Design of a Miniaturized Slot Antenna for ISM Band Applications

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Abstract— A novel miniaturized Slot Antenna is proposed at 2.4 GHz Industrial, Scientific, and Medical band applications especially for bio medical applications. By properly positioning the feed and slots, proximity coupled feeding technique can be realized. Through optimization, a really compact size of 10 mm x 10 mm x 1.5 mm is achieved. The simulated results show that a narrow bandwidth of 2.393 - 2.410 at -10 dB for FR4 (εr = 4.4) substrate. The simulated results show that a narrow bandwidth can be realized with | S11| below -10 dB and axial ratio above 4 dB. Additionally, Total Gain, Directivity is found to be good enabling to be implemented for biomedical devices. Proximity coupled feeding technique ensures no radiation problems to the skin of the patient. Furthermore, the Linear Polarization and small size enables the antenna's reliability with the Receiver Antenna due to its liberty to be placed at any positions. Thus, the results show that the desired ISM band can be well covered and size of the proposed antenna is found to be accurate for many future ISM band bio-medical applications with best output values and performances.

Key words: Proximity Coupling, Meandering, Slot Antenna, Linear Polarization, ISM band

I. INTRODUCTION

The miniaturization of electronic hardware and embedded systems has facilitated increasing interest in new applications for wearable communications, with such body centric networks becoming important in medical, military, and commercial sectors. For example, continuous wireless remote monitoring and logging of vital signs is useful for supervising the health status of patients suffering from chronic diseases or providing early indication for impending heart attacks. Such remote health care solutions have the potential to compensate for limited health care resources. With the growing concern of human health and the convenience of medical care, the idea of biomedical devices that can be implanted into human bodies has been brought up and widely studied.

Many clinical applications including retinal prosthesis, neural recording, glucose monitoring, temperature monitors, pacemakers and cardiovascular defibrillators, functional electrical stimulators are already using implantable medical devices to support and improve the quality of patients' lives. Likewise, specialist professions such as fire service, police, and military are keen on integrating a network of small mobile terminals into clothing for monitoring and short range communications between team members in an attempt to increase survivability, awareness, and performance.

Many of these emerging applications are focused on integration of radio frequency (RF) transceiver modules with embedded signal processing and sensor circuitry for small, low power wireless nodes, with much of the interest being for operating bands at 2.45 GHz and below. Clearly, these systems are required to be miniaturized, lightweight, low profile, robust, flexible, and capable of unobtrusive and continuous monitoring, all of which must maintain the reliable communication with high performance.

In the miniaturization of wireless systems, the antenna presents a significant problem as its performance is directly related to their physical size, involving a trade-off between design parameters such as efficiency, bandwidth, and radiation characteristics. It is widely accepted that antenna performance is significantly affected by close proximity to the human body.

Furthermore, these effects will vary between different antennas, ground plane size, separation distances, and near-field proximity coupling.

II. RELATED WORKS

Numerous numerical and experimental studies have been carried out on the performance of various microstrip antennas based on their application in Bio-medical devices.

Some research works are based on the adoption of multilayer configurations to reduce the antenna size. Some works focus on the design of dual-band or triple-band antennas. Dual-band antennas can be applied to a system with dual-mode operation, where the Medical Implant Communications Service (MICS) band is intended for data communication and the Industrial, Scientific, and Medical (ISM) band is intended for start-up signal, thus saving the total power consumption. Additionally, a 3D-spiral small antenna was proposed for biomedical telemetry. Furthermore, in consideration of the matching and compatibility issues of antennas, the effect of insulating layers on the performance of implanted antennas was analyzed systematically. Flexible and conformal antennas were also proposed for biotelemetry in practical implanted systems.

