Wireless Power Transfer - The Example of Inductive Power Transfer in Cell Phone Charging

The idea of **Wireless Power Transfer (WPT)** originates from the 19th century and the results from the pioneering research work of Nikola Tesla, a Serbian-American scientist and futurist. Today, Wireless Power Transfer represents technology which **enables** Internet of Things (IoT) concept, machine-to-machine communication, wireless charging of various devices such as wearables, cell phones, toothbrushes, cars etc. In general, WPT systems can be applied to power up various devices either replacing the batteries, such is the case of passive RFIDs and near field communication devices, or completely eliminating the need for wired power assemblies.

WPT basically involves **a transmission of electrical energy** from a power source to a load **without usage of electrical conductors**. In this application note, we will consider an example of a near field WPT, also known as inductive-WPT, or IPT.

Various coil models and the results for an entire power charging scenario involving the coils will be explained. A **real-life scenario** demonstrating how a smart phone can be inductively charged while resting on a dedicated charging pad will be presented. Realistic distances between the phone and the charging pad are considered ranging from several millimeters to a meter.

Only the **radio frequency (RF) aspects of this scenario** will be investigated. In the other words, non-linear rectifying elements and other circuitry required for the operation of the WPT link will not be considered. The analysis of RF aspects should be sufficient to draw some important conclusions. The S-parameters calculated using an EM simulator will be presented. **WIPL-D** software, a full wave 3D EM **Method-of-Moments (MoM)** based solver, has been used throughout this note for versatile geometry modeling and simulations. The simulations are very efficient even when using **standard, non-expensive hardware**.

Solitary Coils

As a first step in studying a real-life WPT example, models of two coils were investigated. The first model represents a coil which was intended to be used in a cell phone. In the following text it will be referred to as a *Receiving coil*. For the sake of initial analysis, the receiving coil is modeled and simulated without dielectric support and will be referred to as *Receiving coil without dielectric support*. The inner radius of the receiving coil without dielectric support is about 5 mm while the outer radius is about 20 mm (Figure 1). It is a planar coil with 15 turns. The width of the metallic strip is 0.5 mm.

The second coil considered represents a coil used as energy source coil installed in the charging station. It will be referred to as *Charging coil*. The inner radius of the charging coil is about 10 mm while the outer radius is about 50 mm (Figure 1). Again, it is a planar coil with 15 turns. The width of the metallic strip is 1.5 mm.

Both models were created and simulated using **WIPL-D Pro CAD**. The receiving coil is loaded with series impedance comprising a 50 Ohms resistor, a solenoid with inductance value of 31.5×10^{-5} H, and a capacitor with a capacitance values of 2 pF. The charging coil is loaded with series impedance which comprises 50 Ohms resistor, 30.8×10^{-5} H solenoid, and 2 pF capacitor.

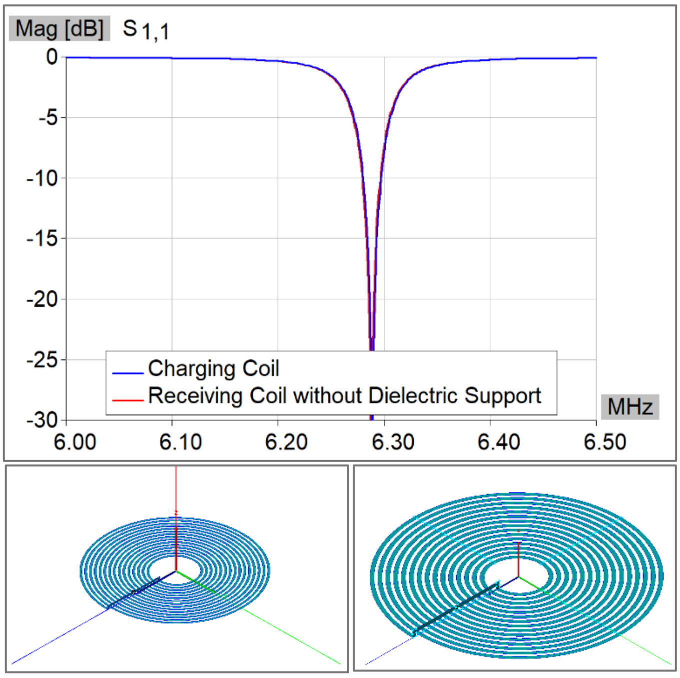

Figure 1. WIPL-D Pro CAD models of the simulated coils with S_{11}-parameters compared.

