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A REVIEW OF IMPLANTABLE AND WEARABLE ANTENNAS FOR WIRELESS BIOMEDICAL APPLICATIONS

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ABSTRACT

Implantable devices trend started in 1960's and this technology is emerging very vast in the field of Biomedical applications. Multiplenumber of wearable devices are emerging for Biomedical applications. Lot of work has been done to improve the efficiency, accuracy and to reduce the size and cost of these devices. In both implantable and wearable devices the most important component is antenna. Improvement of the device is mainly dependant on the improvement of antenna performance in all the ways. This paper gives a review on the work done in the design of the antenna. Multiple numbers of antenna geometries are presented and their performance is compared.

Keywords: Implantable antennas, Wearable antennas, Wireless Body Area Network (WBAN), planar antennas, miniature Antennas, Biotelemetry, Biomedical therapy, Wireless Biomedical Applications.

I INTRODUCTION

At the end of 19th century Electromagnetic waves started their way in the form of X-rays .Then onwards these waves are helping the mankind in multiple ways for vast number of applications.[1, 2]. The trend of implantable devices started in 1960's in the form of pacemakers and pills with sensing capability and is emerging with new challenges in Biomedical applications. These implanted devices collect the patient's information and provide wireless communication to the base station [3, 4].

Wearable device technology started in 1980's.Initially these devices have less number of applications. But 2003 onwards these devices stated their way towards biomedical field. By utilizing IOT technology multiple numbers of wearable devices are developed for health monitoring purpose.FitBit is an example of a wearable device which is developed for monitoring the human health. These devices are very much useful for health monitoring purpose. Work need to be done to increase the number of applications.

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Implantable and wearable devices have a great future scope. Optimization need to be done to improve the performance of these devices. The basic component of these devices is an antenna which is working at biomedical frequency band.Imroving the performance of the antenna impacts the optimization of the implantable or wearable device. Numbers of antennas are already in use to work in the biomedical frequency band. These antennas are to be optimized and new geometries are to be proposed for optimization.

Figure1. Examples of commercially available implantable monitoring devices

(a) GlucoDay (b) Pillcam.

While designing the antenna the parameters, such as radiation efficiency, band width, coupling with the lossy biological tissues are to be taken care. This paper gives a brief reviewon various geometries of antennas working in Biomedical frequency band. Section II is about Biomedical frequency band and the guidelines to be followed for the design of implantable antennas. In Section IIImultiple geometries are presented with their performance results.IVth section gives a comparison of the proposed geometries.SectionVis about Conclusions and future scope.

II BIOMEDICAL FREQUENCY BAND

Unlike traditional antennas that operated in free space, implantable antennas should consider many kinds of requirements as implantable antennas are placed in human bodies. These requirements include miniaturization, patient safety, communication ability, biocompatibility, power consumption and lifetime of the implantable circuits. The detailed requirements are as follows.

Miniaturization is one of the basic and key requirements for biomedical devices. Thanks to the development of integrated systems, integrated implantable circuits can be designed using CMOS technology and the integrated chip is very small and very suitable for biomedical devices. Implantable antennas will occupy much space of biomedical devices as implantable devices operate at very low frequency, typically at medical implant communications service (MICS) band (402-405 MHz) or medical device radio communications service band (MedRadio, 401MHz – 406MHz). In this condition, miniaturization for implantable antenna design is very crucial and is becoming one of the greatest challenges in the implantable antenna design.

High-permittivity dielectric substrate/superstrateis the easiest way to reduce the dimensions of implantable antennas. High-permittivity could shorten the effective wavelength and thus causing the resonant frequency shifts to lower frequency.

Rogers RO3210/RO3010/6002 is widely utilized for implantable antenna design. The relative dielectric constant of Rogers RO3210/RO3010/6002 is 10.2. In order to further reduce the size of implantable antennas, some research groups used much higher permittivity substrate to design implantable antennas.

The Medical Device Radiocommunications Service (MedRadio) is in the 401 – 406, 413 – 419, 426 – 432, 438 – 444, and 451 – 457 MHz range. MedRadio spectrum is used for diagnostic and therapeutic purposes in implanted medical devices as well as devices worn on a body. For example, MedRadio devices include implanted cardiac pacemakers and defibrillators as well as neuromuscular stimulators that help restore sensation, mobility, and other functions to limbs and organs. In addition, Medical Body Area Networks (MBANs), which are low power networks of sensors worn on the body controlled by a hub device that is located either on the body or in close proximity to it, operate in the 2360-2400 MHz band.

ISM stands for Industrial, Scientific and Medical frequency band. Applications of this band include process heating ,medical diathermy etc.Communication equipment operating in this band must tolerate any interference generated by ISM applications as there is no regulatory protection from ISM.