A planar inverted-F antenna (PIFA) is the most commonly adopted antenna type for implantable systems [3]. Slot antennas [5] and loop antennas [6] were also proposed for some applications. The MICS band covering 402 - 405 *MHz* is the most popular for implantable antenna designs, but the antenna with proper size for implantation is usually electrically too small at this band and adequate radiation efficiency cannot be guaranteed. To realize the compactness of the antenna, other frequency bands like the 433.1 - 434.8 *MHz*, 902 - 928 *MHz*, and 2400 - 2500 *MHz* Industrial, Scientific, and Medical (ISM) bands are also suggested for implantable medical device biotelemetry [4]. But high frequency would cause high absorption of electromagnetic energy by a human body and high free-space path loss in propagation as well.

Considering the coupling between an implanted antenna and an external antenna of the base station used to collect the patients' information, on one hand, it is difficult to position the implanted system within an adequate area and maintain a perfect angle with respect to the external side during surgery. On the other hand, under certain circumstances, the mobility of the patients with an implanted system should also be considered.

Different methods have been studied such as introducing slight perturbation by truncating patch corners, adding tails and cutting cross slots adopting aperture-coupled feeding configurations and cutting a gap to a loop antenna. Besides, further compactness can be realized by employing high permittivity substrates and adopting a slow wave structure such as adding shorting pins in close proximity to the feeding probe [2] and loading parasitic elements. Good circular polarization should be realized within a limited size [1].

The size of the antenna can be further reduced by employing meandering process. The slot length can be adjusted in such a way so that to achieve maximum isolation when placed close to each other. EM coupling can be done to achieve further Gain values in such a miniaturized structure.

III. Antenna Design and Discussion

The main goal is to design and simulate an antenna for 2.4 GHz ISM band with minimum size and best performance. The proposed antenna is a slot antenna with a compact size of 10 mm x 10 mm x 1.42 mm using various optimization strategies.

To achieve antenna compactnessFR4 (ε_r = 4.4 and tan δ = 0.02) with thickness of 1.42 *mm* is used as substrate.

A. *Configuration of Linearly Polarized Implantable Antenna*

The configuration of the proposed antenna is shown in Figure 1. For convenience, the center of the configuration is set as the original point, and the system is illustrated in Figure 2 as well.

As can be seen from the Figure 2 it is a slot antenna with a slot line of length 23 mm and width 0.5 mm. This is placed with less coupling with itself by using Meandering process thus minimizing the size. Remove certain areas of the bottom plane of the substrate to improve Isolation and to reduce coupling if future modifications are introduced. An L-feed of length 3.75 mm ($L_f < \lambda/4$) and width 5 mm is made on the top of the substrate in such a way that it touches the Slot to produce Proximity coupling between upper and lower layers. Then a vacuum box of dimensions 80 mm x 80 mm x 70 mm is created, which is λ/4 from each side of the substrate. To define Lumped port excitation, a rectangle in the XZ plane is created with dimensions same as that of the feed (length = 1.68 mm and width = 1.5 mm). As per the transmission line model, length of the patch can be found as

$$L = \frac{c}{2fr\sqrt{\varepsilon_{reff}}} = \frac{c}{2fr\sqrt{\varepsilon_r+1}\,/2} = \frac{\lambda}{2\sqrt{\varepsilon_r+1}\,/2} \qquad - (1)$$

Where $\boldsymbol{\varepsilon}_{\mathbf{eff}}$ is the effective dielectric constant, $\boldsymbol{\varepsilon}_{\mathbf{r}}$ is the Dielectric constant of the substrate. Next boundaries and PerfectE excitations are assigned to the feed, bottom plane and the vacuum box. Lumped port excitation with 50 Ω impedance is assigned to the rectangle in the XZ plane. After optimization, a compact size of 10 mm x 10 mm with a height of 1.42 mm can be achieved. Longer current-flow paths excited on radiating slot reduces resonance frequency thus achieving a compact size.

Proximity coupled feeding technique is used where the L-feed is Electro-Magnetically coupled with the Slot in the Bottom layer.