Two Coils – Inductive Power Transfer in Free Space

The next scenario of interest comprises the two coils as described (the charging coil and the receiving coil without dielectric support). The charging coil was moved along z axis and swept along y axis. S-parameters were calculated for six positions: the reference one where the centers of both coils are located at the origin, i.e. one above the other, and then in five positions corresponding to the increments of 10 mm along y axis (a distance between the coil centers amounting 10 mm, 20 mm, 30 mm, 40 mm, and 50 mm). The illustrations of the six scenarios are presented in Figure 2. The simulated values of S_{21}-parameter corresponding to the power transmission between the coils are shown in Figure 3.

Optimization of Transmission by Changing Resistances on Coils

In order to maximize the power transfer between the two coils, the optimum source and load resistances of the coil system were investigated. It was assumed that the source and load resistances are the same. The model where optimization was performed was the first one as described, where the centers of both coils coincide with the origin.

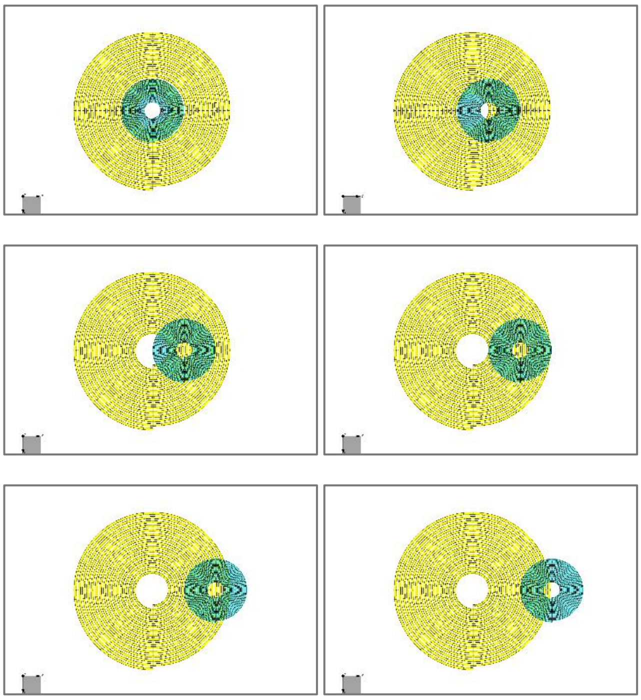

Figure 2. Swept position of receiving coil over larger, charging coil.

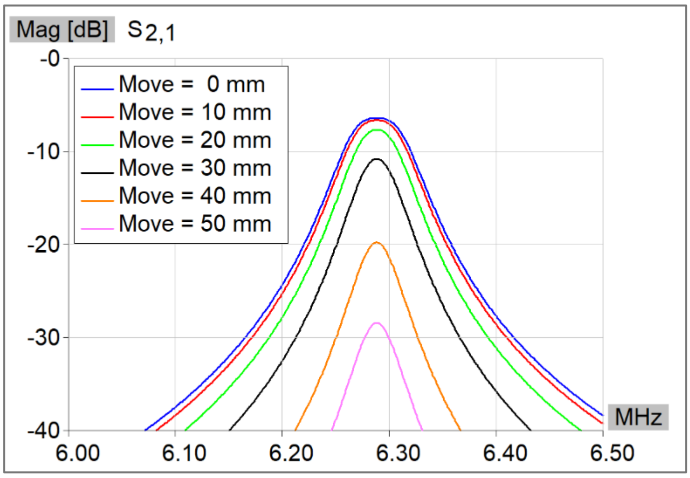

Figure 3. S_{21}-parameters representing transmission between two coils after moving receiving coil.

