Fast and Accurate WIPL-D Simulation of Wireless Power Transfer (WPT)

Seminal work in the area of wireless power transfer (WPT) has been carried out by Nikola Tesla back in 1914. At recent times there is an increased interest among researchers to further develop the power transfer concept and to implement it efficiently in consumer appliances. Wireless communication devices such as mobile phones, battery-free sensors, passive RF identification tags (RFID), Internet of Things (IoT), and similar systems will significantly benefit from the use of WPT. The wireless powering approach provides more freedom as it substitutes the traditional powering concept where a cable is permanently required for the operation or must be reconnected each time during battery recharge.

A classic work has been described in [1] where the authors have shown WPT over a distance of 2 m. The basic WPT theory has been developed based on the coupling mode theory, and an experiment has been carried out to confirm the findings. In particular, a 60-W bulb has been lightened up. The experimental setup has been analyzed using a commercially available electromagnetic (EM) simulator in [2]. Optimal source and load resistance have been found from simulation data.

This application note presents how a WPT experimental setup described in [1] and [2] can be **efficiently analyzed using WIPL-D software suite**. The suite features a solid modeler seamlessly integrated with WIPL-D landmark **full wave, Method of Moments (MoM) 3D EM solver**. The solver requires meshing of the boundary surfaces of the model objects only, not the entire volume containing the model parts. Accordingly, **there is no need to define a model volume by introducing a boundary box and specify artificial boundaries at the box surfaces**. This inherent property significantly reduces the model complexity and dramatically contributes to the calculation efficiency.

WPT Link with Four Coupled Inductors

An experimental setup has been described in [1]. The setup has been slightly modified in [2] for the purpose of EM simulations. Modified setup presented in Fig. 1 will be the subject of this application note.

A generator, i.e. the input port of the WPT link is connected to a single loop inductor which is inductively coupled to the transmitting coil. On the other side of the WPT link, the receiving coil is inductively coupled to a single loop inductor connected to a resistive load representing the output port of a power transfer network. Both, the transmitting and receiving inductors, are spiral resonators made of copper wire. A diameter of resonators is 600 mm with five turns on 200 mm length. They are placed at a 2 m distance from each other. Single-loop inductors are both with a diameter of 500 mm. All of the inductors are made by 4 mm diameter copper wire.

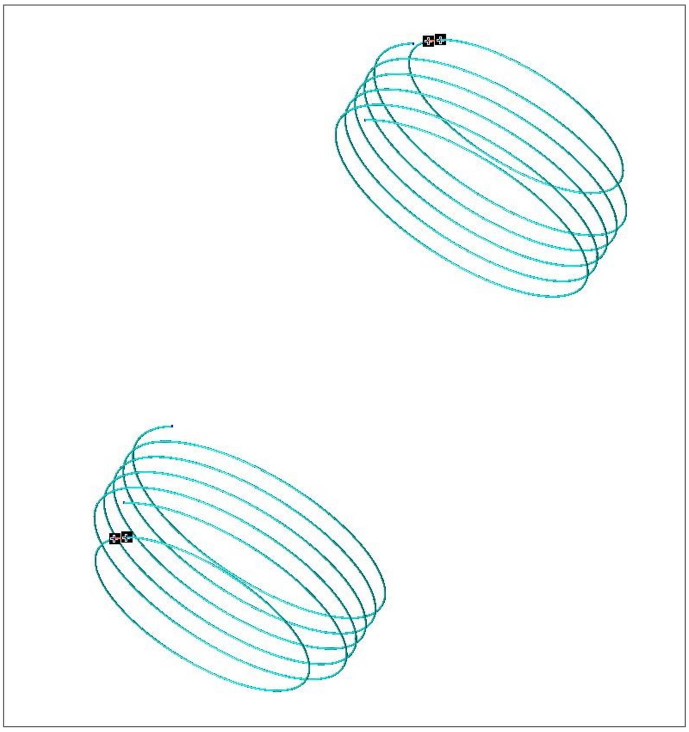

Figure 1. Model of WPT classical example (not to scale).

Modeling of WPT Link in WIPL-D Pro CAD

A model of a WPT link as described in the previous section can be built in WIPL-D suite using two approaches. The first one is a **wire model** which is inherently an approximate one as the current flowing on a wire is approximated to have only longitudinal component while the transversal currents are neglected. The second one is a **plate model** where all components of the current are taken into account. The advantage of the wire model is that the simulations run fast, and the advantage of the solid, plate model is that it is highly accurate.

