Chapter 25
Design of Implantable Antennas for Medical Telemetry:
Dependence upon Operation Frequency, Tissue Anatomy, and Implantation Site

Asimina Kiourti
School of Electrical and Computer Engineering-National Technical University of Athens, Greece

Konstantina S. Nikita
School of Electrical and Computer Engineering-National Technical University of Athens, Greece

ABSTRACT

Implantable Medical Devices (IMDs) with wireless telemetry functionalities in the radio-frequency (RF) range are recently attracting significant scientific interest for medical prevention, diagnosis, and therapy. One of the most crucial challenges for IMDs is the design of the integrated implantable antenna which enables bidirectional wireless communication between the IMD and exterior monitoring/control equipment. In this paper, a parametric model of a miniature implantable antenna is initially proposed, which can be adjusted to suit any antenna design and implantation scenario requirements in hand. Dependence of the resonance, radiation, and safety performance of implantable antennas upon (a) operation frequency, (b) tissue anatomy and dielectric properties, and (c) implantation site is further studied. Simulations are carried out: (a) at 402, 433, 868 and 915 MHz considering a 13-tissue anatomical head model, (b) at 402 MHz considering five head models (3- and 5-layer spherical, 6-, 10- and 13-tissue anatomical) and seven dielectric parameter scenarios (variations ±20% in the reference permittivity and conductivity values), and (c) at 402 MHz considering 3-layer canonical models of the human head, arm, and trunk. The study provides valuable insight into the design of implantable antennas. Finite Element and Finite Difference Time Domain numerical solvers are used.

INTRODUCTION

Implantable Medical Devices (IMDs) with wireless telemetry functionalities in the radio-frequency (RF) range are nowadays used to perform an expanding variety of diagnostic and therapeutic functions. Example applications include temperature monitors (Scanlon, 1997), pacemakers and cardioverter defibrillators (Wessels, 2002), functional electrical stimulators (FES) (Guillory & Normann, 1999), blood-glucose sensors (Shults, 1994), cochlear (Buchegger, 2005), gastric and bladder controllers (Sani, 2009), glucose monitors (Karacolak, 2008), retinal implants (Gosalia, 2004) etc. As technology continues to evolve, new implantable medical devices are being developed, and their use is expected to rapidly increase from an already large base.

A key and critical component of RF-enabled IMDs is the integrated implantable antenna, which enables bidirectional wireless communication between the IMD and exterior monitoring/control equipment. Designers of implantable antennas need to deal with a number of challenges, including miniaturization, biocompatibility, impedance matching, radiation performance, and compliance with international safety guidelines for the specific absorption rate (SAR). Patch designs are usually preferred, because of their flexibility in design, shape, and conformability. Furthermore, patch antennas lend themselves easily to a number of miniaturization techniques, including use of high-permittivity dielectric materials, lengthening of the current flow path excited on the radiating patch, addition of shorting pins between the ground and patch planes, and vertical stacking of multiple patches (Kiourti & Nikita, 2012a).

Medical implant communications most commonly take place in the medical implant communications service (MICS) band (402.0–405.0 MHz), which is regulated by the United States Federal Communications Commission (FCC, 1999) and the European Radiocommunications Committee (ERC, 1997). The 433.1-434.8, 868.0-868.6 and 902.8-928.0 MHz industrial, scientific and medical (ISM) bands are additionally suggested for biotelemetry in some countries (ITU-R). However, focus is on the MICS band, because of its advantages to be available worldwide and feasible with low power and low cost circuits, reliably support high data rate transmissions, fall within a relatively low noise portion of the spectrum, and acceptably propagate through human tissue.

Since implantable antennas are intended to operate inside human tissue, their performance strongly depends on the surrounding tissue environment. This includes the anatomical features of the individual, the dielectric parameters (permittivity, ε_r, and conductivity, σ) of the biological tissues, and the part of the body where the antenna is to be implanted, known as the implantation site. For example, smaller size (female and low body mass index male) anatomical models have been found to exhibit higher radiated power levels and far-field gain values (Sani, 2009). Uncertainties and inter-subject variability in dielectric parameters need also to be taken into account. Maximum standard deviations of 16% have been reported in the dielectric parameter values of rat brain tissue (Bao, 1997), while a decrease in permittivity and conductivity values by 4% and 10% has been recorded for pig tissue within 4 h after death, respectively (Schmid, 2003). Dependency of dielectric parameters on the age of the subject has also been highlighted (Conil, 2008). Finally, the intended implantation site determines the types and structure of the tissues surrounding the antenna, and, therefore, its dielectric loading. For example, skin-implantable antennas might operate in a different way while implanted within the skin-tissue of different parts of the body.

In this study, a parametric model of a miniature implantable antenna is proposed, which can be adjusted to suit any antenna design (e.g. size, material etc) and tissue model (e.g. implantation site) requirements in hand. Dependence of the resonance, radiation, and safety performance of implantable antennas upon

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