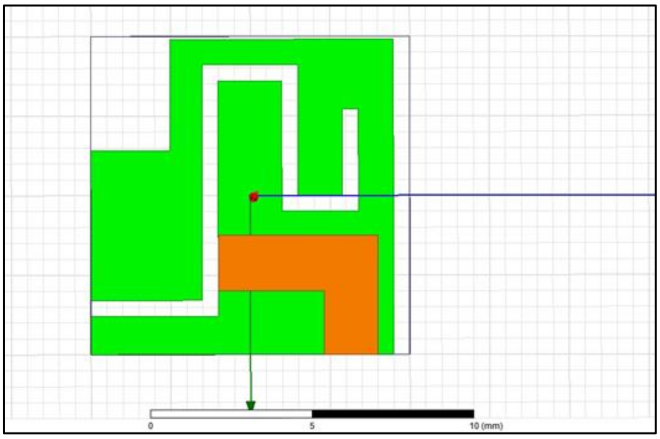

Fig. 1: Top view of the proposed antenna

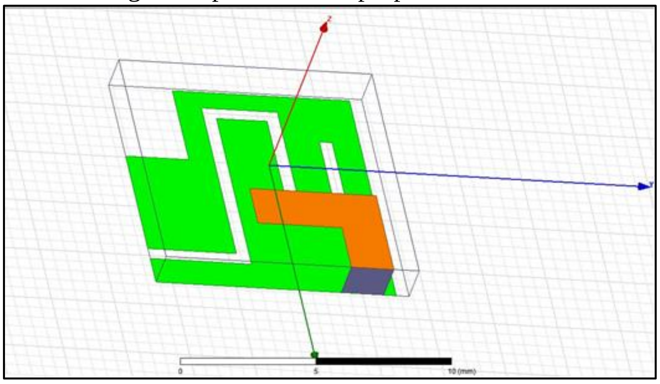

Fig 2: Side view of the proposed antenna

IV. Result Analysis and Discussions

Modal solutions of the system Return Loss, Total Gain, Directivity, Polarization, etc. can be found out and can be compared with the given specifications. If they failed to satisfy the desired specification, the design parameters of the antenna are altered. Sensitivity of the antenna to changes in design parameters can also found out until the optimum performance is achieved.

A. *|S11| parameter*

It is a parameter to indicate how well the matching between the transmitter and antenna has taken place. From Fig 3, the simulated |S11| below -10 *dB* is having very little Reflection and Return loss of -16.5211 dB at a Centre frequency of 2.404 *GHz*, thus considered to be perfectly matched antenna. Almost 95% is radiated.

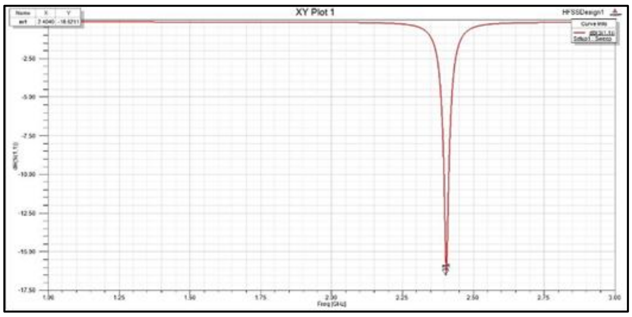

Fig. 3: Simulated |S11| parameter

B. *Surface current distribution*

Proximity coupling of the feed and the Slot can be effectively noticed and this can be seen from the Figure 4 and Figure 5.