Both of the models have been built in WIPL-D Pro CAD environment using available wire and solid modeling options. In particular, due to the **built-in helix primitive**, drawing of the structures is straightforward. Once a wire model of the WPT link is created, the solid plate model immediately follows as it can be obtained simply, by sweeping a circle along wire elements.

WIPL-D Pro CAD environment include the proprietary mesher which divides boundary surfaces of a solid model to a number of quads. Alternatively, long wire elements are transformed into smaller wire elements. Meshing is fully automatic, but the user can to some extent take control and influence the process. One of the elements that control a maximum size of the quads or wire segments is ***Mesh Size*** parameter. By adjusting the parameter one can refine the mesh and examine the convergence of the result to ensure a high accuracy.

Determining the Resonant Frequency of the Transmit / Receive Inductors

The first set of simulations of a WPT system has been carried out to determine the resonance frequency of a helix inductor. The models are presented in Fig. 2. For each of the models five simulations have been performed with varying ***Mesh Size*** parameters. The resulting locations of the nodes defining wire segments in wire model are presented in Fig. 3.

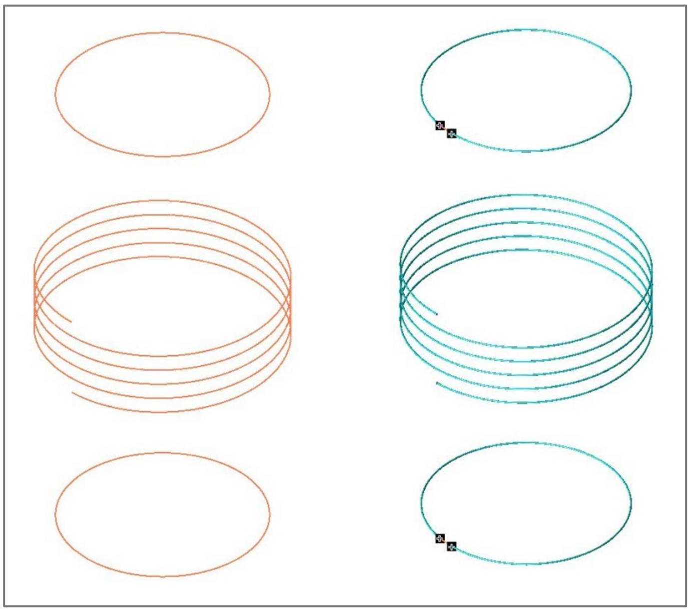

Figure 2. Models of the resonance determining structures. Left – wire model. Right – plate model.

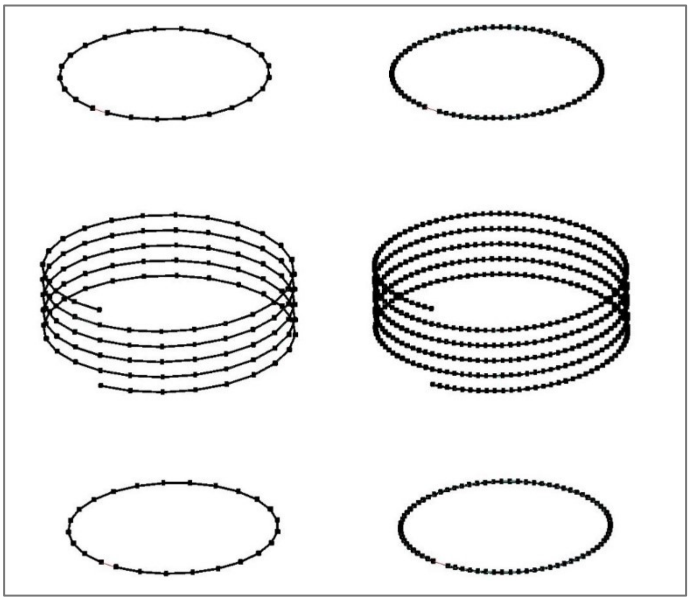

Figure 3. Location of nodes in wire model as *Mesh Size* parameter takes different values. Left – 8cm. Right – 2 cm.

The density of the nodes along the inductors is similar for wire and plate models. The only difference is that for each node from the wire model, a plate model has a group of nodes located along the wire circumference, as presented in Fig. 4. The number of the nodes along the circumference can also be controlled by the user as explained in the figure.

