Development of a Highly Integrated (sub 1 cm^2) Wirelessly Powered Implantable Medical Device (WPIMD) using a custom RFIC design

Abstract

This document presents a short summary of recent work over the past quarter in the MCCI funded WPIMD project.

Introduction

In the last report, the main subject of this work was introduced, namely the development of a Wirelessly Powered Implantable Medical Devices (WIMDs) that are rapidly emerging in a wide range of Medtech applications. In addition, the last report summarized the key findings of a review study on WPIMD devices reported in the literature. The last report also outlined the need for the development of a high-level MATLAB model for use in calculating wireless power transfer (WPT) performance in WPIMD applications. The goal of this modelling work is to provide a first-order analysis of the potential RF power that can be delivered to an implanted device. The following section provides a short summary of the Analytical MATLAB Model that has been developed during Q2, 2022.

WPIMD Analytical Modelling

Figure 1 shows the general operation of a WPIMD RF Front-End: Where an external transmitter (TX) antenna is used to direct RF energy to an implantable device, which has an on-chip receiver (RX) antenna. This RX antenna is used to harvest this RF energy, which can then be converted into a usable DC output voltage using an RF-DC rectifier. A challenge in the design of such devices is in ensuring that enough power is received to operate the device, and hence the early stages of this project has involved investigating the wireless power transfer limits for these types of systems.

Typically, Electromagnetic (EM) tools such as HFSS (High Frequency Structure Simulator) is used to simulate WPIMD structures – this is a FEM (finite element method) simulation tool which is used to solve Maxwells equations for antenna structures in order to investigate power transfer limits in WPIMDs. While this simulation tool is very accurate, simulation times are lengthy (hours → days and more), and hence the goal of this work is to develop an analytical model which can generate fast, approximate results for these types of systems.

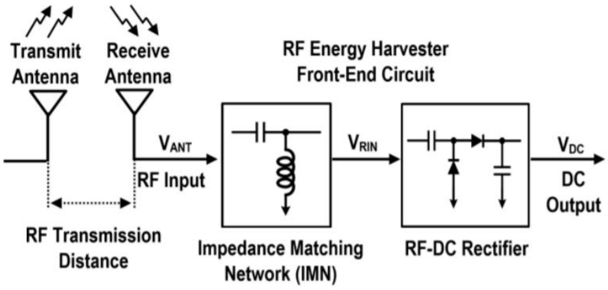

Figure 1: WPIMD RF Front-End [1]

Sources of Power Loss

In the developed analytical modelling work over the past 3 months, a number of sources of power loss have been accounted for to-date:

- Antenna parameters, e.g. Directivity and gain
- Free-Space Propagation Losses
- Biological Tissue Losses (Multi-Layer)

Wireless Power Transfer Modelling

As a first order analysis of WPT in a WPIMD system, a far-field, plane wave solution model has been developed. The biological tissue layers between the external TX antenna and implanted RX antenna have been approximated as a layered planar tissue model (Figure 2) [4 – 7], in which the frequency-dependent electrical parameters of each tissue layer can be predicted using a Cole-Cole Dispersion Model (CCDM) (Figure 3). [2, 3]. The electromagnetic wave propagation through this layered tissue structure is modelled using the Wave Matrix Method described in [7].

In general, the biological tissue parameter fitting is poorly approximated by the CCDM at low frequencies, but is a much better approximation of tissue parameters at higher frequencies – as WPIMDs are typically operated in this higher frequency range (as it allows for device miniaturisation + higher bandwidth), this Cole-Cole Modelling is a suitable approximation of biological tissue behaviour.

A number of test-cases with different layered tissue structures were simulated in HFSS, with the results being compared with the analytical results developed in the MATLAB model. The results agree to a reasonable degree of accuracy (~4 dB average error) and provide a good first estimate of available electrical power at the implant.

