Wireless Charging – Wireless Disturbance?

With the development of a universal inductive charging system, Finepower GmbH from Munich has underlined its leading position in power electronics and battery charging systems. After many developments in the field of offboard and onboard charging devices for industry and electromobility, Finepower is now already working on improving the charging technology of tomorrow.

By Dipl.-Ing. (TUM) Georg Heiland, Finepower GmbH and Dr.-Ing. Christof Ziegler, TDK Electronics AG

Introduction

Inductive charging systems for electric vehicles are currently hot topics for research, development and standardization. Typical examples of applications include contactless recharging of trucks, forklifts and AGVs in the industrial sector as well as electric vehicles in road traffic. Due to the varying system properties of the vehicles, such as ground clearance, battery voltages, coil geometries and current carrying capacity, at the moment every manufacturer is aiming to develop its own inductive charging unit tailored to the requirements of a particular vehicle fleet. By contrast, as part of the research project UnIndCha (Universal Inductive Charging) sponsored by the Bavarian Ministry of Economic Affairs, Energy and Technology (StMWi), Finepower is currently working on establishing an inductive charging station capable of working with the highest possible number of different vehicle types – with correspondingly different receiver coils and battery systems.

TDK Electronics AG (formerly EPCOS AG) is involved in the project as a manufacturer of transmitter and receiver coils for inductive charging systems and focuses particularly on ensuring the electromagnetic compatibility (EMC) of universal systems. In addition, the Associate Professorship of Energy Conversion Technology at the Technical University of Munich (TUM) and the Technology Network Allgäu (TNA) at Kempten University of Applied Sciences are contributing fundamental research papers.

Frequency tuning versus variable resonant circuit tuning

Normally, inductive charging systems are tuned to a particular frequency, whereby capacitances are connected to the transmitter coil on the transmitter and receiver side. With this combination, the system can be designed for the normatively required transmission frequencies. Such a combination of coils and capacitances creates a resonant (oscillating) circuit, which has a particular natural frequency known as the resonant frequency.

$$f_r = \frac{1}{2\pi\sqrt{LC}}$$

Depending on the positioning of the transmitter and receiver coils in relation to each other, the resonant frequency shifts to higher or lower values depending on the change of inductance, which defines the resonant frequency.

To maintain the required charging power the transmission frequency then needs to be adjusted accordingly.

Instead of varying the transmission frequency, an alternative method varies the tuning of the resonant circuit. For instance, additional capacitances are switched on or off to keep the resonant frequency constant. Figure 1 shows a circuit built in the research project.

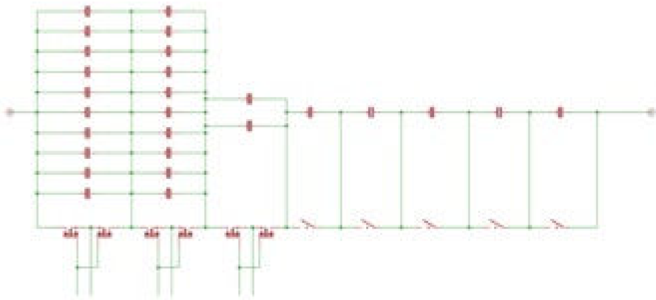

Figure 1: Circuit for variable tuning of an inductive charging system as implemented in the research project

Influence on emitted electromagnetic interference

In inductive charging systems, the energy transfer is performed via the magnetic field that results from the high-frequency AC current flowing through the transmitter coils.

If we look at this current in an oscilloscope, a sinusoidal shape can be seen that corresponds to the resonant frequency of the transmission system. The physics of the electromagnetic waves explain that the time-based change in the magnetic field corresponds to the time-based change in the coil current (Maxwell's law describing the magnetomotive force):

$$N \cdot I = \oint \vec{H}\, d\vec{l}$$

However, despite the apparently perfect curve shapes for the current and magnetic field, such a system cannot satisfy the required normative limits without further filtering efforts due to additional harmonic frequency components, that are more or less distinct depending on the main operating frequency.

These harmonics always occur, if the operating frequency differs significantly from the resonant frequency. Depending on the sign of this deviation, the following examples of current forms can result under the same load conditions (simulated using parameters of the real system).

