Resonant Inductive Coupling Wireless Power Transfer

Author: Elisenda Bou Balust, Thesis Advisor(s): Eduard Alarcón Cot, Jordi Gutierrez Cabello
contact email: elisenda.bou@upc.edu

I. Introduction

Recent research on wireless power transfer (WPT) using resonant inductive coupling has demonstrated very promising efficiencies (above 80%) [1] at large distances compared to the antenna dimensions (more than three times the receiver/transmitter diameters). Due to the number of applications that could benefit from WPT: from electric vehicles to sensor networks, commercial electronic devices, health equipment, biomedical implants, in-space systems and so on, the development and optimization of this technology is of great interest. Since RIC is still a very novel technology, different models should be proposed to analyze and predict the behavior of these systems and to increase the overall efficiencies and transmission ranges.

II. RIC and EM Wireless Power Transfer

II.A. Electromagnetic Wireless Power Transfer (WPT)

EM Wireless Power Transfer consists on the transmission of electric energy through electromagnetic fields. These fields experiment behavioral changes, predicted by Maxwell's equations, which define two terms of electric and magnetic fields (radiative and non-radiative). Maxwell's equations state that the electric fields produced by changes in charge distribution are different from those produced by a change in magnetic field. Similarly, the behavior of magnetic fields produced by changes in electric currents is different from the ones produced by a change in electric fields. For these reasons, in the spatial region very close to currents and charge distributions, the EM field is dominated by electric and magnetic components produced directly by currents and changes in charge distributions. This is called the electromagnetic near-field region.

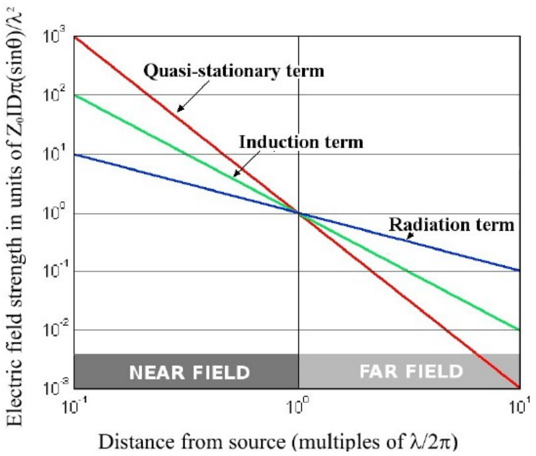

Figure 1. Radiative & Non-radiative behaviors of EM fields.

On the other hand, at distances far from there the EM field becomes dominated by the electric and magnetic fields indirectly produced by the change in the other type of field, and thus the effects of the charges and currents at the EM source are negligible. This part of the EM field predominantly radiative constitutes the far-field. Both behaviors can be observed in Fig. 1.

II.B. Resonant Inductive Coupling (RIC)

The transmission of wireless power transfer using electromagnetic induction was first demonstrated in the early 20th century by Nikola Tesla. Since then, electromagnetic induction (EMI) has been used for the powering of artificial hearts and implantable devices. While the early systems used non-resonant links, later systems increased their efficiency by implementing resonant transmitter coils thus creating a resonant inductive coupled link. In such a link, each coil is capacitively loaded forming a tuned LC resonating at a common frequency, which allows to transmit significant power over a wider ranges. The equivalent circuit of the link is shown in Fig.2.

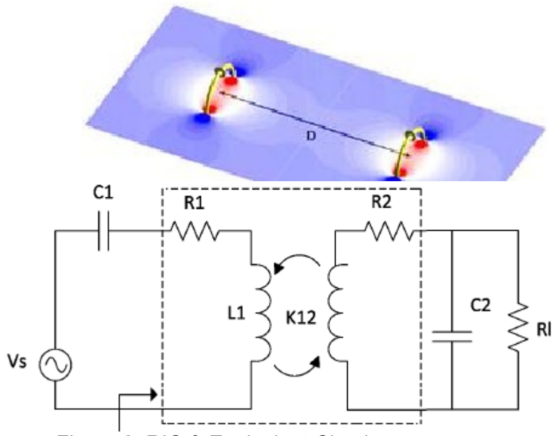

Figure 2. RIC & Equivalent Circuit

III. Objectives & Thesis Work

Because RIC is a very multidisciplinary field, different analysis have been performed from the physical theory, the antenna theory and the circuit theory. One of the main objectives of this thesis is to develop a unified, design-oriented, scalable model that can predict accurately the behavior of RIC systems under different conditions.

In this thesis, we developed a model that merges these three different points of view, showing a complete agreement between theories under optimal conditions and steady-state analysis. Also, we demonstrated that the circuital analysis is the only one that can predict the behavior of this systems under transitory state.

Finally, the optimal parameters to achieve maximum power transfer efficiency have been found and introduced into the model as design-oriented guidelines towards maximum efficiencies: optimal input frequency, resonant frequency, distance between transmitter and receiver antennas, source equivalent resistance and optimal load resistance. The effects of an unmatched load onto the PTE are shown in Fig.3.

