Application Note

Proprietary wireless power transfer solution for high performance including data transmission

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1 Introduction

With the increasing spread of wireless power transfer in consumer electronics, e.g. in smartphones and charging stations, manufacturers of industrial and medical technology are focusing more and more on this technology and its benefits. This technology offers interesting approaches, especially for industries and areas where harsh working conditions are common, such as construction machinery, explosive atmospheres (ATEX), agriculture, etc. For example, expensive and vulnerable slip rings can be superseded, reducing maintenance and extending the life-cycle of the product.

In medical technology, too, contactless energy transfer offers numerous benefits. Special requirements for hygiene and sterility of medical devices apply here, while the devices and systems must also be resistant to harsh cleaning agents and chemicals. Contactless energy transfer eliminates the need for special connectors with (for example) particularly good seals. Since increasing amounts of data are transmitted wirelessly – e.g. via WiFi, Bluetooth, etc. – transferring the required energy wirelessly as well is a sensible development. The aim of this application note is to show the developer how a proprietary contactless power transmission system rated at several hundred Watts, including data transmission, can be created simply and efficiently.

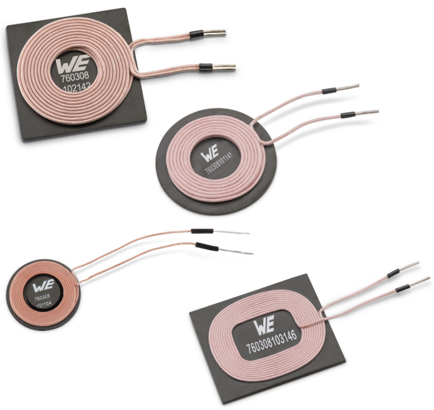

Figure 1: Wireless Power Coils from Würth Elektronik

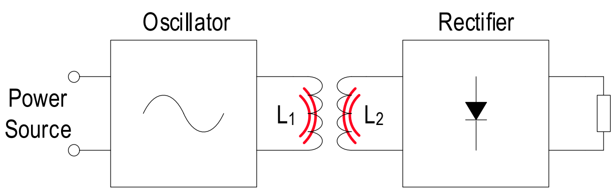

Figure 2: Principle of wireless power transmission

2 How inductive wireless power transmission works

We use only near-field energy transmission. This type of transmission includes inductive coupling based on the magnetic flux between two coils. As shown in figure 2, the transmission path consists of four main components. On the transmitter side, there is a transmitter coil; and an oscillator, which works as an inverter. On the receiver side, the system consists of the receiver coil and the rectifier, which generates DC from the AC input. The oscillator generates an alternating current from the input DC voltage, which then generates an alternating field in the transmitter coil (L1). Due to the counter-induction between the two coils, the energy is transmitted between the transmitter coil (L1) and the receiver coil (L2). The alternating current in the transmitter coil induces an alternating voltage in the receiver coil (according to Faraday' law of induction), which is then rectified and passed on to the load.

A problem with larger distances between the transmitting and receiving coils is that the stray flux increases sharply, and thus the efficiency of the energy transmission decreases. This corresponds to the function of a transformer with loose coupling. This can be remedied by resonant inductive coupling.

By means of resonant inductive coupling, the range as well as the efficiency can be increased. This represents an extension of pure inductive coupling, with a capacitor being inserted in series with the transmitting and receiving coils. The result is an LC series resonant circuit, also referred to as a resonant tank. To achieve the best possible efficiency of energy transmission, the resonant frequencies of the oscillating circuits must be tuned. The very high stray inductance will be almost completely compensated with the capacitor in series to the WPT coil. The resonance between the two oscillating circuits leads to an improved magnetic coupling between the transmitter and receiver coils at the selected resonance frequency.

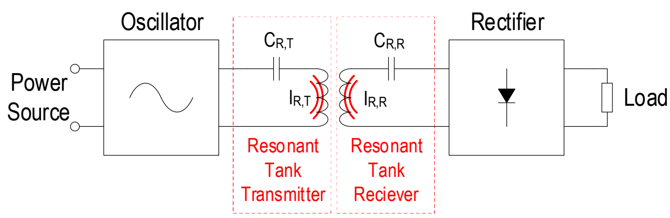

Figure 3: Principle of resonant inductive energy transfer

The principle of inductive resonant energy transfer can be very easily applied in practice. The following chapter describes a proprietary solution.

