Analysis of a Energy Harvester for Medical Applications

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Abstract

Due to advances in nanotechnologies it is possible to create smaller circuits, which led to a decrease of size of medical implanted devices. Now a days most of the volume of those devices occupied by batteries, therefore, to decrease the size of the devices several energy harvesting systems relying in different types of energy have been studied in order to recharge and/or replace batteries. In this paper the main goal is to present and analyse the behaviour of a circuit – designed as a RF rectifier, which also works as a voltage doubler – can be used to power a implantable device designed to study the watertightness and innocuity of new types of encapsulation *in vivo*.
Keywords: Energy harvesting; Radiofrequency; Radiofrequency energy harvester; Coil Sizing.

1. Introduction

For decades titanium was the to go choice for implanted medical devices. Titanium is not only biocompatible but also very durable, but since it is a metal it acts as a Faraday cage which inhibits the use of external power sources (e.g., radiofrequency) to recharge the its battery. And since they can't be recharged, when the battery discharges there is a need to undergo a operation in order to change the battery, which could be avoided if the implant relied on energy harvesting methods to either supply energy to the implant or to recharge its batteries.

In order to fight that, numerous researches focusing in non metallic biocompatible casings for implants were and are being made. And that is what lead to this study. Various biocompatible materials have been idealized and tested *in vitro*, i.e., for simulated environmental properties that are expected in vivo (e.g., humidity, temperature; etc) this simulation is good to put aside casings that definitely wouldn't work *in vivo*. But are not enough because there are are variables that cant be simulated such as how the scar tissue develops around the casing, therefore a *in vivo* test is required.

The *in vivo* testing will be done in rats, therefore the overall circuit and its casing dimensions should be in the order of the milimeters.

2. Background

A circuit designed by INESC_ID to work coupled to 50 Ω antenna, consists in two T-match networks and a differential rectifier which also works as a voltage multiplier, Fig. 1. [1]

The coils in the matching network have a outer diameter of 298 µm. When a coil is crossed by a time variant magnetic field a induced electromotive force, $f.e.m$, will be generated at its terminals,

$$f.e.m = \frac{\Delta \Phi_E}{\Delta t}, \quad (1)$$

if the $f.e.m$ is strong enough to bias the rectifier, 15.847 mV, a DC signal will be supplied to the load of the circuit.

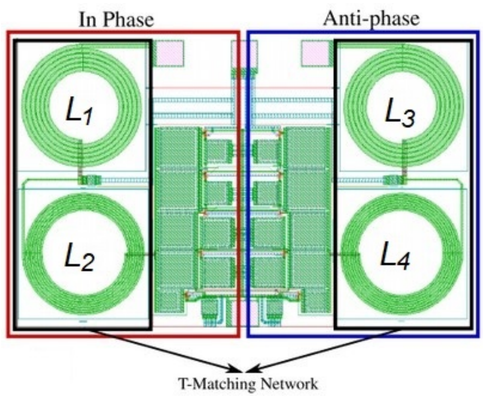

Figure 1: Layout of the circuit

3. Magnetic Field Generator

In order to test the hypotheses that the previous circuit can be used as a inductive energy harvester a time varying magnetic field has to be created. When a time varying current goes through a coil it generates a magnetic field with the same frequency than the current, therefore if a signal generator is connected to a coil it will be a time magnetic field generator.

In this study the signal generator R&S®SMA100A was used, and three different coils were manufactured in order to study how the circuit behaved under different magnetic fields conditions.

The manufactured coils were:

- A pancake coil, Figure 2, with outer diameter of 16 mm and inner diameter of 5 mm, which inductance and parasitic resistance and capacitance are present in Table 1.

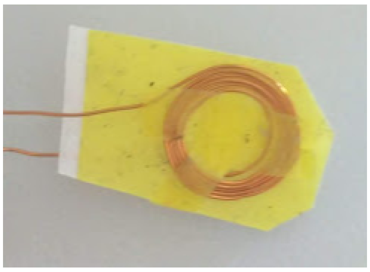

Figure 2: Pancake coil

Table 1: Parameters of the pancake coil

Z [Ω]	R_{par} [Ω]	C_{par} **[nF]**	L **[nH]**
13.81	8.87	3.31	305.91

- A solenoid, Figure 3 with 6 turns with diameter 5mm and length of 20 mm, Table 2 presents its parameters.

Figure 3: Solenoid

Table 2: Parameters of the solenoid

Z [Ω]	R_{par} [Ω]	C_{par} **[nF]**	L **[nH]**
4,52	1,67	7,56	133,89

- A Helmholtz coil, Figure 4, which consists in two equal windings each one composed by 20 turns with diameter equal to 10 cm, and the distance between the windings is equal to the radius, 5 cm. The Helmholtz coil is know for generating a almost homogeneous field between their windings.