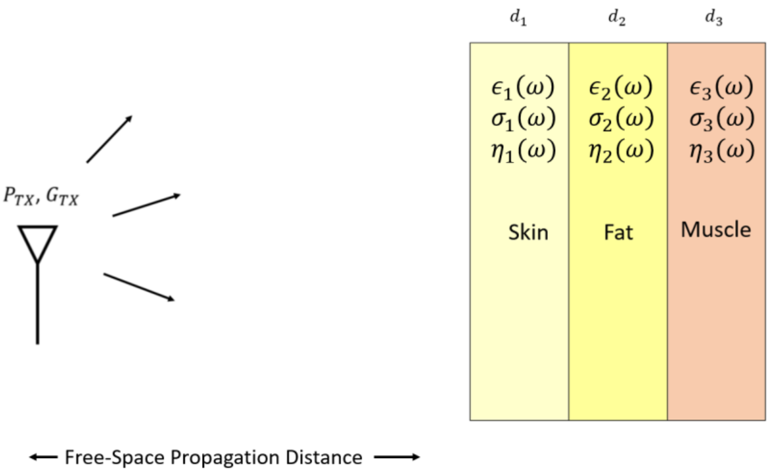

Figure 2: Frequency-Dependent Layered Planar Tissue Model Approximation

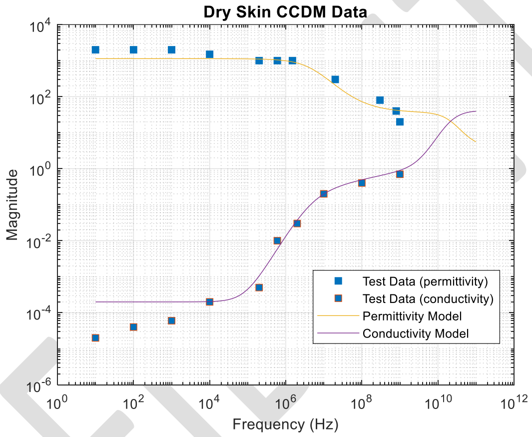

Figure 3: Example of Frequency-Dependent Prediction of Biological Tissue Electrical Parameters

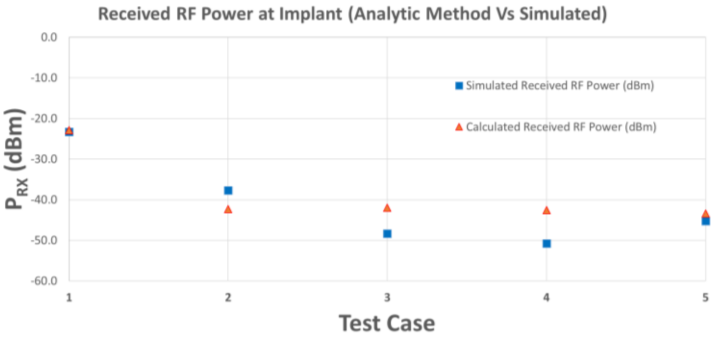

Figure 4: Comparison of Analytical Model with Simulated Results

Future Work

Validation of analytical model and a literature review of State-of-the-Art RF-DC rectifiers is also in progress.

References

[1] Wide Power Dynamic Range CMOS RF-DC Rectifier for RF Energy Harvesting System: A Review, Choo Chia Chun et al.

[2] The dielectric properties of biological tissues: III. Parametric models for the dielectric spectrum of tissues, Gabriel et al.

[3] Variation of Cole-Cole Model Parameters with the Complex Permittivity of Biological Tissues, Tarek M. Said

[4] The Dependence of Electromagnetic Far-Field Absorption on Body Tissue Composition in the Frequency Range From 300 MHz to 6 GHz, Christ et al.

[5] Planar Multilayer Model of Human Tissue Exposed to a Plane Electromagnetic Wave, Grund et al.

[6] The Reflection of Electromagnetic Field by Body Tissue in the UWB Frequency Range

[7] Electromagnetic Waves and Antennas, Sophocles J. Orfanidis, Rutgers University