USE OF METAMATERIALS IN WIRELESS POWER TRANSMISSION FOR BIOMEDICAL APPLICATIONS: ELECTROMAGNETIC COMPUTACIONAL MODELING

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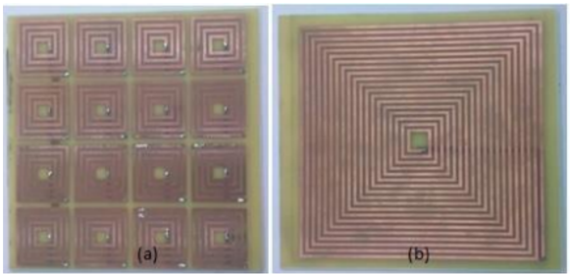
Objectives

Wireless power transmission can be used in various sectors of society, such as recharging electric vehicles, smartphones and even supplying electromechanical devices like artificial organs and VADs - Ventricular Assist Devices. In these biomedical cases, the advantage of wireless power transmission is the absence of potential extracorporeal connections, contributing to a system much less harmful to human health. However, the process is often very inefficient due to, among other factors, scattered fluxes and coil misalignment.

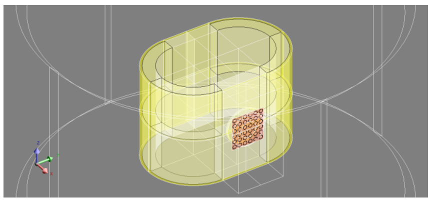
The objective of this project, therefore, is the electromagnetic computational modeling analysis of a metamaterial (MM), a device designed to enhance the magnetic flux in transcutaneous energy transmission (TET), thereby increasing the process efficiency. The MM consists of a printed circuit with copper trace spirals forming a regular grid and is inserted between the generating and receiving coils. The receiving coil is located inside the human body, while the generating coil and the MM are typically attached externally to the human skin. Some examples of MMs are shown in Picture 1 (on the left, MM with 16 square spirals, and on the right, MM with a single square spiral).



Picture 1: Examples of squared spirals MMs

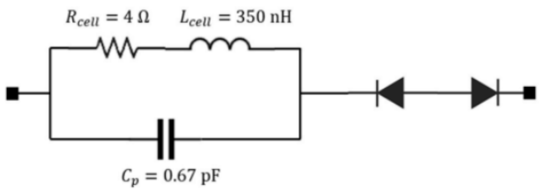
Materials and Methods

In this study, the Altair Flux® software [1] was employed to simulate the TET system, which is a specialized platform for low-frequency electromechanical design projects. Furthermore, the aim is to continue the work initiated in [2] (see Picture 2), which simulated a conventional MM under sinusoidal conditions. The results showed an increase in magnetic flux, as expected, but with only a slightly significant improvement.



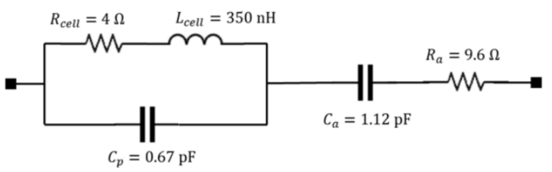
Picture 2: Modeling of the human body [2]

Building upon the idea proposed in [3], it is observed that metamaterials (MMs) exhibit intriguing properties such as negative magnetic permeability, electric permittivity, and negative refractive index. However, these properties tend to be constrained by limited bandwidths due to the requirement for high-quality factor (Q-factor) response cells. The solution proposed in the article is based on the utilization of nonlinear elements - Duffing resonators - within the MM, primarily consisting of RLC circuits with nonlinear capacitance. The equivalent circuit, mainly composed of a pair of varactor diodes (where capacitance varies with voltage), is illustrated in Picture 3.



Picture 3: Proposal for a nonlinear MM lens [3]

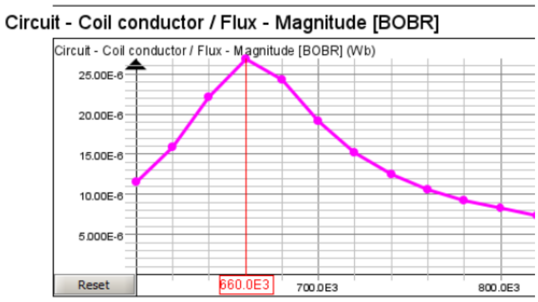
However, the formulation in the harmonic regime (magnetodynamic) does not allow for nonlinear elements like diodes. Therefore, the equivalent circuit model represented in Picture 4 was employed.



Picture 4: Proposal for a nonlinear MM lens for small signs [3]

Results

As the initial result of the simulation in the harmonic regime with the approximate model from Picture 4, the frequency response depicted in Picture 5 was obtained.



Picture 5: Magnetic flux magnitude in the receiver coil in Wb as a function of frequency in Hz

In this manner, a ressonante peak is observed at the frequency (previously determined based on the parameters of the electrical bipole).

Conclusions

The result shown in Figure 5, using the approximate model from Figure 4, does not exhibit a significant difference compared to the previous conventional MM configuration. Therefore, to properly model the nonlinear component (Figure 3), it was necessary to perform simulations in the time domain. This work is still ongoing as transient resolution is much more complex and time-consuming.

References

[1] Altair Flux® - Low Frequency Electromagnetic Analysis for Electrical Engineering, https://www.hyperworks.com.br/product/flux (09/2023);

[2] Lucas Prado Castelo, Viviane Cristine Silva. INICIAÇÃO CIENTÍFICA – FAPESP- PROC. 2018/15106- 2- RELATÓRIO FINAL EPUSP (São Paulo). 2019;

[3] J. V. de Almeida, X. Gu, M. M. Mosso, C. A. F. Sartori, and K. Wu, "Nonlinear Metamaterial Lenses for Inductive Power Transmission Systems Using Duffing-Resonator Based Unit Cells," J, vol. 4, no. 4, pp. 727-748, 2021.