Design and Characterization of a Microcoil for Inter-Arterial Monitoring

Kovner Chalumo, Physics, Howard University

NNIN REU Site: Materials Science Research Center of Excellence, Howard University
Principal Investigator: Gary L. Harris, Ph.D., P.E., Professor and Associate Director, MSRCE, Howard University
Mentor: Abhishek Motayed, MSRCE, Howard University
Contact: kchalumo@howard.edu, GHarris@msrce.howard.edu

Abstract:

This paper focuses on the design and characterization of a micro-implantable telemetric system used for monitoring inter-arterial blood pressure, and monitoring parameters (physical dimensions, inductance, capacitance, resistance) of the device that effectively modify the efficient transmission of power.

Evaluation and characterization of an implantable telemetric unit is of utter importance because of parasitic electric effects that take effect during transmission of electromagnetic waves at high alternating current frequencies. These electrical parasitic effects are responsible for signal degradations as well as other hindering phenomena. There are requirements that this system must fulfill; it must be powered remotely, ergo, doing so efficiently, consume little to no power (ideally), and present little if any effect on the human body. Silicon carbide technology offers interesting perspectives for inter-arterial, inter-cranial, and inter-ocular sensor development.

Introduction:

Telemetry involves the transmission of information/data from a fixed point to a remote receiving system. The information/data that is sent telemetrically can, for example, be the response of a capacitive unit implanted in a human artery. Proliferations of this example are used frequently in medical applications. Implantable medical devices are not limited to, but include, monitoring inter-arterial, inter-cranial, and inter-ocular measurements.

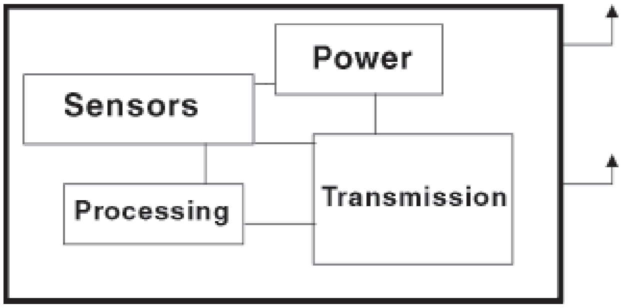

Figure 1: A simplified telemetric unit for monitoring purposes: sensors, processing circuitry, transmission circuitry, power circuitry, and housing case.

Implantable telemetric units can be implemented in micromechanical technologies using silicon as a building block. Other means have proven themselves difficult and inefficient. So using micromachining and silicon, there is a greater feasibility that telemetric systems can be made economically efficient.

Telemetric System Configuration:

A simplified rendition of a telemetric unit can be seen in Figure 1. Telemetric monitoring operates on the principal of continuous measurement of certain parameters, with transmission of these data to a remote system. Figure 1 displays the crucial components necessary for a minimal telemetric unit: the power controller, signal circuitry, transmission circuitry, and sensor device, without compromise to the housing case. An ideal microtelemetric system for implantation consumes little power, is powered remotely and is capable of transcutaneous transmission.

Figure 1 implies various implementations. The power source can be either a battery or an inductively coupled power link. The latter implementation is the main focus of this paper. The device in Figure 1 essentially works as a transceiver, capable of functioning remotely, void of any battery power. So, inductive coupling participates heavily, if not most heavily, in sound transfer of power from the remote to the host implanted system. The sensor device can be configured using piezoresistive, capacitive, or resonant sensors. We have decided to utilize a capacitive sensor because monitoring blood pressure requires measuring stress variations in blood level. The other sensors are incapable of this function.

Theory:

The objective of this research is a preliminary task which involves characterizing a planar microcoil for use in an implantable microsystem. The task is preliminary because it is part of a process which includes designing, characterizing, and fabricating a telemetric device for inter-arterial blood pressure monitoring. This paper focuses on the design and characterization of a planar microcoil so that transmission of power from a remote system to host is maximized and efficient.