Desired frequency band	Frequency	Maximum EIRP (Equivalent Isotropic Radiated Power)
Medical Device Radio communication Service (MedRadio)	401-406MHZ	-16dBm
Industrial,Scientific and Medical Band	2.4-2.5GHz	20dBm

III IMPLANTABLE ANTENNAS WITH VARIOUS GEOMETRIES

Existing implantable antennas can be categorized into flexible and rigid antennas.

3.1 Rigid Embedded Implantable Antennas

These antennas are made of rigid copper and can be only placed inside the implantable device .These antennas cannot be bent around it because of its non-flexibility.

PIFA:

As the resonant length of microstrip patch antenna is halfwavelength, while the resonant length of PIFA is quarterwavelength. Thus, a PIFA is a better type to reduce the antenna size compared with a microstrip antenna. In this condition, PIFAs have been studied by many research groups. It can be seen that the PIFA structure is a common antenna type for implantable antenna design. As for the PIFA, two types of PIFAs were designed and

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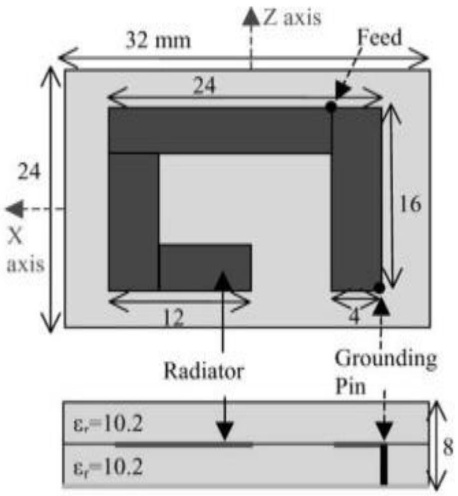
studied to understand which one is a better shape to design an implantable antenna [11].

A spiral meandered Planar Inverted-F Antenna (PIFA) is proposed. That antenna is shown in Fig3.1. It is of a large size (24×32×8) mmfor real implants. Moreover, its shape is not conformal to cylindrical implants.The edges leaves an unexploited space around them which waists a considerable internal space. Furthermore, despite of the antenna relatively large size, it obtained a narrow bandwidth of around 50 MHz as shown in Fig3.2. A much wider bandwidth is desirable in order to guarantee coverage of the bands of interest at different plantations locations and orientations



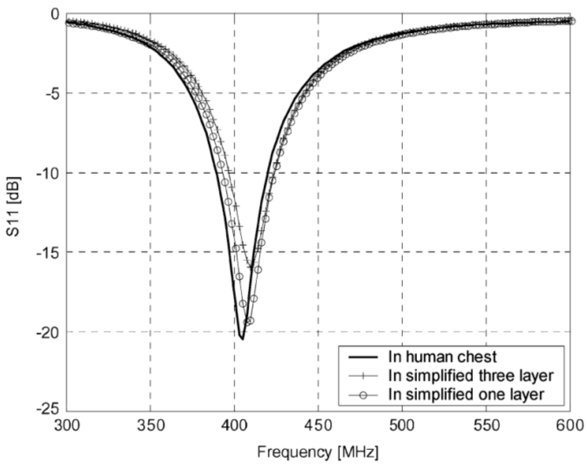


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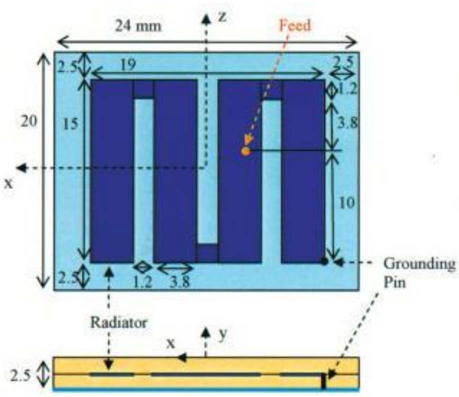
Fig 3.1PIFAgeometry **Fig 3.2 Frequency response of PIFA**

Themodified PIFA designs are shown in Fig 3.3 and 3.4.Same problem of the large size and non- conformity exist in these designs.They also had a bandwidth narrower than 50 MHz around the MedRadio band. A (19.5×10.8×2.5) mm^3 PIFA was also proposed for implantable applications at 868 MHz. The attenuation in the human body tissues and free space loss at this frequency are larger than that at the MedRadio band.