The optimum value of the source and load resistors had been found manually by sweeping down the resistance value in steps of 5 Ohms. According to results shown in Figure 4, the optimal resistivity is found to be 5 Ohms.

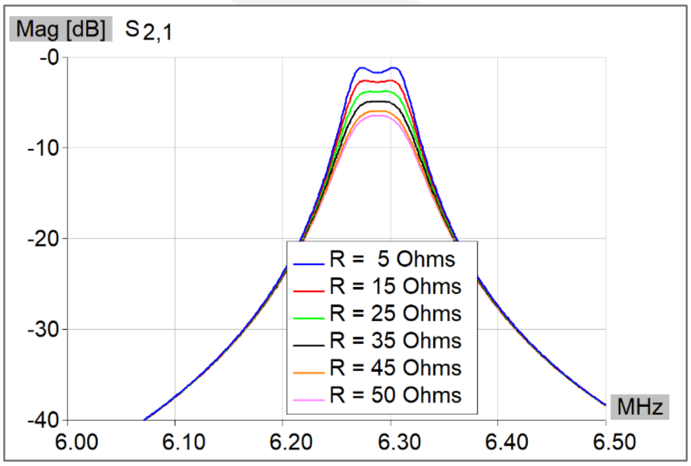

Figure 4. S_{21}-parameters (transmission between coils) for various resistor values.

Receiving Coil on Substrate

In order to make the most realistic model of the WPT, a dielectric substrate was added to the receiving coil. A dielectric material with relative dielectric constant of ε_r=1.5-j0.0001 has been was added to the inductor structure, as illustrated in Figure 5. The metallic structure of the coil is the one used previously without a dielectric support. The outer radius of the circular dielectric substrate is 24 mm.

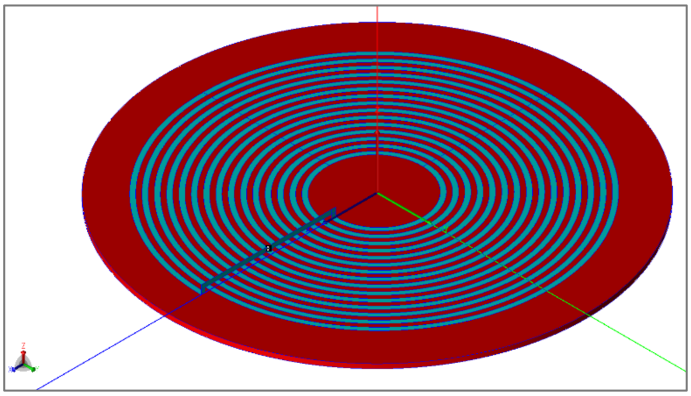

Figure 5. Receiving coil with dielectric support.

The results for a receiving coil with and without the dielectric support are compared in Figure 6. Since the results are in good agreement, it can be concluded that the coil with the dielectric support can also be used with a 5 Ohms resistor loading in order to achieve maximum wireless power transfer.

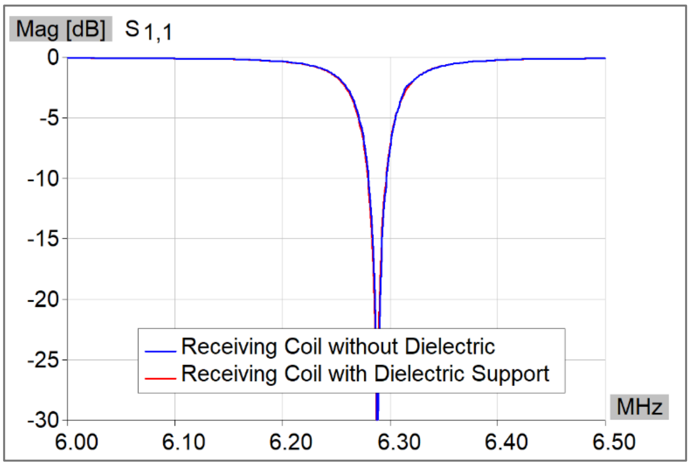

Figure 6. S_{11}-parameters for receiving coils with and without dielectric support.