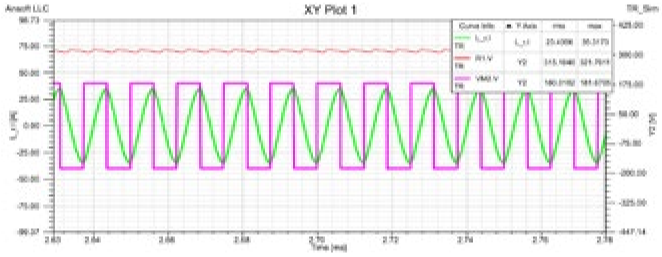

Figure 2: Expected current and voltage forms at the transmitter coils at an operating frequency that is above the resonant frequency of the system (above resonant operation)

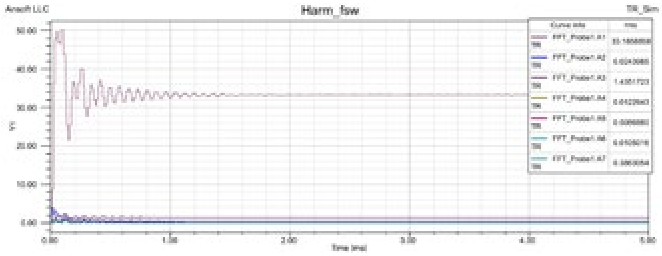

Figure 3: Expected amplitudes of the harmonics of the coil current at an operating frequency that is above the resonant frequency of the system (above resonant operation)

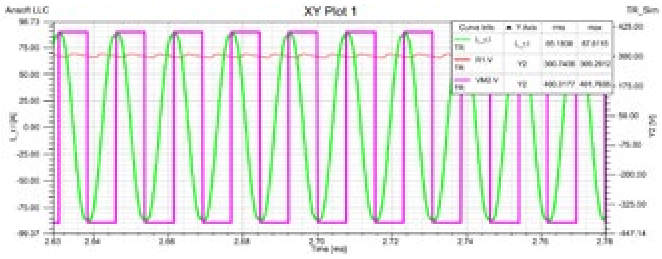

Figure 4: Expected current and voltage forms at the transmitter coils at an operating frequency that is below the resonant frequency of the system (below resonant operation)

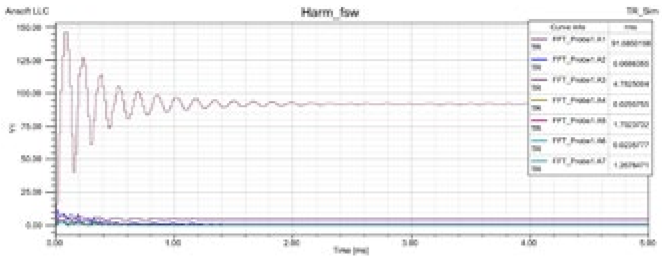

Figure 5: Expected amplitudes of the harmonics of the coil current at an operating frequency that is below the resonant frequency of the system (below resonant operation)

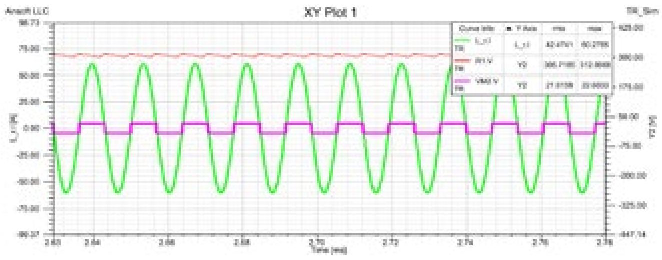

Figure 6: Expected current and voltage forms at the transmitter coils at an operating frequency that corresponds to the resonant frequency of the system (resonant operation)

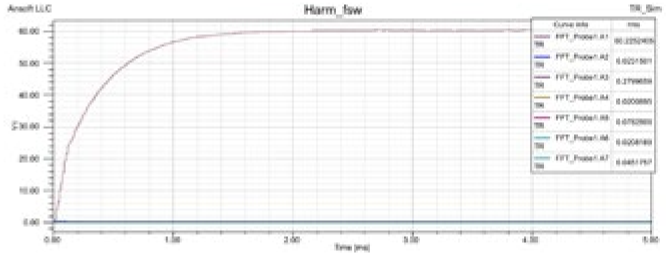

Figure 7: Expected amplitudes of the harmonics of the coil current at an operating frequency that corresponds to the resonant frequency of the system (resonant operation)

A frequency analysis of the current form (FFT) yields the following values for the harmonics:
A comparison of the harmonics of the coil current shows that the values are significantly lower for the case “resonant operation”:

Harmonic	**% of fundamental wave**		
	Above resonant	Below resonant	Resonant
1	100.00	100.00	100.00
2	0.07	0.08	0.04
3	4.34	5.21	0.47
4	0.04	0.03	0.03
5	1.81	1.95	0.13
6	0.03	0.03	0.03
7	1.17	1.38	0.07

Table 1: Coil current harmonic analysis in dependence of operating point

However, normative requirements are related to magnetic field strength, not the coil current. The following assessment provides a qualitative overview of the resulting emitted magnetic fields based on the current harmonics in Table 1.

