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IMPLANTABLE ANTENNAS FOR BIOMEDICAL APPLICATIONS

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ABSTRACT

Implantable antenna technology is a current trend in biomedical applications. Implantation is being used in Biotelemetry and Biomedical therapy. The trend of implantation started in 1960's with implantable pace makers and is emerging with improving the size and efficiency of implantable devices. Biomedical applications cover Biotelemetry and Biomedical therapy. Realization of implantable antennas demands for work in various s areas. This work can be categorized as (a) Choosing different antenna configurations suitable for lossy media, (b) minimizing the size of antennas and improving the efficiency, (c) packaging of antennas with proper insulating layers (d) testing the performance to enhance the range of Biomedical applications. This paper gives a review on the work done in all the above mentioned areas.

Keywords: implantable antennas, wireless body area network (WBAN), planar antennas, miniatured antennas, biotelemetry, biomedical therapy.

1. INTRODUCTION

At the end of 19th century Electromagnetic waves started their way in the form of X-rays for medicinal applications. Since then EM waves are emerging with new challenges in the medical field. EM waves are providing major contributions to Biotelemetry, Biomedical therapy and diagnosis [1, 2].

Biomedical applications using Electromagnetic waves require implantation of antennas inside the human body. The implanted device inside the human body is aimed at collecting the patient's information and to send it to the base station through wireless communication. The trend of implantable devices started in 1960's in the form of pacemakers and pills with sensing capability. The trend of implantable devices is emerging with new challenges in biomedical applications. These implanted devices collect the patient's information and provide wireless communication to the base station. The current research interest is to enhance the range of these Bio medical applications for continuous monitoring of patient [3, 4].

Implantable antennas inside the human body have two types of biomedical applications. They are Biotelemetry and Biomedical therapy. Biotelemetry can build a wireless communication link between human body and outside environment. Biomedical therapy and diagnosis include treatment of diseases and monitoring of various physiological parameters. These applications reduce the health care costs by reducing hospitalization period of the patient. Wireless Body Area Network (WBAN) is the healthcare monitoring system which uses implantable device inside the human body. This system provides home healthcare monitoring of the patient. The model of WBAN system is shown in Figure-1.

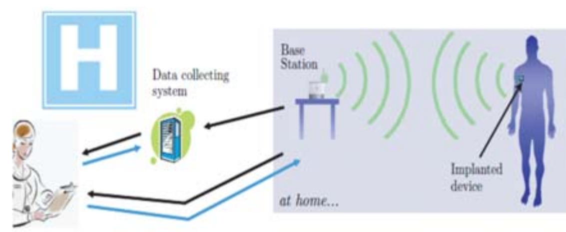

Figure-1. Wireless body area network for home healthcare monitoring of patient.

In the complete WBAN system implantable antenna is the key element. Efficient communication with the base station and miniaturization can be achieved by choosing an optimal design for implantation. Design of WBAN system need the knowledge on several EM aspects such as antenna design and theory, EM field propagation in lossy matter, telecommunication and package engineering [7, 8], material and biological science [9], and security and privacy matters [10].

In fact, despite the great academic and industrial interest on the topic, still few applications make use of such a technology. Besides the pacemaker, the state of the art of implantable sensors commercially available can be represented by the Gluco Day and the Pillcam systems for glucose monitoring and endoscopy, respectively. The former, illustrated in Figure-2(a), is a wearable device with a pervasive micro-fiber capable of measuring the glucose concentration from the interstitial liquid. The latter, shown in Figure-2(b) provides images from the digestive tract over a very short distance (receivers are stitched on the skin of the patient). Both solutions, although extraordinarily improving the medical diagnosis, do not answer to the request of a healthcare monitoring system as "transparent" as possible to the patient.

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Figure-2. Examples of commercially available implantable monitoring devices
(a) GlucoDay (b) Pillcam.

The objective of a wireless healthcare monitoring system using implantable device is to provide reliable information from inside of the human body to an external Base Station (BS). A WBAN system comprises several units. Figure-3 shows the different units of WBAN system. For correct functioning of the entire system it is required to have proper coordination among all the units. Before practical implementation of a WBAN system, proper testing is the most important criteria.

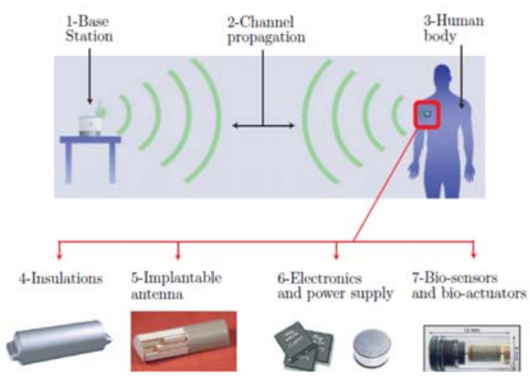

Figure-3. Various units in Wireless Body Area Network (WBAN) system.