Wireless Power Transfer Scenario with Cell Phone

Final scenario for a wireless power link investigation that will be presented here consists of the charging coil with the dielectric support as described used with a cell phone located above. The CAD model of the phone is presented in the Figure 7. The phone model is general, i.e. it does not contain much details. However, the special focus of the particular modeling for WPT purpose is turned to a metal spiral corresponding to the receiving coil, which can be identified in Figure 7. The figure also illustrates the rough modeling of the interior of the cell phone - the electronic devices are approximated by metallic boxes.

Meshed model of the cell phone with the charging coil is shown in Figure 8. Metallic parts of the simulation model and the dielectric supporting receiving coil are shown.

S-parameters obtained after performing the simulations are shown in Figure 9. Resistors representing a component of the impedances on each coil were set to be 5 Ohms.

Simulations

Computer used for these simulations is presented in Table 1.

Table 1. Computer used in the simulations.

Hardware	Description
CPU	Intel® Core™ i7-7700 CPU @ 3.60 GHz
RAM	64 GB
GPU	One card: NVIDIA GeForce GTX 1080

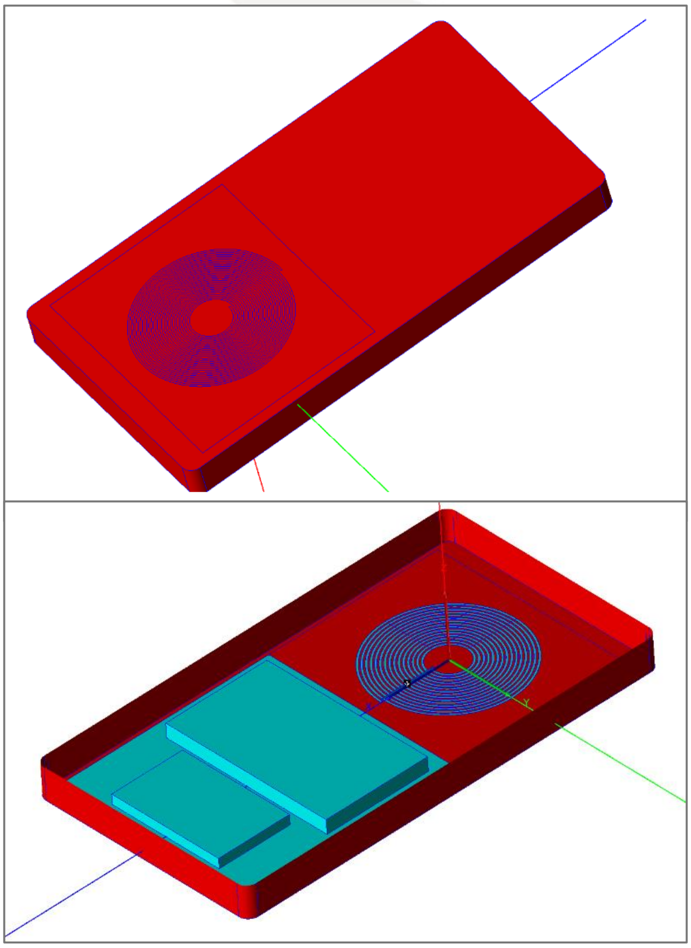

Figure 7. CAD model of the cell phone.

