Biomedical Telemetry: Today's Opportunities and Challenges

Cynthia M. Furse*(1)

(1) Dept. of Electrical and Computer Engineering, University of Utah, 50 S Central Campus Dr, SLC, UT 84112
Email:cfurse@ece.utah.edu

ABSTRACT: Biomedical telemetry is used today to communication with cardiac devices, insulin pumps, and a few other implantable devices that are on the order of 1-2" in diameter. Future systems promise advanced communication with cardiac, optical, neurological and auditory devices that are on the order of a centimeter in dimension. Miniaturized antennas and inductive coupling systems provide the radio interface between air and the implantable device. New materials and methods allow miniaturized communication systems to be seamlessly integrated within the medical device itself. This paper describes recent advances in biotelemetry, the challenges faced today, and opportunities for the future.

INTRODUCTION

Biomedical telemetry provides wireless communication from outside to inside of the body (or vice versa. Current systems have been designed or are being designed to communicate with implantable medical devices such as cardiac pacemakers and defibrillators, [1] neural recording and stimulation devices, [2] and cochlear [3] and retinal [4] implants. Inductive telemetry uses a large transmit/receive coil outside the body to couple power to a smaller coil implanted within the body. This is used both to power the communication electronics in the implant. It is also (typically) amplitude modulated to transmit data to the implant. These coils are often wound around a dielectric or ferrite core to improve the efficiency of transmission and use frequencies under 50 MHz to minimize attenuation of the signal within the body. [6] Most inductive telemetry links are used for subcutaneous applications due to power restrictions for passive devices. Significant advancements in these electronics are enabling smaller and smaller devices, although data rates still tend to be low.

Higher frequency telemetry links are also being developed for medical implants. For cardiac telemetry, a dipole [7] and spiral or serpentine microstrip [8][9], circumferential [10], and a waffle-type design [11] have been designed for implantation in the shoulder. An insulated wire antenna has also been used, and this wire may be used as the lead between the heart and the battery pack/controls of the pacemaker. [10] For smaller implants, a microstrip patch antenna has been successfully used for a retinal prosthesis [12], and a small dipole has been designed for communication with a brain implant. [13] Antennas for these imbedded applications must be small and long term biocompatible. Emerging medical telemetry devices have led to recent advances in the design of small, biocompatible antennas that can be implanted in the human body. The absorption of the fields by the body limits the distance that an external transceiver can be placed from the body. If the power is increased, battery life suffers, and the device may exceed regulations for maximum power absorption (specific absorption rate – SAR) in the body. Implantable medical devices utilize the Medical Implant Communication Service (MICS) band from 402-405 MHz. The maximum bandwidth that can be used by a single device is 300 kHz in this band, and the range is typically 2 meters. The maximum power limit is 25 μW Equivalent Radiated Power (ERP), and the system is required to use clear-channel assessment, where the external device scans all 10 of the MICS channels and chooses the lowest noise channel.

Improvements in transceiver architectures, data mining and data compression are used to provide chip rates on the order of 20 kbps at a distance of 2 meters using low power biotelemetry. Some of the methods used to achieve this efficiency are design of an ultra-efficient sleep mode followed by short bursts of data transmission activity, by using data mining or compression strategies to reduce the actual bits of data to be transmitted, or by improved design of the hardware. One of the significant upcoming opportunities for biotelemetry of this sort if for communication with implanted electrodes for neural recording and/or stimulation. Tiny silicon electrodes may be implanted in the brain or nerves. Previously these systems have been used experimentally to receive brain signals or to transmit small amounts of data via a wired link through the skin. A wireless link is currently being designed using flip-chip bonding to combine the transceiver, inductive coil, power control electronics, amplifier, data processing electronics, and electrode array into a single subcutaneous package, shown in Fig. 1 [5]

978-1-4244-4396-3/09/$25.00 ©2009 IEEE

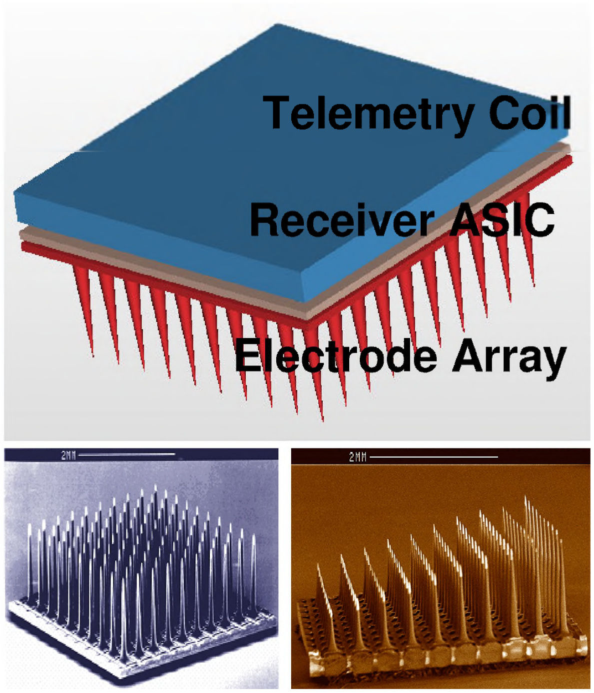

Fig. 1 Utah Electrode Array packaged with a custom ASIC and printed receiver coil (From [14] © 1999)