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3 Practical application of inductive resonant energy transfer

3.1. Design of a full bridge resonance converter

Figure 4 shows the block diagram of a full bridge resonance converter. The circuit diagram can be divided into the following sections:

- Oscillator with fixed duty cycle (50 %) and full bridge MOSFET driver
- Full bridge of 4 switching elements (MOSFETs)
- Series resonant circuit consisting of resonance capacitor and WPT transmitter coil
- Series resonant circuit consisting of resonance capacitor and WPT receiver coil
- Rectifier (bridge rectifier or synchronous rectifier)

This circuit is not self-oscillating; the switching frequency is determined by the oscillator and is tuned to the resonant frequency of the series resonant circuit.

Advantages of this concept:

- Scalability from low power to very high power (10 W to several 10 kW)
- The current flow in the resonance circuit and rectifier is sinusoidal, good EMC behavior
- The MOSFETs switches at zero voltage, giving very high efficiency > 90 %
- Easily scalable for many different voltages / currents
- By changing the switching frequency, the output voltage can be higher or lower than the input voltage
- Output voltage can be regulated
- Data can be transmitted between receiver and transmitter

3.2. Operation of a full bridge resonance converter

Figures 5a and 5b show the transfer of power between transmitter and receiver. The current (resonant current) is sinusoidal in the transmitting coil, oscillating around the zero point. Energy is transferred in both half-waves of the resonance current $I_{CR/LR}$.

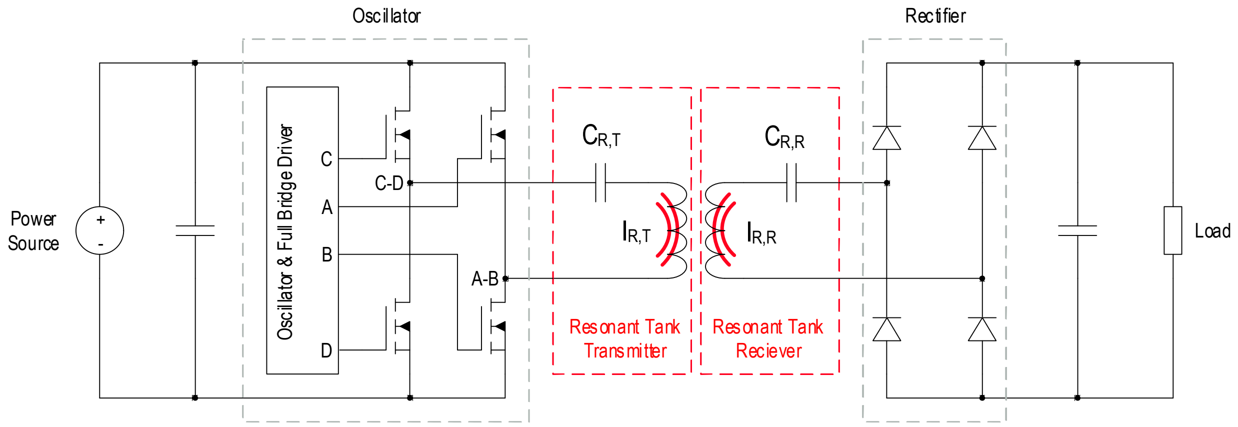

Figure 4: Block diagram of a full bridge resonance converter

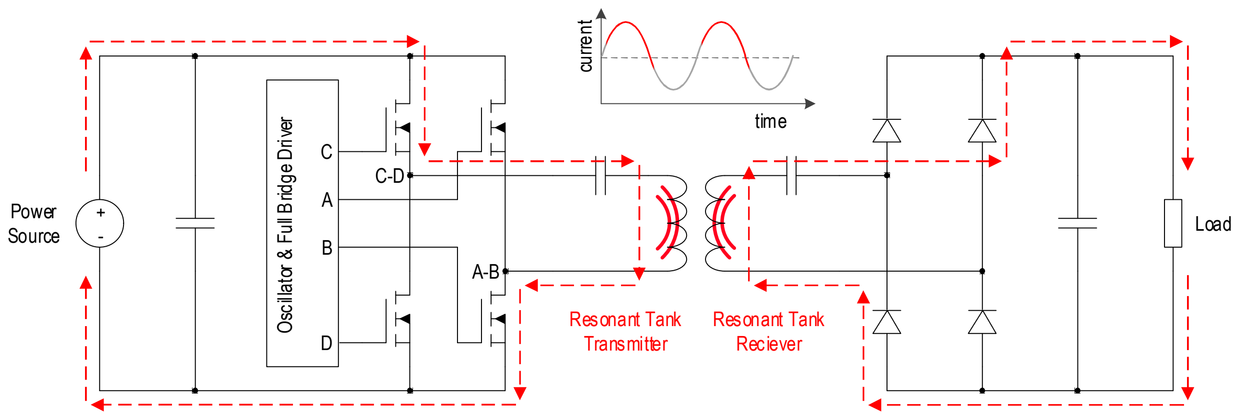

Figure 5a: Principle of energy transfer during the positive half-wave ($I_{CR/LR}$) in the resonance tank