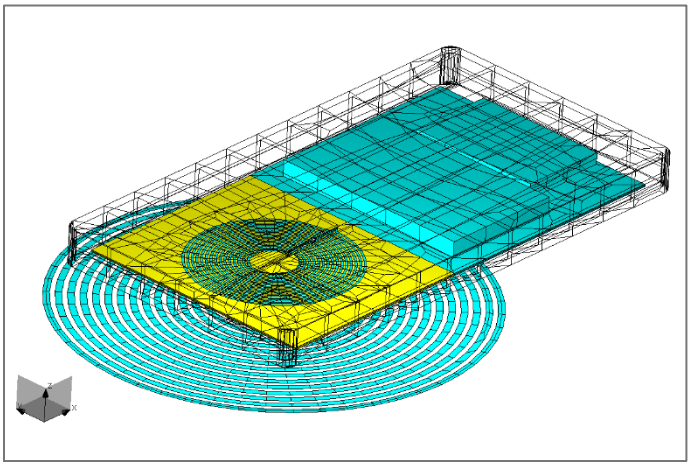

Figure 8. WIPL-D Pro model of the cell phone with the charging coil.

To increase the numerical efficiency of the simulations, a GPU card was used for matrix inversion. The other operations are performed on CPU. All simulations were performed at 11 frequency points. Number of unknowns and simulation time per frequency for each simulated model are given in the Table 2.

Table 2. Number of unknowns and simulation time per frequency for each of the simulated models.

Model	Number of unknowns	Simulation time per frequency [sec]
Receiving coil without dielectric support	2,438	3.2
Charging coil	2,487	3.5
Receiving coil without dielectric support and charging coil	4,922	9.0
Receiving coil with dielectric support	12,175	100.0
Cell phone above the charging coil	31,674	752.8

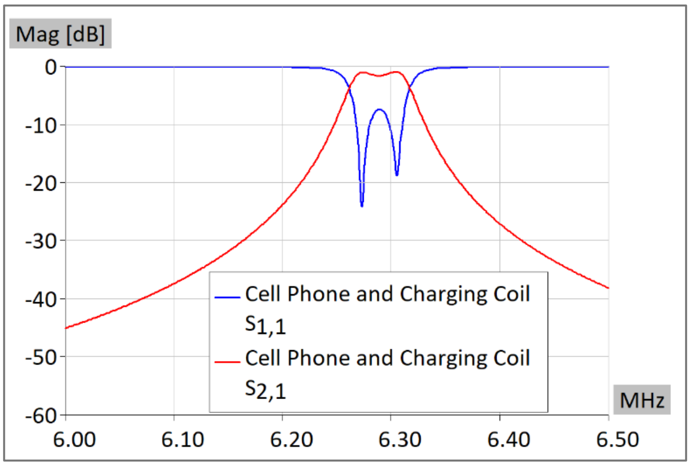

Figure 9. S-parameters after simulating cell phone and the charging coil.

Conclusion

In this paper we demonstrated successful WIPL-D Software computer simulations applied to a challenging EM simulation topic investigating a Wireless Power Transfer (WPT) link. A need for the application of a WPT technology can be recognized in many modern applications, such as Internet of Things (IoT), machine-to-machine communication, wireless charging of various devices etc. The RF aspects of WPT scenarios were investigated using WIPL-D software – a powerful full wave 3D EM Method-of-Moments based solver, applying Surface Integral Equations and Higher Order Basis Functions.

Simulated models are taken from realistic scenarios. Simulations include a charging coil and a receiving coil as solitary devices, and as implemented in a WPT link where a dielectric support for a charging coil is required. Finally, a real-life scenario with a receiving coil located in a mobile phone was simulated. The higest efficiency of the power transfer has been achieved for the case where the axes of the coils were aligned.

Due to the properties of the particular numerical method applied in WIPL-D software, only the boundary surfaces are meshed, not the model volume, and no artificial boundaries are required to limit the model space. Basically, it means that the same number of unknowns is required for simulations as the coils are moved apart. The time required to perform simulations is in all cases presented here acceptable from a practical point of view and allows for implementation of optimization routines even when using a cost-effective computer workstation.