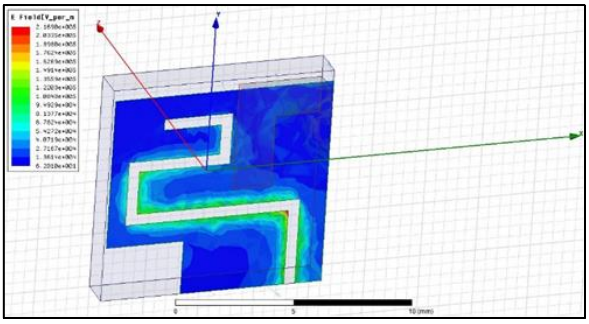

Fig. 4: Current distribution Slot

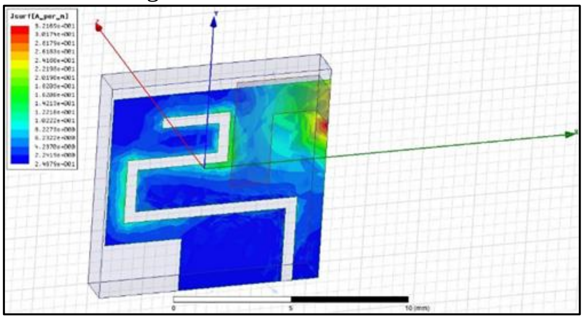

Fig. 5: Current distribution of bottom plane

C. Radiation Efficiency

The implantable antenna is an efficient radiator because of its compact size of 10 mm x 10 mm x 1.42 mm and very high Return Loss of -16.5211 dB. The simulated results shows that the Radiation which shows that the antenna is highly effective.

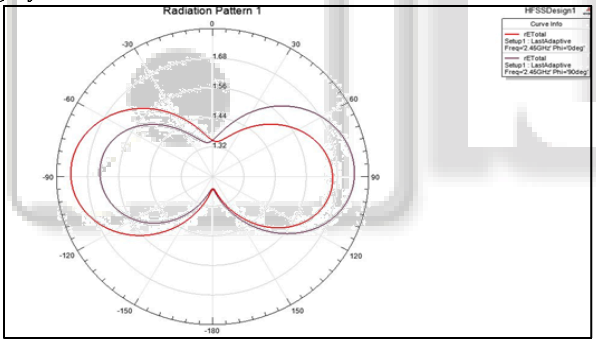

Fig. 6: Simulated 2D representation of radiation efficiency

D. Gain

The realized gain pattern at 2.404 GHz is plotted in Fig 7. The maximum realized gain at -8.3366 dB. It should be mentioned that the realized gains are simulated for the antenna in 80 mm x 80 mm x 70 mm vacuum box. Both the gain values and patterns would change with the phantom size used as well with the dimensions of the antenna proposed. Achieving a maximum Gain when the size is reduced to 147mm2 is considered a good factor when it comes to antenna design. Here EM coupling is utilized by using meandering of the slot enabling to miniaturize the antenna.

Antenna gain is the ratio of the radiation intensity in a given direction to the radiation intensity from an isotropic source. It is linearly proportional to the directivity through the antenna radiation efficiency. Hence it is a direct indication of the directive property of the antenna. The simulated gain patterns show that it has very high gain characteristics rendering effective radiation to the receiver antenna.

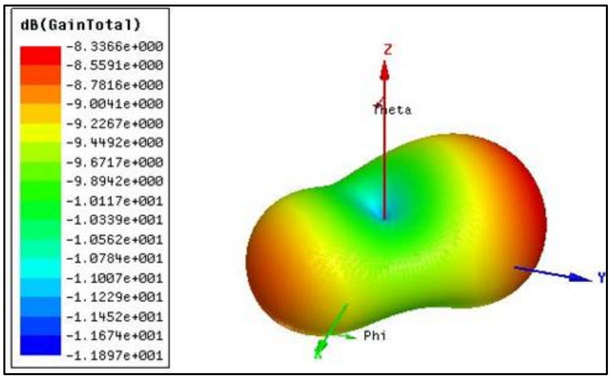

Fig. 7: Total Gain in dB - 3D Representation

E. Directivity

Antenna directivity is a measure of the ratio of the radiation intensity in a given direction from the antenna to the radiation intensity averaged over all directions. Fig 8 shows the simulated Directivity patterns show that it is 1.7149 directional due to the very high Gain characteristics rendering effective radiation to the receiver antenna.