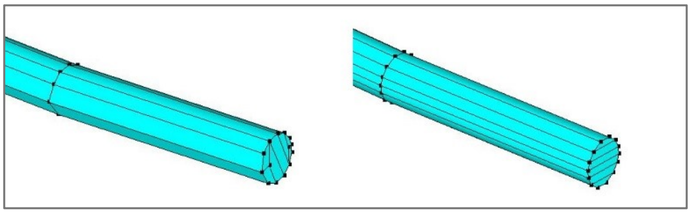

Figure 4. Location of nodes in plate model as *Surface Angle Tolerance* and *Edge Angle Tolerance* take different values. Left – 60°. Right – 30°.

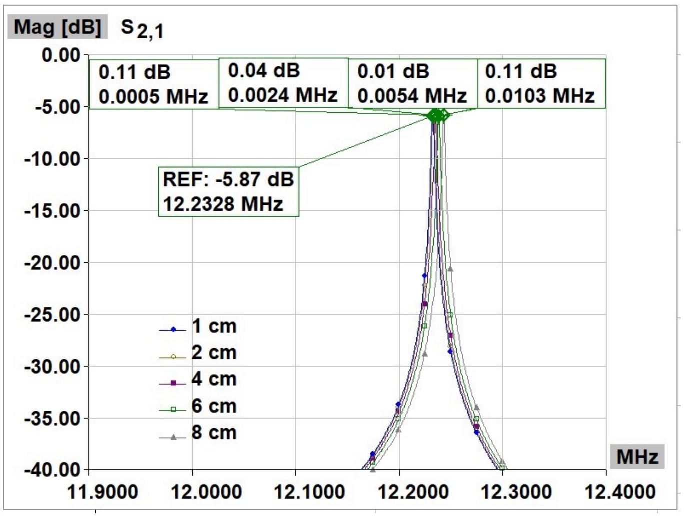

Figure 5. Calculated response of a wire model for resonance calculation setup presented in Fig. 2.

The results of the convergence of the simulations for the wire model are presented in Fig. 5. For the wire model, a value of the Mesh Size parameter does not influence significantly the calculated resonant frequency.

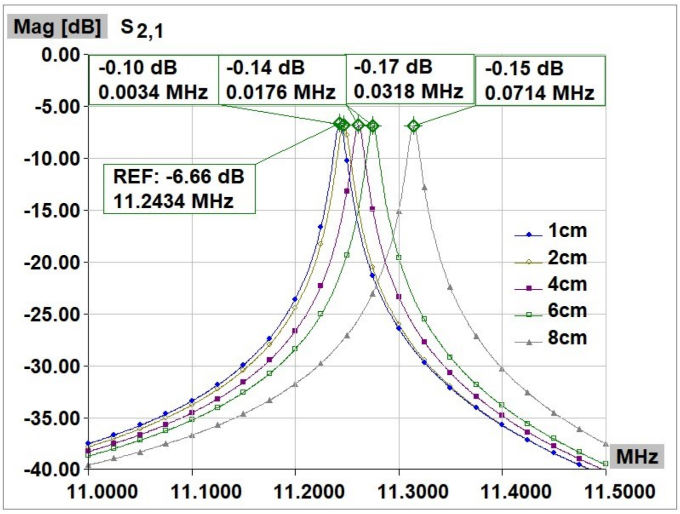

Figure 6. Calculated response of a plate model for resonance calculation setup presented in Fig. 2.

On the other hand, from Fig. 6 it can be concluded that a value of the parameter has noticeable influence on the accuracy in the case of plate model. From practical side, a result obtained for a value of 2cm can be regarded as sufficiently accurate. The subsequent computations can be carried out with this value and the results taken for highly accurate with great confidence. In a similar manner, it has been determined by additional computations that the angle parameters value of 60° provides sufficient accuracy.

Previous results have been calculated for conductors made from copper. Simulations have been repeated for ideal, lossless conductors and the results are summarized in Fig. 7. The difference between the wire and plate model is significant as the calculated resonant frequencies differ more that 10% indicating that the simple wire model is not adequate for this particular scenario. Calculated resonant frequency for the plate model is 11.243 MHz which is in very good agreement with a value of 11.232 MHz calculated in [2].