The various units mentioned in the WBAN system are:

a. Base station
b. Channel
c. Human body
d. Insulations
e. Implantable antenna
f. Electronics and power supply
g. Biosensors and Bio actuators

Base station

Base station consists of several sub systems .The sub systems include control module, Receiving system and internet modem.

Control module stores the information and it drives the entire system with the help of collected information. Receiver module receives the data using an antenna and sends the data to control module. Internet modem is helpful in interconnecting the modules using wireless data transfer.

Channel

Propagation of EM waves between Base station and implanted device need the analysis on scattering and multipath propagation. By reducing the above effects channel efficiency of propagation can be improved.

Human body

Human Body is a hostile environment for implanted antenna and it is highly dispersive, complex and highly lossy in nature. While realizing the implantable antenna the surrounding environment characteristics play important role. Analysis, design, realization and characterization are the different stages of implantation. Each stage has to consider the human body as the surrounding environment.

Insulations

Proper Insulation around the implantable device increases its efficiency and also avoids any adverse reaction of the living tissues. Proper insulation increases the efficiency almost by three times the efficiency without insulation.

Implantable antenna

Implantable antenna is the key element in a WBAN network. Major objectives while choosing the radiator are compactness, cost and efficiency. 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 review on all the concerned fields for the realization of WBAN system. Section II is about choosing antenna configuration in the presence of lossy media. Section III discuses about the Guidelines to be followed for the design of implantable antennas. Section IV is about Insulating layers to improve the performance of implantable antennas and Antenna Measurements. Section V is on Conclusions and future scope.

2. ANTENNA IN THE PRESENCE OF LOSSY MEDIA

Design of implantable antennas requires the comprehensive knowledge of antennas surrounded by lossy biological tissues. Theoretical aspects related to the presence of lossy matter and their consequences on the characteristics of antennas are to be analyzed. As the description of the antenna performance (radiation efficiency, bandwidth, etc.) is highly dependent on the selected body model, it is required to mimic the human body in terms of numerical analysis and physical realizations.

3. GUIDELINES FOR THE DESIGN OF IMPLANTABLE ANTENNAS

The implantable antenna plays a key role to obtain robust communication links in a WBAN system. The allocation of the Med Radio frequency spectrum, together with the ISM and UWB bands, boosted the

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research on this subject leading to the design of optimized implantable antennas.

The guidelines for the design of implantable antennas are:

a) Investigate about the general requirements of implantable device, procedures for analysis.

b) Investigate various preliminary solutions to face some of the difficulties of the implantable antenna design in terms of design conception, technological realization.

c) Formulate an efficient design strategy.

The knowledge about the requirements for implantable antennas allows some preliminary investigations from both the design conception and the technological realization point of view. Based on the understanding of the implantable antennas characteristics, new radiators are to be proposed. Based on the acquired knowledge, an original strategy for the design of implantable antennas is proposed.

Preliminary Investigations of Implantable Antennas suggest three different topologies.

- **Large conformal telemetry device:** Integration of a conformal radiator (with dual band characteristics) with the selected transceiver and power supply relaxing the constraints on the physical dimensions;
- **Miniature dual band antenna:** Reduction of the antenna dimensions for a dual band radiator (in the MedRadio and ISM spectrum) with and without electronics.
- **Miniature single band antenna:** Reduction of the antenna dimensions of a single band radiator (in the MedRadio spectrum).

Numerical analysis can be performed with the commercial software High Frequency Structure Simulator (HFSS).

Single layer spiral and meander planar typologies are the most common implantable radiators used in the Med Radio band. Examples are depicted in Figure-4.1. Indeed, their geometries with and without grounding pin facilitate miniaturization. These two typologies are investigated in [18, 19] and compared in [9].

Extensive analysis of these antenna topologies is also reported in [24] and [25], where the effects of different dimensions and materials, and optimization with genetic algorithms techniques are also included, respectively. Both antennas are suited for implantable applications; however the spiral design provides higher radiation efficiency.

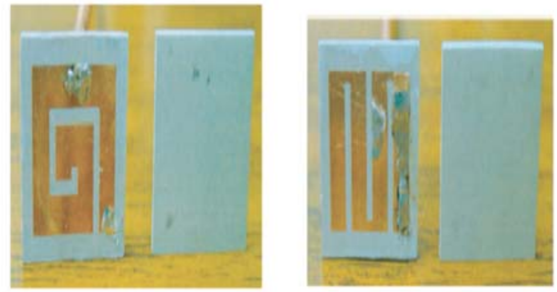
(a) (b)

Figure-4. Planar (single layer) antennas: the (a) spiral and (b) meander designs from [9].

