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Wireless Energy Transmission through the medium of Strongly Coupled Magnetic Resonance for the Application of Embedded Systems

Miss Pallavi V. Lakde[1] **Asst. Prof. Ashish B. Kharate**[2]

[1]PG Student, Sant Gadge Baba Amravati University, Amravati (M.S.)
Department of Electronic & Telecommunication Engineering
Email: pallavilakade2828@gmail.com

[2]Sant Gadge Baba Amravati University, Amravati (M.S.)
Dept.of Electronics and Telecommunication Engineering
Email id: abkharate.2011@gmail.com

ABSTRACT

In this Paper, The Wireless Power Transfer (WPT), Wireless Power Transmission, Wireless Energy Transmission (WET), Or Electromagnetic Power Transfer (EPT) is the Transmission of Electrical Energy Without Wires. In this paper we develop a mathematical model for SCMR to calculate the resonant frequencies other electrical characteristic for the given coil in MATLAB and we briefly summarized the middling methods of wireless power transfer using Strongly Coupled Magnetic Resonance (SCMR) to power embedded system application. The outcomes from the model are experimentally verified through the execution of the several designs. The MATLAB model within 10% of the experimental values is explicit. Also we deliberate the optimal design for maximum wireless power transfer. Prior work shows in wireless energy transmission for resonating coils over 2 meters at 40% efficiency with 60 cm diameter. We significantly design with wireless energy transfer via SCMR over 10 cm using 8 cm diameter coil, approximately 7 times smaller. The Outstanding choice for powering small scale embedded systems application i.e. smaller design.

1. INTRODUCTION.

The transmission of power wirelessly has long been dream of pioneers in the field that would eventually become Electrical Engineering, namely Nikola Tesla. While Tesla was indeed able to demonstrate mid-to-long-range wireless power transfer over a century ago, safe and practical methods for achieving similar results have only been discovered recently in 2007. This method, which exploits electromagnetic resonance, or rather, an object's tendency to oscillate at large amplitudes at specific frequencies, was deemed Strongly Coupled Magnetic Resonance (SCMR) by its discoverers.

From these reviewed methods, we then develop a mathematical model for SCMR to calculate resonant frequencies and other electrical characteristics for a given coil in MATLAB. The results from the model are verified experimentally through the implementation of several design iterations. The MATLAB model is accurate to within 10% of the experimental values. We also discuss the optimal design for maximum wireless power transfer and the constraints associated. Previous work shows wireless power transfer over 2 meters at about 40% efficiency with 60cm diameter resonating coils. We present a significantly scaled down design (Design III) with wireless power transfer via SCMR over 10cm using 8.25cm diameter coils, roughly 7.5 times smaller. The smaller design makes it an excellent choice for powering small scale embedded systems applications.

Although there are many electromagnetic phenomena capable of wireless energy transfer from one point to another (for example, transformers, which demonstrate a high efficiency at very close distances), SCMR is the only method capable of efficiently transferring energy in the mid-range (that does not require an uninterrupted line-of-sight) where the transfer distance is several times greater than the radius of the transmitting device.

Previous work done and a basic understanding of SCMR systems is presented in section 2. Mathematical modelling and MATLAB implementation of resonating coils and their associated geometric and electrical characteristics are discussed in section 3.

We also analyze the effects of varying geometric parameters of a coil on electrical characteristics. Experiments using multiple coil designs and respective results are presented in section 4. In section 5, we discuss possible improvements and future work.

2. BACKGROUND.

The idea behind wireless power transfer via SCMR is quite simple from an intuitive standpoint - objects that share the same resonant frequency will efficiently exchange energy, and lose only a relatively small amount of that energy to any off-resonant objects encountered by the resonating field. In order to use the power obtained at the receiving end resonator, one or several loops will be inductively coupled to the receiver. This is so that the receiving resonator has no direct contact with the electrical load, as it would ultimately alter the resonant frequency otherwise, preventing the coupled magnetic resonance from occurring. A simple illustration of an SCMR system is shown below in Figure1.