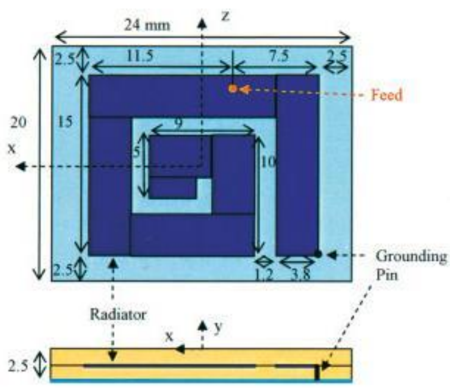


Fig 3.3 Meandered PIFA **Fig 3.5 Spiral PIFA**

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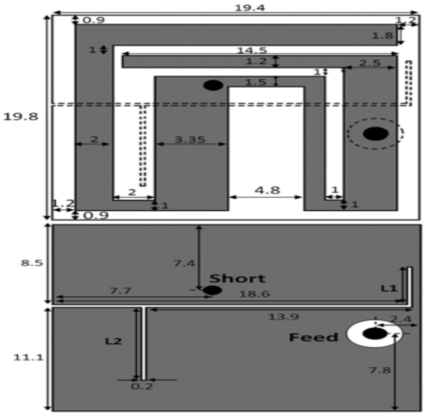
The PIFA is selected for those designs due to several reasons. It can resonate at a frequency around 400 MHz over small physical dimensions and low profile. It also has a smaller electric near field in comparison with other electrical type antennas. A single (915- 928 MHz), dual (356- 610 MHz and 2.45 GHz ISM) and triple (433 MHz ISM, WTMS a 1430 MHz, and 2.45 GHz ISM) band slot PIFA antennas are also proposed . Those antennas are of (12×12×4), (19.4×19.8×1.27) and (19×30×1.6) mm^3 in sizes, respectively which are relatively large for rigid structures for implantable applications. Those antenna structures and reflection coefficient are shown in Figs.3.6and 3.7, respectively. The slot was exploited in those designs to control the matching level, miniaturize the antenna and improve the antenna magnetic properties. This is reflected on larger radiation.



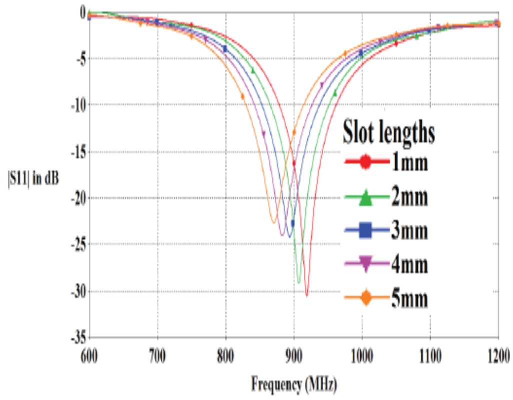
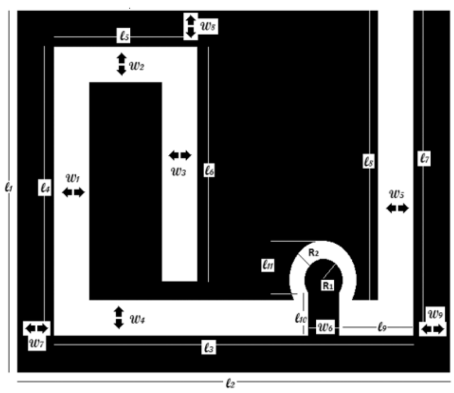


Fig. 3.6 Slot PIFA antennas   Fig 3.7 The reflection coefficient of the slot PIFA antennas

A slot line between a low-dielectric medium and a high-dielectric medium-like skin is used in to work for the MedRadio and 433 MHz ISM bands and obtained a small size of (10×12×1.5 mm^3). The antenna structure and reflection coefficient are shown in Figs. 3.8 and 3.9, respectively.
A slot antenna is proposed in as shown in Fig.3.9 to work for the MedRadio (401-406 MHz) and 433 MHz ISM bands with a size of (10×11×1.27 mm^3). A good matching between the simulation in skin and measurement in skin gel is obtained. However, a much narrower bandwidth is obtained when that antenna is simulated in the human model as shown in Fig.3.10



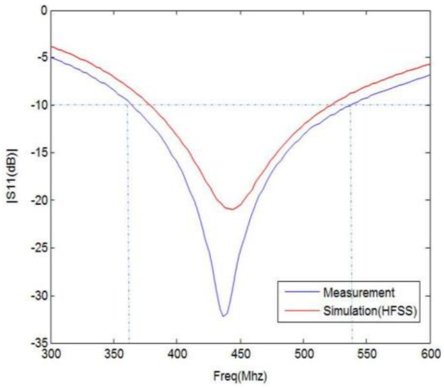
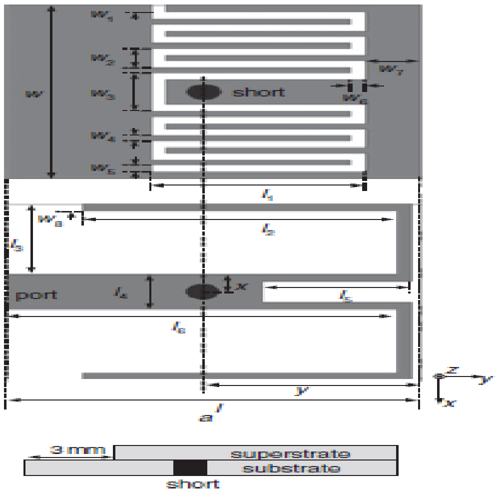