For a straight conductor through which a current flows, a circular magnetic field can be assumed with an amplitude that is inversely proportional to the distance between a magnetic field line and the conductor (near field).

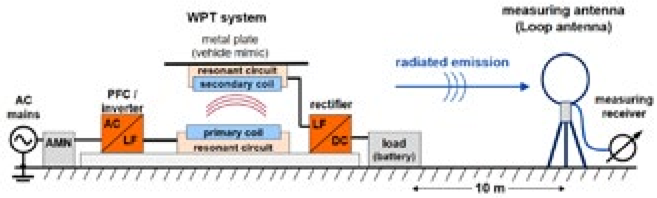

Figure 8: Principle measuring the magnetic field strength with a loop antenna for evaluation of the emitted EMC interference in the frequency range between 9 kHz and 30 MHz

$$|\vec{H}| \approx \frac{I}{2\pi r}$$

The applicable standards require the magnetic field to be measured at a distance of 10 m. In the example shown above, this yields the following approximate field strengths (peak values):

Harmonic [dBµA/m]	Above resonant	Below resonant	Resonant
1	114.5	123.3	119.6
2	51.6	60.8	51.3
3	87.2	97.6	73.0
4	45.6	53.6	50.1
5	79.6	89.1	61.9
6	44.9	51.6	50.5
7	75.9	86.1	57.1

Table 2: Magnetic field harmonic analysis in dependence of operating point [peak values]

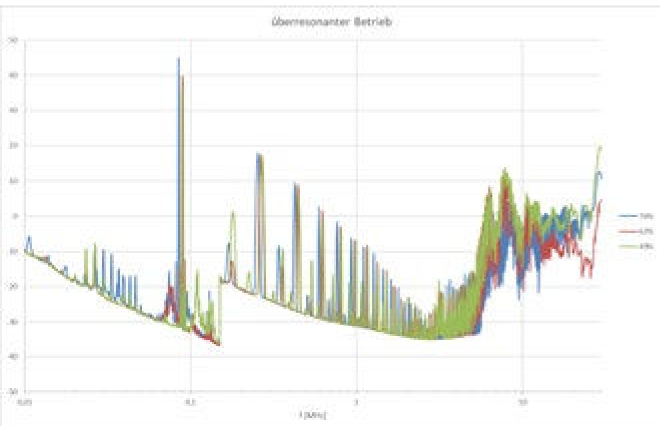

Figure 9: Magnetic field spectrum during operation with different tunings of the resonant circuit, out of resonance in each case

It is easy to see that the spectrum of the current or magnetic field varies extremely at different operating frequencies. In the calculated example above, the lowest emitted interference is expected when the system is operated in resonant mode.

Measurement results

In the research project UnIndCha, a prototype of an inductive charging system was set up and the emitted magnetic interference in the frequency range between 9 kHz and 30 MHz was measured at different transmission frequencies of the WPT system.

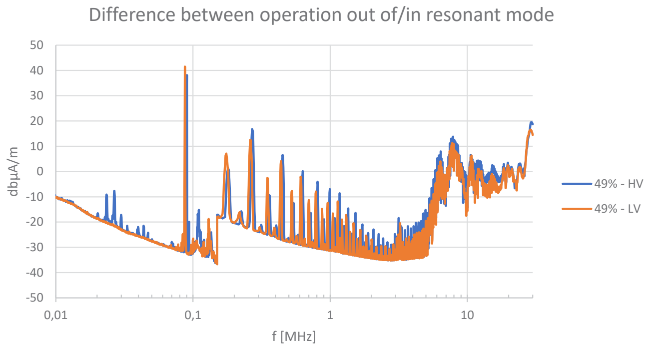

Figure 10: Magnetic field spectrum during operation with the same resonant circuit tuning, with different frequencies (out of/in resonant mode)

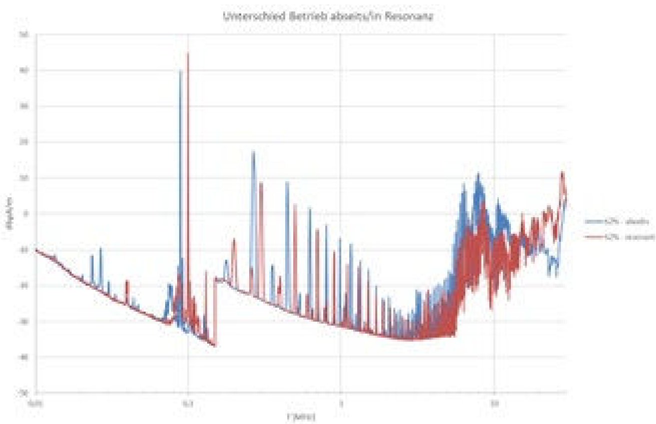

Figure 11: Magnetic field spectrum during operation with the same resonant circuit tuning (but different to Figure 10), with different frequencies (out of/in resonant mode)