Once the theoretical maximum efficiencies and optimal parameters are found, it is necessary to explore different adaptation techniques (frequency and impedance) to force these systems to work under optimal conditions.

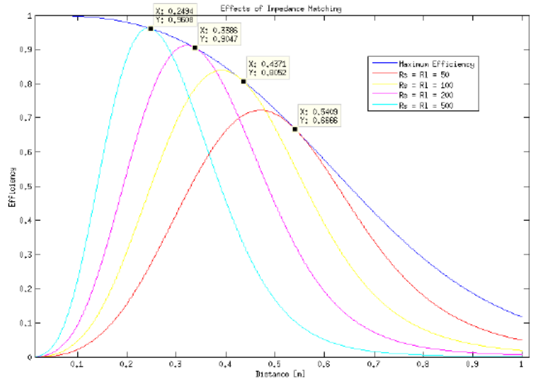

Figure 3. RIC Impedance Matching Techniques

Finally, this thesis aim is to explore techniques such as RIC SIMO/MIMO systems and power-and-data systems to apply this concepts on two different applications: Fractionated Spacecraft and Active Energy Harvesting.

IV. Applications

IV.A. Fractionated Spacecraft

Fractionated spacecraft (Fig. 4) is a type of satellite architecture that distributes the capabilities of a conventional spacecraft across multiple independent modules. These modules are not physically connected but, because they need to act cooperatively, it is necessary to implement a wireless power-and-data bus.

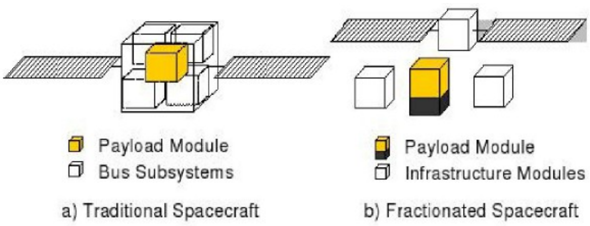

Figure 4. Traditional versus fractionated spacecraft.

For the application of RIC to this fractionated spacecraft bus, different solutions should be developed to cope with the in-space special requirements and limitations.

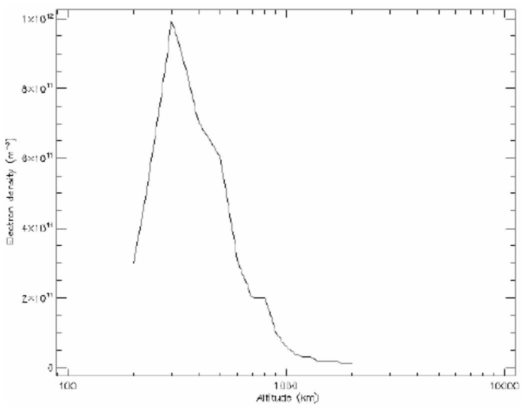

Figure 5. Electron density (plasma effect) Analysis.

This research includes analyzing the plasma effects on near-field wireless power transfer (shown in Fig. 5), increasing the coil performance (magnetic field and coupling) without incurring in mass increments, transmitting power and data simultaneously (space power and telemetry), EM compatibility/potential effects and developing adaptive impedance matching and frequency tuning techniques.

Some of this concepts as well as the interactions between plasma and near-field RIC will be explored by a payload placed inside the UPC Cubesat, project led by Adriano Camps (TSC) and Roger Jové.

IV.B. Active Energy Harvesting

One of the main constrains/problems that wireless sensor networks have is the requirement to individually power each sensor or node. Different energy harvesting techniques have been performed to use ambient energy to power them, but the challenges of powering these devices using the most ubiquitous form of energy (EM energy) are still unsolved. To circumvent this situation, we propose to increase ambient energy by actively adding an inductive EM field and using on-chip RIC spirals to harvest the energy.

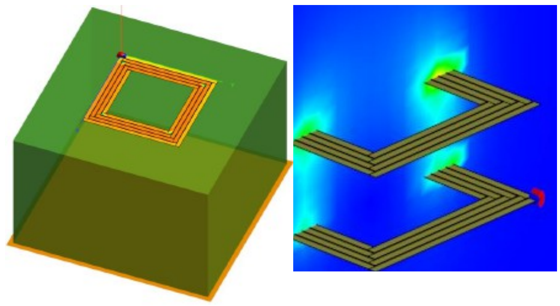

Figure 7. Characterization of on-chip inductors.

V. Acknowledgments

Work partially funded by Thales Alenia Space.

VI. References

[1] André Kurs, Aristeidis Karalis et al, “Wireless Power Transfer via Strongly Coupled Magnetic Resonances,” *Science*, vol. 317, no. 5834, pp. 83-86, July, 2007.
[2] Mehdi Kiani, Uei-Ming Jow, Maysam Ghovanloo, “Design and Optimization of a 3-Coil Inductive Link for Efficient Wireless Power Transmission”, IEEE Transactions on Biomedical Circuits and Systems, vol. 5 no6, December 2011.
[3] Elisenda Bou, Eduard Alarcon, Jordi Gutierrez, “A comparison of analytical models for Resonant Inductive Wireless Power Coupling”. PIERS, August 2012.