Overall dimensions, including the biocompatible superstrate, shown on the right of each figure, are 20 x 24 x 2.5 [mm].

3.1 Comparison of implantable antennas

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

Antenna	Dimension with insulation [mm]	Body Phantom ε'_e	Body Phantom σ'_e	Body Phantom dimension [mm]	Implant depth [mm]	Gain [dBi]
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).

Taking advantage of previous investigations and considerations, an efficient design strategy for implanted antennas is to be proposed. Such a strategy targets a design yielding the best possible power transfer from the implanted device to the Base Station, while reducing the computational requirements. This design strategy comprises the following steps.

a) Fix the external geometry, the maximum volume for the whole telemetry device, and any other specific physical requirements for the targeted application.

b) Perform a first design in a homogeneous lossless medium so as to select the most performing antenna typology.

c) Consider a medium having a dielectric permittivity representative of the tissue surrounding the implant or equal to free space.

Different antenna typologies can therefore be investigated. The final choice will depend on the required bandwidth, the selected packaging and the available technological realizations.

4. a) Make a proper choice of the dielectric material, of the insulation layer and of the body phantom, and include them in the numerical analysis.

b) Set the excitation area so as to minimize the assembly complexity.

c) Optimize the radiator for the given new surrounding environment.

4. Evaluate the performances of the antenna in different body phantoms (from rough approximations to more detailed models). If required, modify the design starting from point 3.

The above mentioned procedure is helpful in optimization of the implantable antenna. This strategy will be applied to the design and realization of an implantable antenna.

4. INSULATING LAYERS AND ANTENNA MEASUREMENTS

In this section the positive effects of insulating layers on the radiated power of implanted sources are discussed. Three simplified models of the human tissues consisting in concentric spherical geometries and excited by ideal sources (electric dipole, magnetic dipole and Huygens sources) are to be analyzed.

Proper choice of the insulating layers improves the radiation efficiency of implanted antennas. This work gives insights on the power radiation of implanted sources. Therefore, it provides valuable information for the design of implanted antennas.

The measurement of implantable antennas at the component level is another major field to test the performance of implanted device. Undesired effects related to the presence of a feeding cable, when characterizing the matching properties of radiators inserted into a body phantom, are to be taken care while taking the measurements

5. CONCLUSIONS AND FUTURE SCOPE

Wireless Body Area Network (WBAN) has wide scope for research in various fields, to enhance the range of biomedical applications. The major challenge in front of microwave antenna researchers is to optimize the implantable devices. The aim of optimization is to reach the ideal conditions.

Keeping into account a wide range of technical and medical concerns, the focus has been concentrated on the implantable antennas, one of the most challenging elements of a WBAN system. In addition to the classical antenna problems, such as miniaturization and its consequent decrease of radiation efficiency, attention need to be paid to the coupling of the EM field with the biological lossy tissues. Furthermore, biocompatibility, physical requirements and the tight coexistence among all the components present in the entire WBAN system are to be taken into account.

REFERENCES

[1] A. Rosen, M. A. Stuchly and A. Vander Vorst. 2002. Applications of RF/microwaves in medicine. IEEE Trans. Microw. Theory Tech. 50(3): 963-974.

[2] 2009. The role of engineering principles in the medical utilization of electromagnetic energies from kHz to visible light - examples. International Journal of Infrared and Millimeter waves. 30(12): 1374-1386.

[3] D. Panescu. 2008. Emerging technologies [wireless communication systems for implantable medical devices]. IEEE Eng. Med. Biol. Mag. 27(2): 96-101.

[4] R. Bashirullah. 2010. Wireless implants. IEEE Microw. Mag. 11(7).

[5] R. S. Mackay. 1961. Radio telemetering from within the body: inside information is revealed by tiny transmitters that can be swallowed or implanted in man or animal. Science. 134(3486): 1196-1202.

[6] W. H. Steinberg, F. A. Mina, P. G. Pick and G. H. Frey. 1965. Heidelberg capsule. In vitro evaluation of a new instrument for measuring intragastric pH. J. Pharm. Sci. 54(5): 772-776.

[7] P. Valdastri, A. Menciassi, A. Arena, C. Caccamo and P. Dario. 2004. An implantable telemetry platform system for in vivo monitoring of physiological parameters," IEEE Trans. Inf. Technol. Biomed. 8(3): 271-278.

[8] K. Najafi. 2007. Packaging of implantable Microsystems. in Proc. IEEE Sensors. pp. 58-63.

[9] E. A. Johannessen, L. Wang, C. Wyse, D. R. S. Cumming and J. M. Cooper. 2006. Biocompatibility of a lab-on-a-pill sensor in artificial gastrointestinal environments. IEEE Trans. Biomed. Eng. 53(11): 2333-2340.