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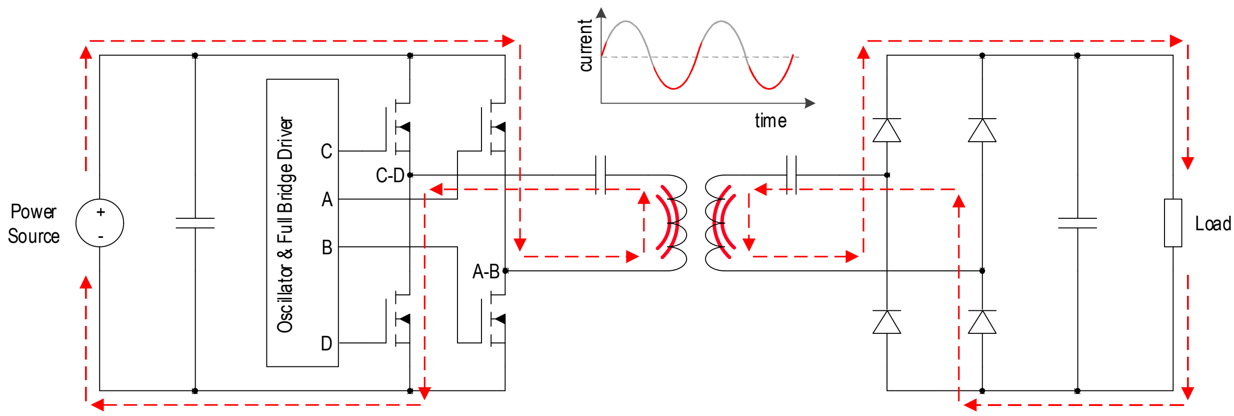

Figure 5b: Principle of energy transfer during the negative half-wave ($I_{CR/LR}$) in the resonance tank

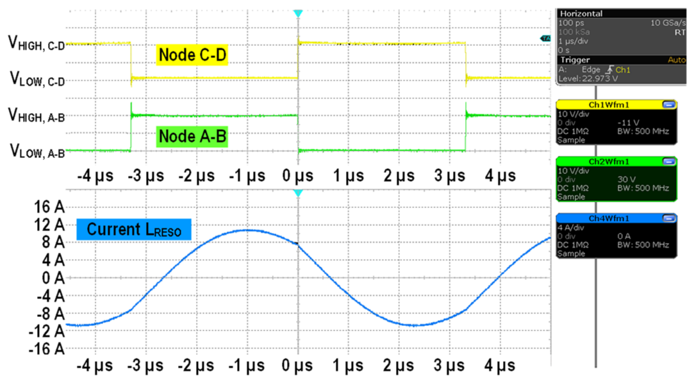

Figure 6: Oscillogram drain signals A-B, C-D and coil current
(U_{In} = 20 V, U_{Out} = 17 V, I_{out} = 6 A, P_{Out} = 100 W)

Figure 6 shows the signals on the resonance circuit. The signals "Node CD" and "Node AB" are the voltage curves within the full bridge. In the high phase of Node AB, the voltage at Node CD is low and vice versa.

As mentioned earlier, the flow of current in the resonance circuit is sinusoidal and a phase shift between the voltage signals and the current signal can be seen. This phase shift occurs because the switching frequency of the full bridge is above the resonant frequency of the series resonant circuit. The operating point is located in the inductive range of the series resonant circuit; the current will follow the voltage.

This is very important for operation, as only through this phase shift to the inductive range is ZVS (zero voltage switching) operation possible. This gives the highest efficiency. If the phase shift goes into the capacitive range, i.e. the current precedes the voltage, the converter is no longer working in ZVS mode, but ZCS mode (zero-current switching).

ZCS operation leads to higher losses because the current commutates hard into the body diodes of the MOSFETs. In unfavourable circumstances, this can destroy the MOSFETs

3.3. Relationship between switching frequency and resonance frequency

The left-hand side of the following simulation shows a simplified model of this circuit. Only the resonance circuit of the transmitter and receiver is shown. This is sufficient for reviewing here.

