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Wireless transmission of electrical power: biomedical applications

Having particularly taken a liking to the electromagnetism courses I've been taking this year, I wanted to find applications for it in the medical field.
My study makes it possible to recharge biomedical implants wirelessly , preventing the risks and complications associated with invasive surgery.

Thematic Positioning

PHYSICS (Wave Physics).

Key-Words

wireless power transmission
electromagnetic induction
resonant coupling
yield optimization
semi-resonant cavity

Annotated bibliography

For more than a century, the transmission of electrical power wirelessly by induction has been of interest to the scientist Tesla, without having any concrete applications. Nowadays, a return to this technique has become imperative as more and more portable technologies requiring electricity become available, including medical implants. To spare patients wearing these devices the inconvenience of surgery, recharging them by induction is a good idea, especially as the magnetic field has little effect on the human body, as opposed to an electric field **[1]**, and also causes less heating **[4]**.

This is based on Faraday's theory. The basic principle is to create a magnetic induction field in a coil, which will cause a variable current to flow at a specific frequency in the receiving circuit.

There are two types of coupling: non-resonant, i.e. independent of the frequency of the current in the transmitting circuit, and resonant, which depends on the natural frequencies of the transmitting and receiving circuits.

Non-resonant mode "cannot charge portable devices over distances of more than 1/5th the size of the power transmitter" **[1]**, whereas resonant coupling allows this distance to be exceeded by more than 2 or 3 times the size of the transmitter or receiver **[1]**.

We will concentrate our study on resonant couplings, which is not, however, without constraints. In fact, this type of coupling only works efficiently when the transmitter and receiver are perfectly aligned **[7]**, which is a constraint when the installation conditions are taken into account. The presence of an aluminium plate in the vicinity of one of the resonators could reduce the efficiency from 96% to 37% **[7]**, a slight asymmetry between the two resonators would drastically affect transmission, the coil size/transfer distance ratio, imposed by the installation conditions, also has a major influence on the coupling coefficient, and therefore on efficiency **[1]**, human tissue is dispersive **[4]**.

However, measures can be taken to overcome all these problems and even improve this performance further: firstly, opt for the optimum frequency for transmitting power through human tissue, which is of the order of GHz (considering the compromise between received power and tissue absorption). This conclusion uses Debye's model as an approximation of the relative permittivity of the tissues in the human body **[2]**. Other parameters can also be influenced: the proximity of metal plates to the resonators **[7]**, perfect symmetry between transmitter and receiver **[7]**, silvering the coils increases their quality factor Q, resulting in improved efficiency. **[6]** More elaborate geometries have also been designed and tested with a view to improving efficiency **[6]**. Numerical simulation using COMSOL software followed by an experimental approach led to a transfer system consisting of spiral and flat coils, which are less bulky and more efficient **[3]**.As resonant coupling is disrupted by any misalignment, a new coil design was considered in **[4]**: the Split coil, "a receiver coil divided over 3 angles (0°, 45° and 90°)" **[4].**

Another suggestion for optimising the system was put forward in **[1]**: a semi-closed cavity filled with ceramic to act as a waveguide and confine the electromagnetic energy to one area of space, a solution for reducing radiation losses.

Inserting one or two resonators tuned to the same intermediate frequency enables the magnetic field to be "amplified" **[3]**.

Selected Problematic

To avoid the risks associated with invasive surgery, loading biomedical implants by inductive coupling is proving to be an optimal solution. The question is, under what conditions could this induction be achieved? How can it be achieved despite the size of the receiver and the losses of dispersive human tissue?

Aims of TIPE

1) Find the optimum experimental conditions for resonant and non-resonant inductive coupling
2) Use the models suggested in the bibliography to experimentally create my own models in order to improve performance.
3) Numerical simulation of the phenomena involved to ensure the effectiveness of the model designed, taking into account the conditions imposed by the medical implantation.