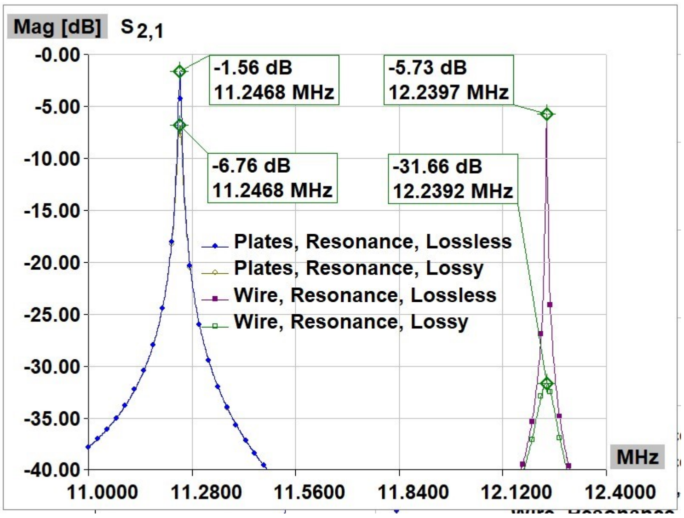

Figure 7. Comparison of resonance calculation using wire and plate models with and without the losses.

WPT Link Simulation

With the convergence of the results established and the meshing parameters providing high accuracy determined, the accurate simulation of the WPT link can be performed. Simulations are again carried out for both, wire and plate model. The WPT models created in WIPL-D Pro CAD environment are presented in Fig. 8, while the results of the simulations are shown in Fig. 9 for both, lossless and copper conductors. Again, the difference between highly accurate plate model and approximate wire model is significant.

A level of the transmission between the generator and the load, which is directly proportional to the efficiency, can be deduced from the results corresponding to the lossy, plate model presented in Fig. 9 and repeated in Fig. 10 for clarity. A value for the transmission for the case of 50 Ω terminations is approximately -12 dB. This value is not impressive and does not represent acceptable solution for a practical WPT link.

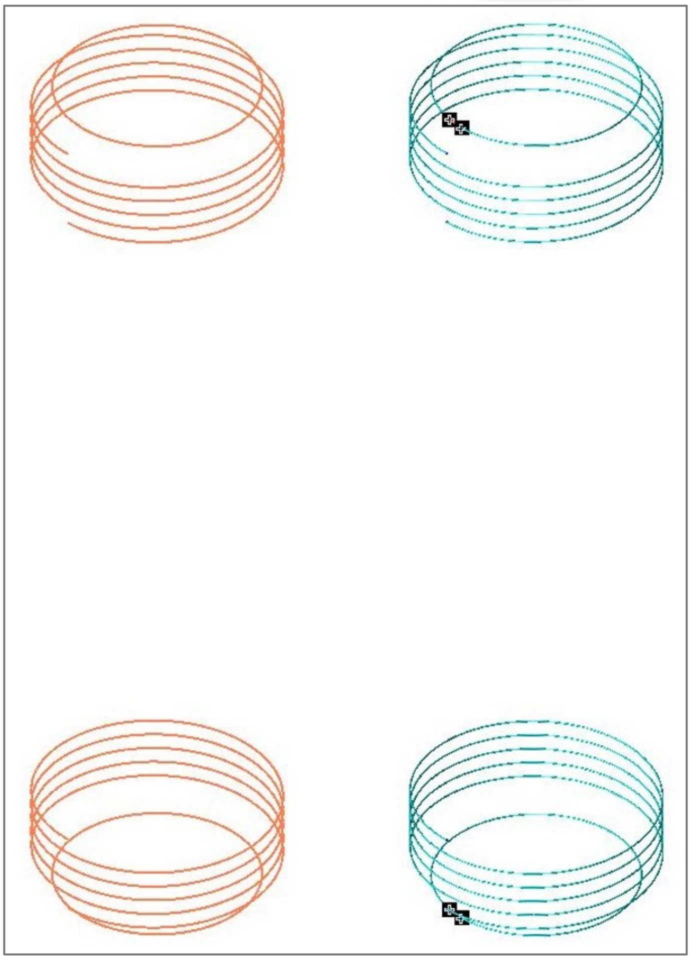

Figure 8. Models of the WPT link structures. Left – wire model. Right – plate model.

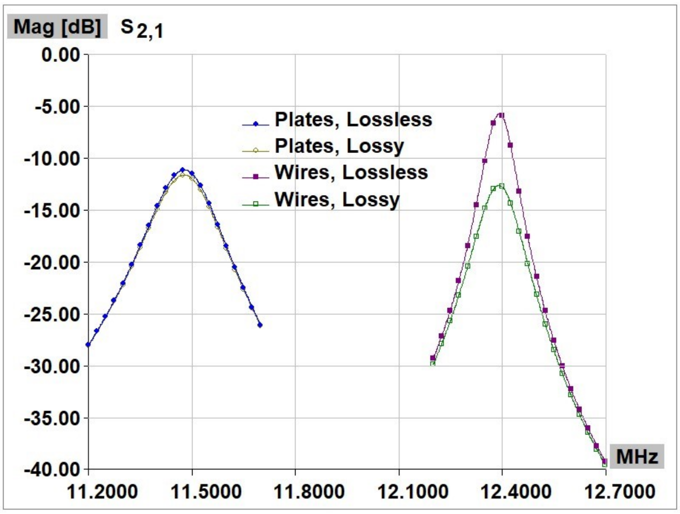

Figure 9. Comparison of WPT simulations using wire and plate models with and without the losses.

