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 Wireless Implantable Medical Devices (WIMDs) that are an emerging area for wireless sensing in a wide range of medical applications.

The last report also detailed progress on the development of a high-level model for analysis of wireless power transfer (WPT) of RF energy from an external reader to the WPIMD implant, where DC power is generated to power the device. In order to use this model, data from real-world WPIMD devices is required to enable calculation of key performance parameters for the implant. This required a detailed literature review of state-of-the art WPIMD devices reported in the literature and are now discussed in the following section.

Literature review for WPIMD devices – Wireless Power transfer

A comprehensive review of 13 start-of-the-art WPIMD devices for implantable applications was conducted. The key parameters of interest are shown in Table 1. These parameters include the external reader antenna topology denoted Tx antenna and the type of receive antenna integrated in the implant, denoted Rx antenna. The frequency of operation is also of key interest as it influences the type (topology) of antennas that can be used as well as physical size of the antennas (Tx and Rx) and also plays a role in determining the level of human body RF tissue losses that are also frequency dependant. The Tx radiated power from the external reader is also a critical parameter to study as this parameter is limited by safety regulations in order to meet specific absorption rate (SAR) limits defined by regulatory authorities. Finally, knowledge of the received (RX) radio frequency (RF) power received by the implant antenna, enables several key WPT performance parameters to be estimated relating to wireless power transfer.

These performance parameters include Power Transfer Efficiency, measured in dB, that expresses the ratio of P_{RX} to P_{TX} that is achievable. Looking at Table 1, this quantity is shown to range from -3.26 dB to -57 dB. This large range depends mainly on the antenna types and dimensions as well as the type of coupling employed, such as near-field and far-field coupling that greatly affects the amount of power that can be received at the implant antenna.

Other key parameters that affect WPT performance include the reader-to skin distance and the implant depth. All of these parameters are listed in Table 1.

Table. 1. Analysis of literature for WPIMD WPT performance

Ref.	Tx Antenna type	Rx Antenna type	Operation frequency (MHz)	Antenna size (mm)	P_{TX} (mW)	P_{RX} (mW)	Power transfer efficiency (dB)	Reader to skin distance (mm)	Implant depth (mm)
1	Loop	Loop	400	1 × 1 × 0.9	82	0.08	-30.12	3	12
2	Loop	Loop	402	1 × 1 × 0.9	19	0.005	-35.83	3	12
3	Loop	Loop	39.86	11 × 11 × 1.8	245	114.8	-3.26	NA	10
4	Loop	Loop	907	6.5 × 6.5 × 0.05	29	0.118	-24	5	11
	Patch	PIFA	1470	NA	1000	6.7	-21.75	5	50
5	Log-periodic	PIFA	610	π × 5 × 5 × 2.2	1	2.00E-06	-57	1950	50
6	Loop	Loop	1078	π × 1.25 × 1.25 × 15	480	1.26	-25.8	20	33
	Loop	PIFA	915	π × 5.5 × 5.5 × 1.28	1000	0.338	-34.9	184	16
7	Log-periodic	PIFA	915	16 × 14 × 1.27	316.2	0.0324	-39.9	500	10
8	Patch	Slot	2450	12 × 12 × 0.3	1000	12.2	-19.2	60	3
	Antenna Array	Dipole (Fractal)	945	12 × 10	125	15.384	-9.2	10	110
9	Loop	Loop	2	27-turn Diameter 27; wire Diameter 0.381	1400	430	-5.11	NA	5
10	Loop	Loop	915	2 × 2	250	0.214	-30.68	0	15
	Horn	PIFA	2400	4 × 8 × 0.635 × 2	908.23	0.067	-41.3	481	19
11	Loop	Loop	160	2 × 2.18	146	1.17	-20.96	2.5	7.5
12	Slot arrays	Loop	1600	Diameter 2 × 3.5	500	0.195	-34.09	10	40
	Loop	Loop	0.5	Diameter 5 × 20	329	100	-5.16	NA	100
13	Slot	PIFA	1500	9 × 13 × 0.8	1000	5.6	-22.5	10	45

Table. 1 provides valuable empirical data for high-level modelling of WPT performance for WPIMD devices. The next step for analysis is to use this data to compute the potential DC power that can be derived from these available levels of Rx power, once RFtoDC conversion is applied.

Conclusions

- The main achievement for the last quarter have been a detailed survey of the literature for WPIMD devices and extracting key performance data.
- This performance data will be used for further analysis of WPIMD power-level analysis to determine the limits of DC power that can be delivered to the implant. This in turn will help define the type of circuit blocks that can be powered and will be valuable to help choose low-power circuit topologies for RFIC integration.
- One of the key challenges to-date has not been technical but related to resourcing in identifying a suitable PhD candidate for this work. Particularly, a candidate with the required RFIC design skills.
- In the last 2 weeks, (as of the end of September), we have identified a recently graduated H1.1. student with RFIC and Analog IC design experience. We have already talked with this student and have identified him as a very suitable Masters candidate and planning to interview this candidate on Wed 20th October, 2021.
- The goals for the next quarter are a more detailed analysis of the high-level WPT model to provide an estimate of the range of DC power levels that can be provided within the implant after rectification.
- In addition, a key ongoing focus is the continuation of interviews for a suitable PhD candidate.