[10] D. Halperin, T. Kohno, T. S. Heydt-Benjamin, K. Fu and W. H. Maisel. 2008. Security and privacy for implantable medical devices. IEEE Pervasive Comput. 7(1): 30-39.

[11] Medical Device Radio communications Service (MedRadio), Federal Communication Commission (FCC) Std. CFR, Part 95.601-673 Subpart E, Part

ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

95.1201-1221 Subpart I,2009, formerly Medical Implanted Communication System (MICS).

[12] Electromagnetic compatibility and Radio Spectrum Matters (ERM); ShortkeCPX N Range Devices (SRD); Ultra Low Power Active Medical Implants (ULP-AMI) and Peripherals (ULP-AMI-P) operating in the frequency range 402 MHz to 405 MHz; Part 1 and Part 2, European Telecommunications Standards Institute (ETSI) Std. EN 301 839-1/2 V1.3.1, 2007.

[13] Sharing between the Meteorological Aids Service and Medical Implant Communications Systems (MICS) operating in the Mobile Service in the Frequency Band 401-406MHz., (ITU-R) Std. ITU-R Recommendation SA 1346, 2001.

[14] Standard for Safety Levels with Respect to Human Exposure to Radio Frequency Ele-ctromagnetic Fields, 3 kHz to 300 GHz, Institute of Electrical and Electronics Engineers (IEEE) Std. Std C95.TM, 1999.

[15] Standard for Safety Levels with Respect to Human Exposure to Radio Frequency Ele-ctromagnetic Fields, 3 kHz to 300 GHz, Institute of Electrical and Electronics Engineers (IEEE) Std. C95.TM, 2005.

[16] W. Xia, K. Saito, M. Takahashi, and K. Ito. 2009. Performances of an implanted cavity slot antenna embedded in the human arm. IEEE Trans. Antennas Propag. 57(4): 894-899.

[17] L. Bolomey. 2010. Generic DSP-based implantable body sensor node. Ph.D. dissertation, EPFL, Lausanne.

[18] J. Kim and Y. Rahmat-Samii. 2004. Implanted antennas inside a human body: simulations, designs, and characterizations. IEEE Trans. Microw. Theory Tech. 52(8): 1934-1943.

[19] R. W. P. King and G. S. Smith, Antennas in Matter: Fundamentals, Theory, and Ap-plications, 1st ed. Cambridge, Massachusetts and London, England: The MIT Press, 1981.

[20] C. Gabriel. 1996. Compilation of the dielectric properties of body tissues at RF and microwave frequencies. Brooks Air Force Base, Texas (USA), Tech. Rep. Report N.AL/OE-TR.

[21] R. E. Collin and F. J. Zucker. 1969. Antenna Theory Part II, ser. Inter-University Electronics Series. McGraw-Hill Book. Vol. 7.

[22] P. S. Hall and Y. Hao. 2006. Antennas and Propagation for Body-centric Wireless Communi-cations. Norwood, MA, USA: Artech House. Chapter 9.

[23] R. Fenwick andW. Weeks. 1963. Submerged antenna characteristics. IEEE Trans. Antennas Propag. 11(3): 296-305.

[24] R. Hansen. 1963. Radiation and reception with buried and submerged antennas. IEEE Trans. Antennas Propag. 11(3): 207-216.

[25] R. Moore. 1963. Effects of a surrounding conducting medium on antenna analysis. IEEE Trans. Antennas Propag. 11(3): 216-225.

[26] P. B. Johnson, S. R. Whalen, M. Wayson, B. Juneja, C. Lee, and W. E. Bolch. 2009. Hybrid patient-dependent phantoms covering statistical distributions of body morphometry in the U.S. adult and pediatric population. Proc. IEEE. 97(12): 2060-2075.

[27] P. Soontornpipit, C. Furse, and Y. C. Chung. 2004. Design of implantable microstrip antenna for communication with medical implants. IEEE Trans. Microw. Theory Tech. 52(8): 1944-1951.198 Bibliography.

[28] P. Soontornpipit, C. M. Furse, and Y. C. Chung. 2005. Miniaturized biocompatible microstrip antenna using genetic algorithm. IEEE Trans. Antennas Propag. 53(6): 1939-1945.

[29] J. Kim and Y. Rahmat-Samii. 2006. Planar Inverted-F antennas on implantable medical devices: Meandered type versus spiral type. Microwave and Optical Technology Letters. 48(3): 567-572.

[30] W.-C. Liu, S.-H. Chen and C.-M. Wu. 2008. Implantable broadband circular stacked PIfA antenna for biotelemetry communication. Journal of Electromagnetic Waves and Ap-plications. 22(13): 1791-1800.