References

[1] WEI WANG : ÉTUDE DE LA TRANSMISSION D'ÉNERGIE SANS FIL (WPT) BASÉE SUR LA RÉSONANCE COUPLÉE MAGNÉTIQUE : *https://publications.polymtl.ca/1496/1/2014_WeiWang.pdf*

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[3] Laroussi Bettaieb, François Costa, Jean-Christophe Lourme : Transmission d'énergie par couplage inductif. Application aux capteurs biomédicaux intégrés : *https://hal.archives-ouvertes.fr/hal-01065235/file/Transmission_d_energie_par_couplage_inductif._Applications_aux_capteurs_bio medicaux_integres.pdf*
[4] Hicham Jouaicha : Transmission d'énergie sans fil pour les implants biomédicaux :
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[5] Mustafa Adil Hussain : Design and Implementation of Wireless LowPower Transfer for Medical Implant Devices :
https://iopscience.iop.org/article/10.1088/1757-899X/745/1/012087/pdf
[6] André Kurs, AristeidisKaralis, Robert Moffatt, J. D. Joannopoulos, Peter Fisher, Marin Soljačić : Wireless Power Transfer via Strongly Coupled Magnetic Resonances :
http://www.sawaya.ecei.tohoku.ac.jp/common/item/pdf/doctor/091208.pdf
[7] Xiaofang Yu, TorbjornSkauli, Bjorn Skauli, et al. : Wireless power transfer in the presence of metallic plates: Experimental results :
https://eprints.gla.ac.uk/252873/1/252873.pdf

DOT

[1] *August-September: theoretical study of another TIPE subject: preventing noise pollution by absorption, reflection or diffusion.*

[2] *October-November: several attempts at acoustic isolation using diffusion, attempts at isolation using an acoustic screen and anti-noise fractals: isolation is only allowed for certain frequencies for the screen, building fractals is not feasible in my school's laboratory: the subject was abandoned.*

[3] *December-January: exploration of new avenues and choice of current subject, theoretical study of the efficiency of the device and research into the parameters to be taken into account during the experiment, development of the experimental protocol taking into account the availability of equipment in the lycée laboratory, bibliographical study in search of new ideas for designing a coil with optimum efficiency, the idea of the resonant cavity.*

[4] *February: non-resonant, then resonant inductive coupling experiments under various conditions, taking measurements and calculating the mutual inductance coefficient and efficiency*

[5] *March: writing of python code to choose the optimum size and shape for the coil, lengthy research into the method to be adopted for the experimental design of* *flat spiral coils with resonant cavities*

[6] *April-May: solved the problem using modelling clay to support the flat coils, designed and cobbled together two semi-resonant ceramic cavities and their respective coils, experiment failed due to the size of the wire used (too thin), tried to design new coils with a stiffer wire, difficulty in completing the work due to the wire's lack of flexibility, developed a system of two plates to help obtain the desired flat spiral coils, successfully completed the experiment. Unsuccessful attempts to gain access to COMSOL software because of its cost, in order to simulate the model taking into account the required dimensions of the receiving coil, unsuccessful search for other simulation software: CST Studio Suite for example, technical problems that I was unable to resolve* *bobine, longue recherche sur la méthode à adopter pour concevoir expérimentalement les bobines plates en spirale avec les cavités résonantes*

[7] *Avril-Mai: résolution du problème avec de la pâte à modeler qui a servi de support pour les bobines plates, conception et bricolage de deux cavités semi-résonantes en céramique et leurs bobines respectives, expérience en échec à cause de la dimension du fil utilisé (trop fin), tentatives de conception de nouvelles bobines avec un fil plus rigide, difficulté à mener à bien le travail à cause du peu de souplesse du fil, élaboration d'un système de deux plaques qui aident à obtenir les bobines plates en spirale souhaitées, réalisation de l'expérience avec succès. Tentatives en échec de trouver accès au logiciel COMSOL à cause de son coût, afin de simuler le modèle en tenant compte des dimensions requises de la bobine réceptrice, recherche en vain d'autres logiciels de simulation:*

CST Studio Suite par exemple, problèmes techniques que je n'est pas pu résoudre

[8] *juin: tentative de rédiger un code python qui permet d'obtenir la simulation désirée, en échec*