By changing default port impedances from 50 Ω to 5.8 Ω, the transmission level rises up to approximately -2.4 dB, as presented in Fig. 10. This confirms the value for optimal port impedances found in [2]. Further decrease of the port impedance does not contribute to the increase of transmission efficiency but leads to the characteristic appearance of two transmission maxima, also indicated in Fig. 10.

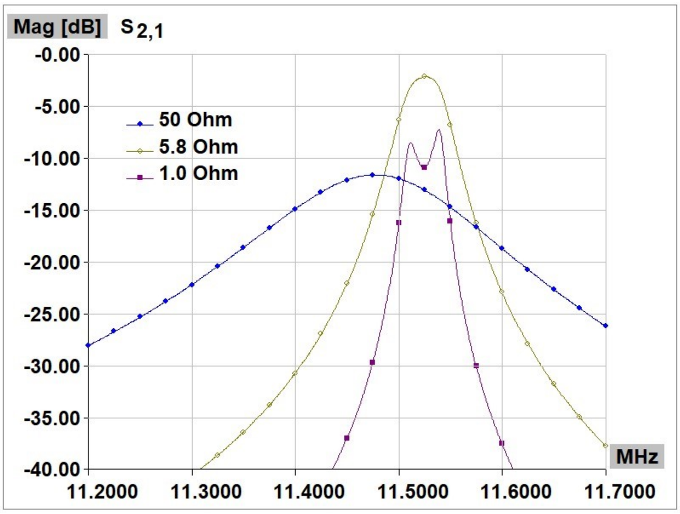

Figure 10. The influence of port impedance to WPT transfer efficiency.

Simulation Details

All the simulations presented have been performed using a standard desktop PC with the technical specifications listed in Table 1. The installed amount of RAM is sufficient to support incore operation for all of the calculations described in this application note.

The relevant computation data are summarized in Table 2. **Simulations are very fast, around 5 minutes per frequency**. Although the simulation time for a wire model is almost negligible, for the particular case of WPT link it does not represent acceptable approximation.

Table 1. Computer used for the simulation.

Hardware	Description
CPU	Intel® Core™ i7-8700 CPU @ 3.20 GHz
RAM	32 GB

Table 2. Number of elements, number of unknowns, and simulation time per frequency.

Mesh Parameter 2 cm	Number of elements	Number of unknowns	Simulation time per frequency [seconds]
Plate model	12,524	25,030	310
Wire model	2,630	2,628	0.5

Conclusion

This note explains how an inductive wireless power transfer (WPT) link can be simulated using WIPL-D Pro CAD, a full electromagnetic (EM) simulator and solid modeler design environment. The example used to demonstrate the features of the modeling environment has been taken from the literature. Two helical resonators have been coupled to input and output inductive loops respectively. As the numerical method implemented requires only the meshing of the boundary surfaces of the model parts, the simulations of the four inductors structure are very fast. The convergence of the results has been easily established by calculating the resonant frequency of a helical inductor identical to the one used in the particular WPT. Once the optimal meshing parameters are determined, speed and high accuracy of the analysis are both ensured. The accuracy of the solid (plate) inductor models has been confirmed high, while the much faster, thin wire approximation, is not adequate for this particular case.

Variation of the port impedances can be carried out to establish the optimum generator and source impedances providing efficient wireless power transfer. The results calculated using WIPL-D program suite are in excellent agreement with the data available from the literature.

All of the calculations have been carried out using standard desktop PC. The simulation time per one frequency point of the WPT link simulation is approximately 5 minutes.

References

[1] A. Kurs, A. Karalis, R. Moffatt, J. D. Joannopoulos, P. Fisher, and M. Soljačić, "Wireless Power Transfer via Strongly Coupled Magnetic Resonances," *Science*, vol. 317, no. 5834, pp. 83–86, July 2007.

[2] M. Dionigi, M. Mongiardo and R. Perfetti, "Rigorous Network and Full-Wave Electromagnetic Modeling of Wireless Power Transfer Links," *IEEE Microwave Theory Tech.*, vol. 63, no. 1, pp. 65–75, Jan. 2015.