Below is a list of physical phenomena that participate in effectively reducing/increasing efficient power transfer:

Self-Inductance: Self-inductance is defined as the magnetic flux per unit current in a coil. Simply, self-inductance is two times the energy stored in the magnetic field divided by the square of the current through the coil. We have focused on the self-inductance of various coils that operate on low-frequencies and have no skin effect.

Series Resistance: The series resistance of a planar microcoil can be divided into two. One which is dependent of frequency and one which is not. The frequency dependent resistance is a result of the strong time-varying magnetic fields produced by the alternating current in the circuit. The dependent resistance is a result of the wire materials resistivity, which varies for different materials. This series resistance can be deduced using Ohm's law.

Parallel Resistance: The parallel resistance is caused by the finite resistance of the insulating layer in which the coil is placed. The influence of parallel resistance is negligible; therefore, we will disregard it in our endeavors.

Parasitic Capacitance: The parasitic capacitance of the microcoil is composed of 3 individual capacitances; the capacitance between the turns and substrate, the coil's turns and the capacitance between the pads and substrate.

Mutual Inductance: The mutual inductance between two coils depends on the self-inductance of the receiver coil and a special parameter, which is a measure of the coupling, and depends on the relative positioning of both the coils.

Q-Factor: The Quality-factor of a receiver is a measure of efficiency. The q-factor of a coil is directly proportional to the transmitted energy the coil receives, yet indirectly proportional to the energy of heat dissipated by that receiver. Another way to express the efficiency of a coil is in terms of the coil's impedance or output voltage with respect to the frequency at which the coil operates. Hence, the greater the quality factor the better the transmission.

Results and Conclusions:

As the outer/inner ratio of the coil increases, z (Figure 2), the resistance and capacitance of the coil decreases. We realized a indirect relationship between the two. In contrast, the intrinsic resonance frequency and Q-factor increase with the outer/inner ratio. If the frequency of the transmitter remains constant, the preceding statement fails to hold any validity. The Q-factor reaches a maximum when the outer/ratio of the coil is about 0.3. As the intrinsic resonance frequency increases, the amount of energy for collection increases. The Q-factor of a microcoil can be maximized by three main factors; 1. decreasing the series resistance of the microcoil, 2. decreasing the parasitic capacitance, and 3. increasing the self-inductance of the microcoil.

Acknowledgements:

Gary L. Harris, Ph.D., P.E. Professor and Associate Director, and Abhishek Motayed, both of MSRCE, Howard University.

References:

[1] C.R. Neagu, Characterization of a planar microcoil for implantable Microsystems, Sensors and Actuators A62 (1997), pp. 599 - 611.

[2] R. Puers, Linking sensors with telemetry: impact on the system design, Tech. digest 8th Int. Conf. Solid State Sensors and Actuators. Stockholm, Sweden, June 25 - 29 June, 1995, pp. 47 - 50.

[3] F.E. Terman, Radio Engineers Handbook, McGraw-Hill, London. 1943.

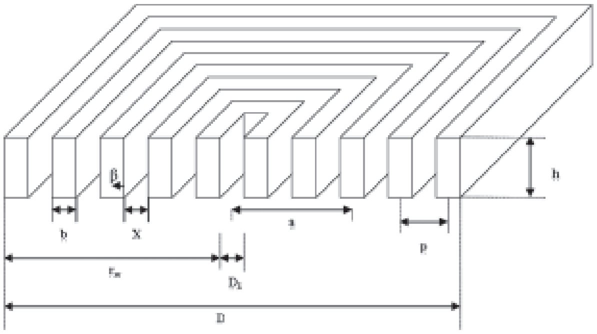

Figure 2: Cross-section of a planar microcoil displaying geometric parameters and the relations between them. $z = D_i/D$, $p = x_1+b$, $r_w=(D_i-D)/2 = D(1-z)/2$, $a = (D_i+D)/4 = D(1+z)/4$, $s = D_i+r_w = D(1+a)/2$, $N = R_w/p = D(1-a)/2_p$; *where* D = *diameter of coil,* r_w = *winding depth,* b = *width of wire,* h = *height of wire,* a = *mean radius of coil,* D_i = *internal diameter,* β = *current depth penetration,* x_1 = *distance between adjacent turns.*