Fig. 3.9 Slot Antenna   **Fig. 3.10 The reflection coefficient of the slot antenna .**

Loop antennas are also popular for implantable designs as they are magnetic and of many attractive characteristics in general. A meandered loop antenna is designed as shown in Fig. It was designed on a circular Rogers 3010 substrate of 5.5 mm in radius and 0.635 mm in height to cover the (401-406) MedRadio and 902-928 MHz bands as shown in Fig. 2.17. That antenna had been coated both on the top and bottom with a biocompatible material called SU8 with the thickness of 50 um. The maximum gain values of the proposed antenna in the arm of the CST Gustav body model were -35.6 and -26.3 dBi at 402 MHz and 902 MHz, respectively. Those gain values were much smaller than most of by exploiting a wake up receiver as the device transmits data only when is needed.



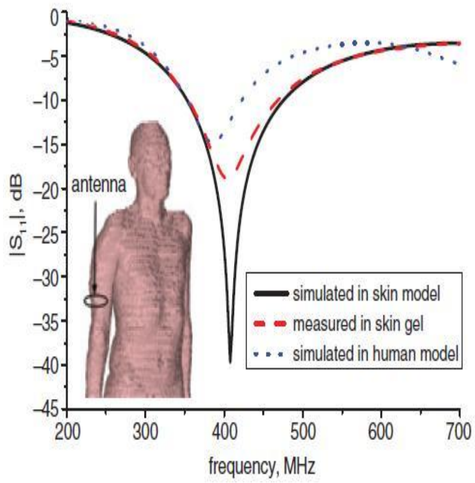


Fig 3.11 Meandered loop antenna **Fig 3.12 reflection coefficient of loop antnna**

As explained above, most of the proposed designs were heavy in weight and narrow in bandwidth. They also exploited a considerable space inside the implant. This stricts the battery size and implant life accordingly. Moreover, it restricts the number of sensors inside the implant and the variety of the implant applications accordingly (more sensors provide more functions). These problems also exist for the conformal embedded designs. However, they can be mitigated with the use of flexible designs which are thin and can be bent around the implant wall leaving extra space of internal components or reduce the implant size for the same components. Obviously, they can also reduce the implant weight significantly.

IV COMPARISON OF DIFFERENT ANTENNAS

Table given gives an idea about different types of implantable antennas and their performance and sizes are compared. These work at med band radio frequencies

Table 4.7.: Comparison of Different Implantable Radiators in the MedRadio Band.

Antenna	Dimension with insulation [mm]	Body Phantom			Implant depth [mm]	Gain [dBi]
		ε'_e	σ'_e	dimension [mm]		
Spiral based on [18]	38.0 x 42.0 x 4.0 = 6384.0	49.60	0.51	50 x 40 x 20	5	-30.6
Spiral PIFA [92]	17.0 x 27.0 x 6.0 = 2754.0	42.80	0.64	50 x 40 x 20	7	-35.0
Meandered PIFA [80]	22.5 x 22.5 x 2.5 = 1265.6	46.70	0.68	103 x 103 x 8.5	3	-24.9
Stacked PIFA [167]	3.6^2 x π x 0.7 = 28.5	46.70 13.1 57.4	0.69 0.09 0.74	100 95 90	$\simeq$ 2	-55.6
PIFA with 3D ground plane [82]	40 x 30 x 13.2 = 15600.0	38.10	0.53	100 x 100 x 50	4	-28.0
FIFA	$\simeq 16^2$ x π x 33.8 = 27184.0	57.10	0.79	90	$\simeq$ 18	-29.2
Painted FIFA	6^2 x π x 18.2 = 2058.4	57.10	0.79	90	$\simeq$ 34	-29.1
FRH	17 x 17 x 18 = 5202.0	57.10	0.79	80 x 100	$\simeq$ 20	-28.5

*[mm]. Three values are for box geometries, two for cylindrical (diameter x height), and one for spherical (diameter).

V CONCLUSION

In order to facilitate bending, implantable antennas need to be thin which strict the techniques of miniaturizing them. While PIFA was a good option for rigid embedded designs as explained above, it cannot be easily obtained for flexible designs of a very thin substrate and radiator. This makes meandered and spiral radiators suitable for such flexible designs. However, spiral radiator is difficult to design over a loop structure that is preferred for magnetic applications as this requires a thick third dimension (the substrate thickness).

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