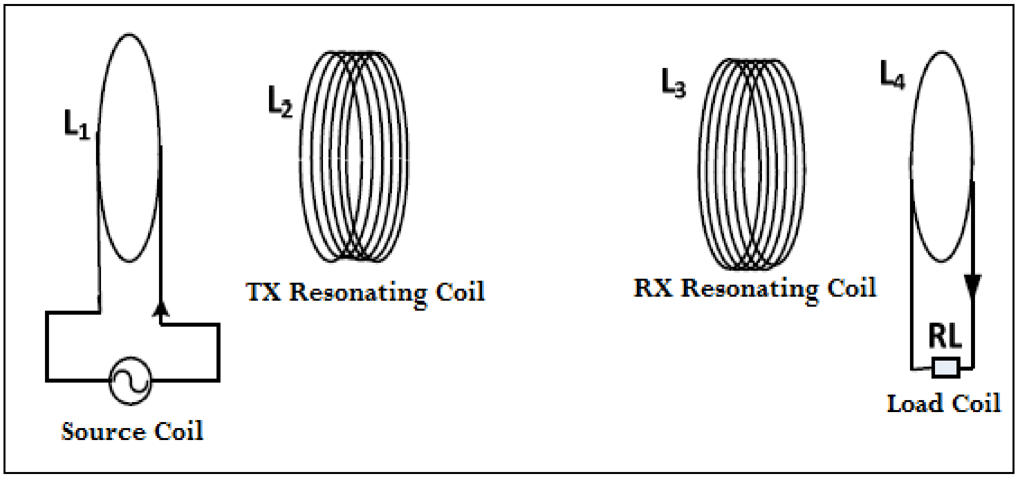

Figure 1 : Basis for an SCMR System

Keywords

SCMR, WPT, WET, PET, MATLAB, Strongly Coupled Magnetic Resonance, Wireless Power Transfer.

3. SCMR MODELING.

3.1 Mathematical Model.

Highly resonant systems that operate in a strongly coupled regime are able to transfer energy efficiently versus non-resonant objects that only interact weakly. Calculating the resonant frequency of loops and helices require careful consideration of their geometry. In this section, we analytically derive the equations used to calculate the electrical characteristics and eventually the resonant frequency and quality factor, of the coils. We will also see that in order to obtain the maximum power transfer efficiency, the quality factor, Q needs to be maximized. The equation for maximum Q is later presented and used to work our way back to the optimal geometry required for maximum power transfer. The following characteristics of a coil/loop are considered:

i.Capacitance, C
ii.Inductance, L
iii.Resonant Frequency, fo
iv.Loss (Impedance), Γ
v.Quality factor, Q

These key characteristics are directly related to the geometric parameters of the helix under consideration, as well as the physical properties of the helix material (in our case, copper).

i.Cross sectional radius of wire, rc
ii.Radius of coil, r
iii.Number of turns, N
iv.Pitch, s

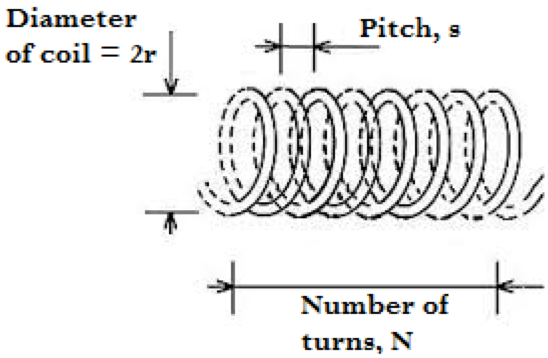

Figure 2. Coil geometry

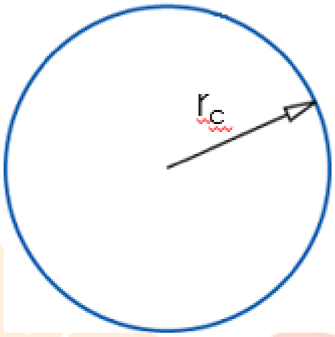

Figure 3. Wire Cross-section

3.2 Inductance, Capacitance and Resonant Frequency.

$$L = \mu_0 r N^2 \left[In\left(\frac{8r}{rc}\right) - 2 \right] \quad (1)$$

$$C = \frac{2\pi^2 r \varepsilon_0}{In\left[\frac{s}{2rc} + \sqrt{\left(\frac{s}{2rc}\right)^2 - 1}\right]} \quad (2)$$

$$f_0 = \frac{1}{2\pi\sqrt{LC}} \quad (3)$$

Where, μ_0 is permeability of free space and ε_0 is permittivity of free space. It is important to note that (1) and (2) can be used to describe a loop (N=1), which will have negligible self-capacitance.

Substituting (1) and (2) into (3) yield an equation for the resonant frequency dependent solely on the geometry and physical parameters of the coil. This resonant frequency is the frequency at which the source coil needs to be operated.

MATLAB Implementation, Analysis and Results.

The mathematical equations discussed are implemented in MATLAB. The function requires geometric parameters of the coil and provides the inductance, capacitance, resonant frequency, Q factor and other characteristics of the coil. In this section, we will go through a system level implementation block diagram of the MATLAB model followed by some results.

