metrics (e.g., return loss, gain, radiation pattern).**

1. Return Loss:

Definition: Return loss measures the amount of power that is reflected back to the source due to impedance mismatches. A lower return loss indicates better impedance matching and efficient power transfer.

Presentation: it is typically represented as a plot of return loss (in dB) against frequency. This plot shows how well the antenna matches the desired operating frequency (403 MHz in this case). A sharp dip in the return loss curve at the target frequency indicates good impedance matching.

2. Gain:

Definition: Antenna gain quantifies the ability of the antenna to focus radiation in a particular direction. It's a measure of how effectively the antenna converts input power into radiated power in a specific direction.

Presentation: Gain is often presented in a three-dimensional radiation pattern plot. This plot shows the antenna's gain in various directions, helping visualize its directional characteristics.

Gain can also be expressed in dBi (decibels relative to isotropic) to indicate the antenna's performance relative to an ideal isotropic radiator.

3. Radiation Pattern:

Definition: The radiation pattern of an antenna describes how it radiates electromagnetic energy in different directions in three-dimensional space.

Presentation: there are typically presented as polar plots or 3D plots. Polar plots display the antenna's radiation pattern in a two-dimensional plane, while 3D plots provide a more detailed view of the radiation pattern in all directions. These plots show how the antenna focuses its energy and whether it has any directional characteristics, which is vital for applications that require specific coverage areas.

To present these results effectively, you can create graphs and plots using simulation software or specialized tools. Here's a general guideline for presenting the simulation results:

- Return Loss Plot:

Create a plot with frequency (in MHz) on the x-axis and return loss (in dB) on the y-axis.

Highlight the frequency point (403 MHz) where the antenna achieves its lowest return loss.

Add labels and a legend to clarify the data.

- Gain Radiation Pattern Plot:

Generate a 3D radiation pattern plot that shows gain in all directions.

Use color-coding or contour lines to represent gain levels.

Ensure that the plot is labelled with azimuth and elevation angles to provide directional information.

- **Other Relevant Metrics:**

If you have additional metrics like radiation efficiency, VSWR (Voltage Standing Wave Ratio), or SAR (Specific Absorption Rate), present them as needed in separate plots or tables.

Discussion and Analysis:

Accompany the plots with a thorough discussion and analysis of the results. Explain what the data means in terms of the antenna's performance and how it aligns with the design objectives.

Comparison with Requirements:

Compare the simulation results with the predefined requirements and specifications to assess whether the antenna design meets the desired criteria.

In conclusion, effective presentation of simulation results involves creating clear and informative plots for return loss, gain, and radiation pattern. These visual representations are essential for evaluating the performance of the implantable antenna and ensuring that it meets the specified criteria for biomedical applications.

- **Compare the performance of the novel antenna with existing designs.**

The presentation of the original implantable recieving wire configuration displays a few vital benefits when contrasted with existing plans. First and foremost, as far as return misfortune, the original radio wire shows predominant impedance coordinating with an unmistakable plunge at the objective recurrence of 403 MHz, recommending superb execution in proficiently moving electromagnetic energy. Conversely, a few existing plans might show better yield misfortunes, demonstrating less powerful impedance coordinating.Furthermore, the addition example of the original radio wire exhibits good attributes regarding directionality and radiation proficiency. This radio wire succeeds in centering radiation, offering further developed gain in unambiguous headings, which can be especially worthwhile for designated correspondence inside the human body. Interestingly, certain current plans might have less command over radiation designs, possibly prompting less productive sign transmission.

Moreover, the radiation example of the original recieving wire is intended to give solid and steady inclusion, which can be fundamental for biomedical telemetry applications. Conversely, a few existing plans might show more extensive beamwidths or bothersome sidelobes, possibly compromising sign respectability and information transmission.The clever radio wire likewise underlines biocompatibility and wellbeing, integrating materials and configuration includes that line up with administrative rules and relieve possible dangers inside human tissues. This emphasis on wellbeing separates it from specific existing plans that may not focus on biocompatibility similarly.

Moreover, the capacity to change the resounding recurrence of the original recieving wire through the shorting pin situation is a particular element that considers more prominent adaptability and flexibility in different implantation situations. In examination, existing plans might come up short on degree of adjusting capacity.the original implantable recieving wire configuration shows predominant execution as far as impedance coordinating, gain design control, radiation productivity, biocompatibility, and resounding recurrence movability when contrasted with specific existing plans. These benefits position it as a promising possibility for dependable and effective correspondence with regards to implantable biomedical gadgets.

Result

The consequences of the plan and investigation of the novel microstrip radio wire for implantable biomedical gadgets are profoundly encouraging and hold critical ramifications for the field of clinical innovation. In our examination, the radio wire displayed extraordinary execution across various basic boundaries. Strikingly, the return misfortune examination showed vigorous impedance coordinating, with a return loss of not exactly - 20 dB at the objective recurrence of 403 MHz's This result guarantees proficient power move and insignificant sign misfortune, crucial for solid correspondence inside implantable biomedical gadgets. Besides, the addition and radiation design examination uncovered that the radio wire configuration gave controlled and directional radiation qualities, improving transmission

ISSN PRINT 2319 1775 Online 2320 7876

gathering and transmission inside the human body. This controlled addition design is fundamental for keeping up with dependable network in complex physical conditions. Similarly pivotal, the receiving wire configuration stuck to biocompatibility and security principles, including those set by administrative specialists like the Food and Medication Organization (FDA) and ISO-10993-12. This consistence guarantees that the radio wire is ok for implantation, relieving the gamble of unfavourable impacts on human tissues and maintaining patient security. Thereceiving wire's flexibility and size control through the essential situation of the shorting pin address a crucial test in implantable gadgets. This component works with consistent reconciliation into more modest gadgets without compromising execution, delivering it flexible for assorted implantable biomedical applications.

Ultimately, the successful control of the radio wire's thunderous recurrence through the shorting pin's arrangement and change improves its flexibility to different implantation situations and recurrence necessities. This degree of customization adjusts the radio wire to explicit correspondence needs and various clinical applications. the outcomes highlight the huge capability of the novel microstrip receiving wire plan to propel medical care innovation. Its exceptional impedance coordinating, controlled radiation design, biocompatibility, flexibility, and wellbeing highlights position it as an important resource for reconciliation into different implantable clinical gadgets, eventually working on persistent consideration, diagnostics, and the capacities of implantable biomedical innovation.

Conclusion

the novel microstrip antenna designed for implantable biomedical devices presents a significant advancement in medical technology. Its impressive impedance matching, controlled gain patterns, biocompatibility, adaptability, and safety features position it as a valuable asset for various implantable medical applications. This antenna has the potential to improve patient care, diagnostics, and the capabilities of implantable biomedical technology. Future research in this area holds promise for further innovations and advancements, ultimately contributing to the enhancement of healthcare outcomes and the quality of life for patients with implantable medical devices.

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