The results show that different resonant circuit tunings lead to different levels of emitted interference at otherwise identical operating parameters. These differences are caused by varying deviations between the operating frequencies and the resonant frequency of the system. Depending on the tuning, a reduction of emissions by up to 10 dBµA/m was observed in the various series of measurements.

In line with the theoretical assumptions, the minimum levels for interference emissions were obtained when the system was operated in resonant mode.

In addition, an optimum tuning value of 62% was determined in the measurements, which suggests that with variable tuning the emitted interference increases again if the compensation is too high.

With higher offset positions between transmitter and receiver coil, it can be assumed that the effectiveness of the tuning adaptation increases. Thanks to the option of variable resonant circuit tuning, at higher offset positions it is always possible here to ensure that the system operates within the normatively required frequency range.

Table 3 summarizes the measured harmonic amplitude values at different operating frequencies. Compared to the theoretical values of

Table 2, a qualitative match can be found, although the absolute quantitative values differ.

The discrepancies to the theoretical considerations are primarily caused by the measurement principle that allows to measure only one vector polarization (x,y or z) of the magnetic field, which is a greater or lesser fraction of the overall field vector.

In the theoretical considerations always the maximum value of the field vector was calculated due to the assumption of an ideal, straight conductor and, resulting from this, an ideal, circular magnetic field.

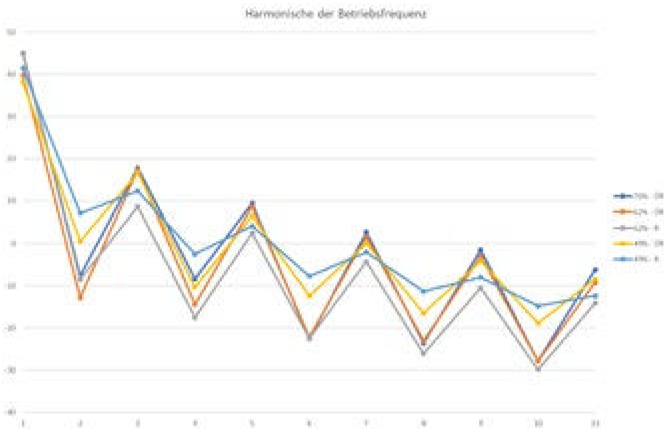

Figure 12: Graphical comparison of the harmonics of the operating frequency of the measured different resonant circuit tunings from Figures 9 - 11

[dBµA/m]	76% – above resonant	62% – above resonant	62% – resonant	49% – above resonant	49% – resonant
1.	45	39.8	44.8	38.1	41.5
2.	-7.6	-12.8	-8.5	0.5	7.1
3.	17.8	17.4	8.7	16.7	12.4
4.	-8.4	-14.4	-17.5	-10.3	-2.5
5.	9.5	8.8	2.5	6.5	4.1
6.	-22.5	-22.1	-22.4	-12.4	-7.7
7.	2.7	1.6	-4.3	0.1	-2.0
8.	-23.6	-23.1	-26.1	-16.5	-11.3
9.	-1.5	-3.0	-10.5	-4.1	-8.0
10.	-27.9	-27.9	-29.9	-18.9	-14.8
11.	-6.2	-9.2	-14.1	-8.4	-12.4

Table 3: Comparison of measured harmonics of magnetic field strength at different operating points

Conclusions

The measurements of interference emissions revealed large variations while operating at different frequencies and tuning settings. A significant reduction of the harmonics was attained during operation at the resonant frequency. Therefore a circuit design with the option to readjust the resonance tuning is very beneficial, particularly at high coil displacements. Such circuit designs have been investigated by Finepower in the research project UnIndCha.

www.finepowe .com

About the authors:

Principal author:
Georg Heiland is employed as a Development Engineer at Finepower GmbH and coordinates research and innovations within the company.

Co-author:
Dr. Christof Ziegler has been working in the EMC laboratory of TDK Electronics AG in Regensburg since 2015, where he supports the development and characterization of components for wireless charging systems. As a member of the committee GAK 353.0.1 “Contactless Charging of Electric Vehicles” in DKE, he is helping to draw up and define standards for this topic.