The block diagram in Figure 4 shows the overall implementation of the mathematical model and the dependencies between characteristics. The model uses the coil geometric parameters as inputs, discussed earlier, and calculates the inductance and capacitance. This allows calculation of the resonant frequency.

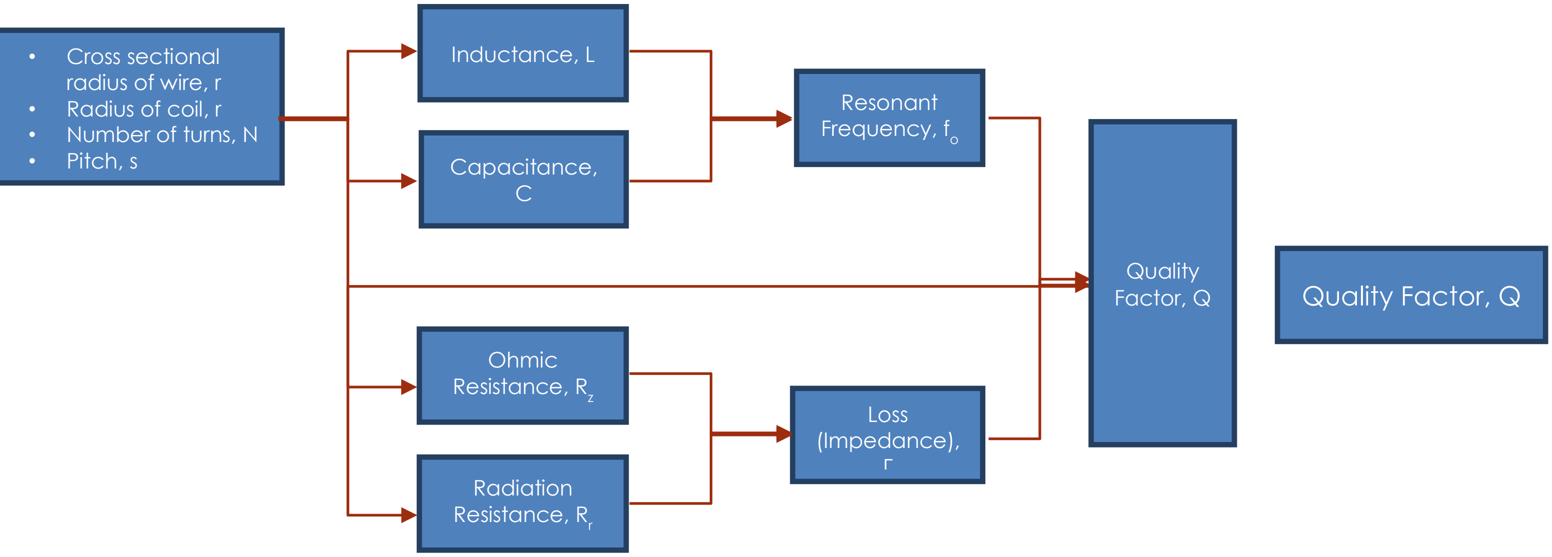

Figure 4. MATLAB System level block diagram

CHALLENGES

Copper tubes used initially. Mathematical model would not comply with experimental results. Solid copper wires used instead. Optimal geometry hard to construct. Non-optimal design adopted.Resonant frequencies extremely sensitive to variations in coil geometry.

CONCLUSION & FUTURE WORK

In conclusion, we successfully developed a scaled-down version of an SCMR system intended for use in future embedded systems. It is lightweight, economical, consistent with the model, relatively easy to maintain, and can be built in just a few hours with proper training. The MATLAB model is accurate within 10% of the experimental values. While our SCMR system is indeed a viable solution, the next challenge to tackle is that of efficiently driving the resonators at higher power. Their products, wireless cell phone charger and wireless electric car battery charger are commercially available but significantly scaled down and therefore, shorter range than 2 meters. The wireless power transmission offers very large possibilities for transmitting power with negligible losses. We introduced future where wireless power is available in home, industries and offices just like wireless internet, i.e. Wi-Fi power, analogous to Wireless internet.

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Authors

Pallavi V. Lakde, is currently appeared M.E. from H.V.P.M's College Engineering & Technology, Amravati, in Sant Gadge Baba Amravati University, Amravati (M.S.) Department of Electronic & Telecommunication Engineering , Her Research interest wireless power Transmission.

Ashish B. Kharate, He is currently an assistant professor in the H.V.P.M's College of Engineering and Technology, Amravati. He has working experience of more than 15 years in H.V.P.M. COET. His Research interest includes Wireless Power Transmission, MATLAB, and Related research using of Embedded systems.