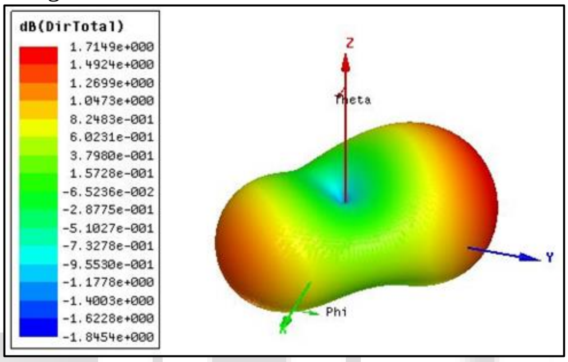

Fig. 8: Directivity in dB - 3D representation

F. Polarization

Antenna polarization indicates the polarization of the radiated wave of the antenna in the far-field region. Typically, this is measured in the direction of maximum radiation. The simulated results shows that it follows a line, hence the wave is linearly polarized. From the Fig 9, Axial Ratio is found to be 5 dB representing that this is a Linearly Polarized antenna.

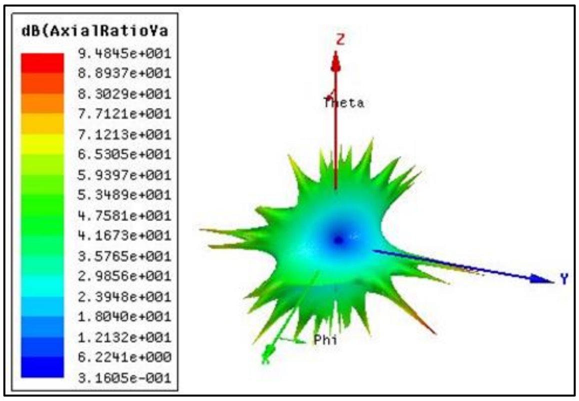

Fig. 9: Axial ratio - 3D representation

By comparing these results with the required specifications, the sensitivity of the device can be analyzed according to the changes in design parameters of size and position of the antenna. Hence by using the mathematical calculations and optimization strategies the optimum performance of the antenna can be achieved successfully.

Slot length (mm)	**Frequency (in GHz)**	**Return Loss (in dB)**	**Gain (in dB)**	**Directivity (in dB)**
23	2.4000	-18.869	-8.1265	1.8954
22.9	2.4080	-16.745	-8.074	1.874
22.8	2.412	-17.97	-7.946	1.859
22.7	2.4280	-20.41	-7.626	1.993
22.6	2.432	-17.911	-7.675	1.833
22.5	2.4480	-17.063	-7.53	1.903
22.4	2.444	-19.173	-7.513	1.818
22.2	2.4680	-16.406	-7.614	1.771
22	2.5080	-18.71	-7.216	1.777

Table 1: Effects of slot length with RL, Gain, Directivity (in dB)

V. CONCLUSION

A Linearly polarized antenna has been proposed for biomedical applications at 2.404 GHz ISM band. Both the Horizontal or Vertical Linear Polarization property can be achieved and the Horizontal configuration has been discussed here. The proposed antenna is designed by properly positioning the feed and slots where proximity coupled feeding technique can be realized. Through optimization, achieved a compact size of 10 mm x 10 mm x 1.42 mm. The simulated results show that a narrow bandwidth of 2.393 - 2.410 at -10 dB for FR4 (ε_r = 4.4) substrate. It can be realized with |**S11**| below -10 dB and axial ratio above 5 dB. Additionally, Total Gain, Directivity is found to be good with high Return loss of -16.5211 dB, enabling to be implemented for Implantable Medical Devices.

Proximity coupled feeding technique ensures no radiation problems to the skin of the patient due to very low spurious radiation. Furthermore, the Linear Polarization enables the implanted antenna's reliability with the Receiver Antenna due to its liberty to be placed at any positions. Thus, the results show that the desired ISM band can be well covered and Linear Polarization property is obtained.

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