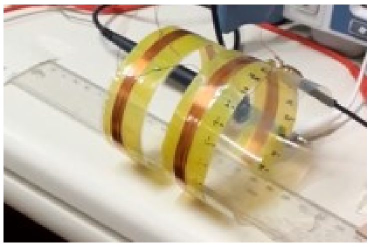

Figure 4: Helmholtz coil

4. Tests and Results

All tests where done with a resistive load of 1 MΩ connected to the energy harvester. Henceforth the magnetic field generator will simply be denominated generator and the energy harvester will be denominated harvester. V_{out} is the DC voltage at the load of the energy harvester read by a multimeter. The influence of different variables were analyzed:

4.1. Relative position between the generator and the harvester

The magnetic flux, Φ, on a area in space, A, is given by,

$$\Phi = B \cdot A \cdot \cos\theta, \quad (2)$$

where B is the magnetic field intensity and θ the angle between the magnetic field and normal vector of the area in study. So a analysis of the behaviour of harvest for different relative positions of the generator where analysed for the different generators, the frequency of the magnetic field was 915 MHz.

- Pancake coil – Since the harvester was connected to a PCB, the analysis was limited, but for distances up to 4 cm the output voltage of the harvester, V_{out}, was higher than 10 mV. As expected, when the distance increases there is a decrease in the V_{out}, that is specially prominent for distances below 1 cm. The test results when the signal generator is providing 2.5 V are in Figure 5 .

- Solenoid – No distance study was made for this generator because there was no power delivered to the load of the harvester for distances in the order of 2 mm.

- Helmholtz Coil – With the signal generator providing 1.42; 2.5 e 3.6 V to its coupled coil, and changing the position along the Helmholtz Coil longitudinal axis and considering the reference position the center of coil, i.e. when the distance to the 1st and 2nd winding is equal, the relation between V_{out} and the distance is

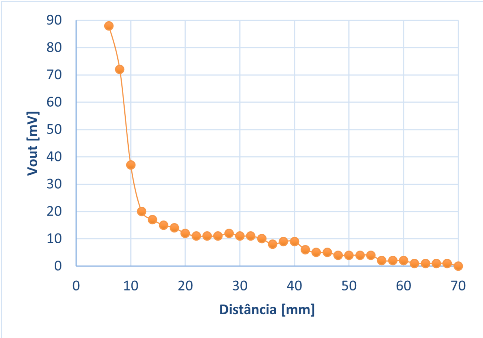

Figure 5: Influence of the distance in V_{out} for a pancake coil

presented in Figure 6. A study of the homogeneity of V_{out} was also done, Figure 7. The behaviour was quite different from the expected, which can be explained because the harvester is a resonant circuit for 915 MHz. Therefore it is capable of increase the inflow of magnetic field even for higher distances.

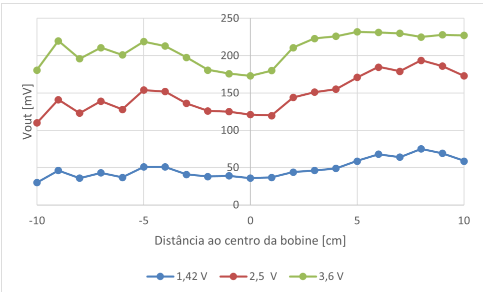

Figure 6: Influence of the distance in V_{out} in a Helmholtz Coil

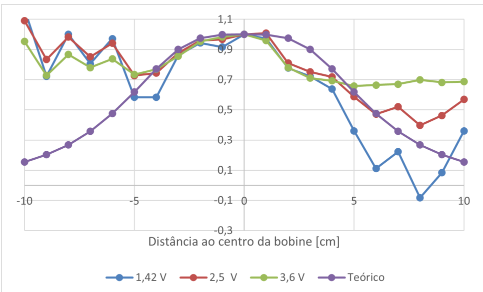

Figure 7: Influence of the distance in V_{out}

4.2. Voltage on the signal generator

This test was done with the generator at the position that lead to the higher voltage at the harvester load with a signal of frequency 915 MHz. A sweep of the voltage given by the signal generator lead to the graphic of Figure 8. As expected when signal generator voltage increases V_{out}. When the voltage at the load was higher than 1 V the swap was stopped because that was a possibility of ruining the circuit, this happened in the solenoide for $V_{source} = 0.71$ V and in the pancake coil for 1.16 V

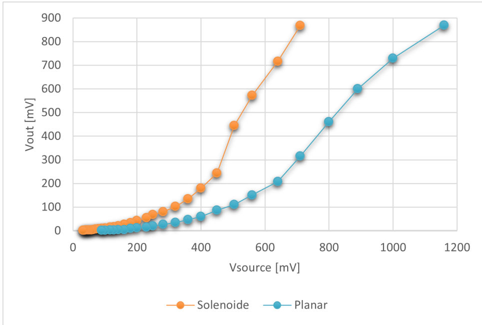

Figure 8: V_{out} for a frequency swap in the pancake and solenoid coils

5. Conclusion

Despite the small dimensions of the circuit it can be used as a energy harvester, and in experiments up to 1 µW were delivered to the load, and it is possible to get higher power. Better results could be obtained if the magnetic field generator was resonant for the desired frequency, 915 MHz.

References

[1] H. Gonçalves. *Radio Frequency Energy Harvesting Circuits*. PhD thesis, Universidade de Lisboa, Instituto Superior Tecnico, 2017.