ANTENNAS FOR BIOTELEMETRY

Designing antennas for imbedded applications is extremely challenging, because of reduced antenna efficiency, impact of the environment on the antenna, the need to reduce antenna size, and the very strong effect of multipath losses. Electromagnetic (EM) waves are greatly attenuated through the highly-conductive (essentially salt water) environment. The spiral microstrip antenna shown in Fig. 2 uses a ground pin to increase the apparent length of the antenna, much the same way a ground plane doubles the height of a monopole antenna. The substrate material below and human body above the antenna plate reduce the effective wavelength and hence the necessary size of the antenna. The body also acts as an absorber, and if allowed to be in direct contact with the antenna would short circuit it. Thus, an insulating (silicone) superstrate laye is used to provide separation between the antenna and body. A version of this antenna has also been used in [9]. Another type of antenna used for communication with cardiac devices is the circumference antenna, which is a monopole antenna that is mounted around the edge of the pacemaker case. [1] For smaller implants, a microstrip patch antenna has been successfully used for a retinal prosthesis, [16] and a small dipole has been designed for communication with a brain implant. [9]

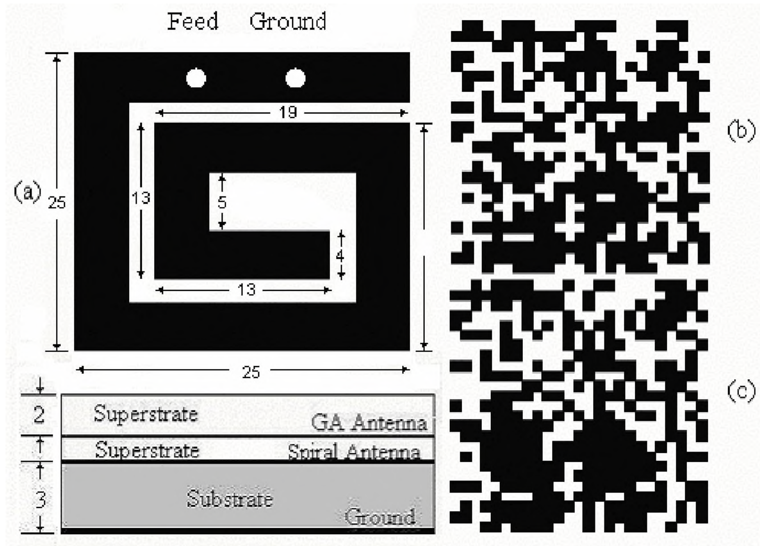

Fig. 2: Microstrip antennas designed for cardiac pacemaker telemetry at 403.5 MHz.. (a) spiral antenna (b) GA antenna option #1 (c) GA antenna option #2. From [12].

DE-TUNING EFFECTS

One of the other major challenges when designing implantable antennas is that the various body tissues and fluids act as dielectric loading on the antenna, significantly altering its performance. Antennas must be designed for their specific location in the body. Some researchers have designed for a 'generic' location using layered models [8] and others have used specific regions of the body such as the chest or shoulder [9] . The trouble with both of these approaches is that the electrical properties and dimensions of the various tissues in the body vary significantly from individual to individual, and even within a single person, and are therefore not precisely known. This ambiguity means that an antenna that is optimized for one location and person may be detuned for another location or another person. The resonant frequency shifts, the impedance changes, and even the radiation pattern may change in extreme cases. This detuning must be considered when designing antennas for realistic configurations, such as the example shown in Fig. 3. This variability significantly reduces the effective bandwidth the antenna can be designed to support, because both the high and low detuned frequencies must be considered.

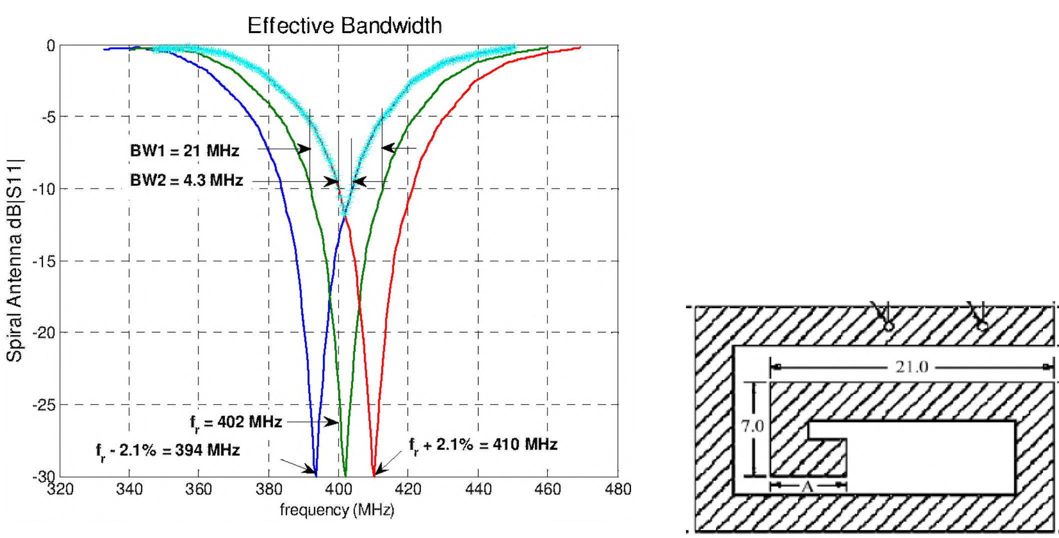

Fig. 3 Example frequency shift (detuning) caused by statistical variation in the electrical properties of tissue for the 402 MHz cardiac pacemaker antenna [8] designed for use in the torso. From [15].

REFERENCES

[1] J. Johansson, "Simulation and verification of pacemaker antennas," *Proceedings 25th Annual Int'l Conf IEEE EMBS*, Cancun, Mexico, Sept 17-21, 2003

[2] K. Guillory and R. A. Normann, "A 100-channel system for real time detection and storage of extracellular spike waveforms," *J. Neurosci. Methods,* Vol. 91, pp. 21-29, 1999

[3] T. Buchegger, et al., "An ultra-low power transcutaneous impulse radio link for cochlea implants," *Joint Ultra Wideband Systems and Technologies (UWBST) and International Workshop on UWBS 2004* (IEEE Cat. No. 04EX812) pp. 356-360, 2004

[4] K. Gosalia, G. Lazzi, M. Humayun, "Investigation of microwave data telemetry link for a retinal prosthesis," *IEEE Trans. Microwave Theory and Techniques*, Vol. 52, No. 8, pp. 1925-1932, Aug. 2004

[5] R.R. Harrison, P.T. Watkins, R.J. Kier, R.O. Lovejoy, D.J. Black, B. Greger, and F. Solzbacher, "A low-power integrated circuit for a wireless 100-electrode neural recording system," *IEEE Journal of Solid-State Circuits* 42: 123-133, January 2007

[6] M. Ghovanloo and G. Lazzi, "Transcutaneous Magnetic Coupling of Power and Data," (invited paper) *Wiley Encyclopedia of Biomedical Engineering*, M. Akay Editor, Wiley (to appear, 2006)

[7] L. Griffiths, "Analysis of wire antennas for implantation in the body," *Master thesis*, Utah State University, Logan, UT, 2002.

[8] P. Soontornpipit, C.M. Furse, and Y. C. Chung, "Design of implantable microstrip antennas for communication with medical implants", *IEEE Trans. MTT*, vol. 52, issue 8, pp. 1944- 1951, Aug. 2004.

[9] J. Kim, and Y. Rahmat-Samii, "Implanted antennas inside a human body: simulations, designs, and characterizations", *IEEE Trans. MTT*, vol. 52, issue 8, pp. 1934- 1943, Aug. 2004.

[10] J Johansson, Wireless Communication with Medical Implants: Antennas and Propagations, PhD Dissertation, Lund University, 2004, ISSN 1402-8662

[11] K. Gosalia, J. Weiland, M. Humayun, and G. Lazzi, "Thermal elevation in the human eye and head due to the operation of a retinal prosthesis," *IEEE Trans. Biomedical Eng*ineering, vol. 51, no. 8, Aug. 2004.

[12] P. Soontornpipit, C.M. Furse and Y.C. Chung, "Miniaturized Biocompatible Microstrip Antenna using Genetic Algorithm," *IEEE Trans. Antennas and Propagation,* June 2005, pp. 1939-1945

[13] M.Sun, M.Mickle, W.Liang, Q.Liu, and R.J. Sclabassi, "Data Communication Between Brain Implants and Computer," *IEEE Trans. On Neural Systems and Rehabilitation Engineering*, Vol. 11, No. 2, 2003, pp. 189-192

[14] K. Guillory and R. A. Normann, "A 100-channel system for real time detection and storage of extracellular spike waveforms," *J. Neurosci. Methods,* Vol. 91, 1999, pp. 21-29

[15] J. Johnson, C. Furse, "Statistical Analysis of Detuning Effects for Implantable Microstrip Antennas," North American Radio Science Conference URSI-CNC/USNC organizers. July 22-26, 2007, Ottawa, Canada

[16] M.Sun, M. Mickle, W. Liang, Q. Liu, and R.Sclabassi, "Data Communication Between Brain Implants and Computer," *IEEE Trans. On Neural Systems and Rehabilitation Engineering*, Vol. 11, No. 2, pp. 189-192, 2003