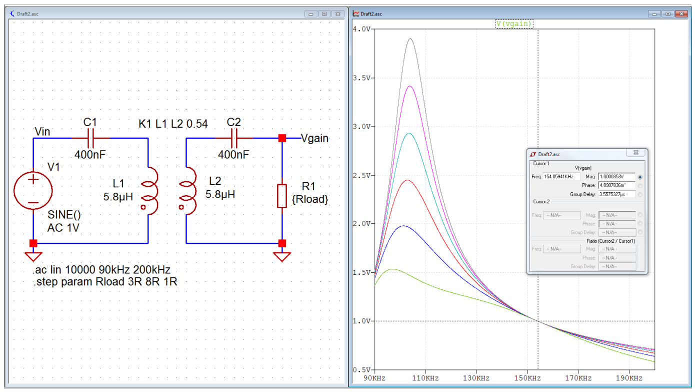

Figure 7: Simulation of resonance behavior under different load conditions

The circuit on the left-hand side shows two series resonant circuits, one each on the transmitter and receiver side. These represent the two resonance tanks in Figure 4. On each side is a capacitor with 400 nF and a WPT coil (760 308 102 142) with an inductance of 5.8 µH. Both oscillating circuits are tuned to each other. For the simulation, we need the coupling factor of the transmit and receive coils. This depends on the distance between the two coils. In our example, we have set the distance to 6 mm, resulting in a coupling factor of 0.537 (0.54). This value was determined by measurement. The resonance frequency of the system, consisting of transmitter and receiver coil, is approx. 100 kHz.

In the Bode plot on the right-hand side, the frequency is plotted on the X-axis and the amplification is plotted on the Y-axis. At amplification = 1 (V_{gain} - V_{in}), all curves of the different load conditions run through one point. In our example this happens at 155 kHz, which corresponds to the switching frequency of the circuit. As mentioned above, the switching frequency is higher than the resonance frequency of the resonant circuit, and here we can see why as well. The following oscillogram (Figure 8) shows the switching frequency and the resonance current.

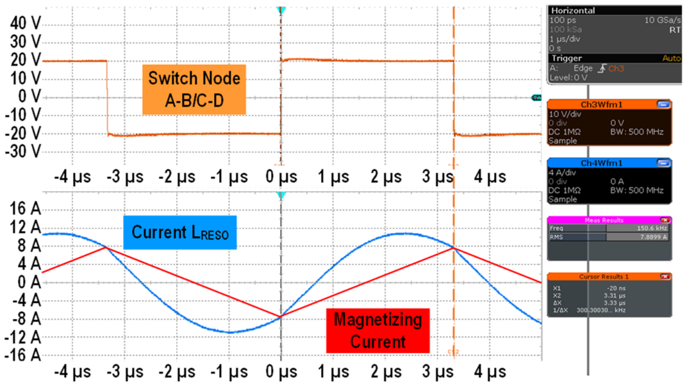

Figure 8: Switching frequency and magnetising current
(U_{In} = 20 V, U_{Out} = 17 V, I_{Out} = 6 A, P_{Out} = 100 W)

The measurement above shows a switching frequency of approx. 150 kHz, which is very similar to the simulation. Figure 8 shows the voltage curve of the switch node A-B/C-D (orange line) and the resonance current through the series resonant circuit on the transmitter side.

From these two curves, it can be seen that a complete energy transfer between transmitter and receiver takes place during each half-wave. The resonance current reaches the magnetising current every time the switch node switches over. The system operates at maximum efficiency at this operating point. On the transmitter side, the MOSFETs switch off at a drain/source voltage of about 1 V (ZVS operation); this voltage depends on the characteristics of the freewheeling diode in the MOSFETs. According to the MOSFET's data sheet, a typical value is between 0.93 V and 1.2 V.

On the receiver side, the rectifier diodes or the synchronous rectifier operate in ZCS mode (zero-current switching). If the current in the resonant circuit (receiver side) reaches 0 V, or when the resonant current on the transmitter side reaches the magnetising current, the current softly commutates between the two bridge branches in the rectifier. The output voltage can be changed by changing the switching frequency. If the switching frequency is reduced, the operating point moves towards the resonance frequency and the output voltage increases.

If the switching frequency increases, the operating point moves away from the resonance frequency and the output voltage decreases. See resonance curve in figure 8.

3.4. Data transmission between transmitter and receiver

This type of connection also enables transmission of data between transmitter and receiver and vice versa. This is possible by modulating the alternating field between the coils. See the following oscillogram (figure 9).

Data transmission is carried out serially with a transmission rate of approx. 9.6 kBaud. The yellow line shows the data stream from the receiver; the green line is the demodulated signal at the output of the transmitter. In our example, data is transferred from the WPT receiver to the WPT transmitter. A practical example is a sensor for pressure, temperature or any other kind of applications. Shown in figure 10 a sensor connected to the WPT receiver is supplied with energy via the WPT coil and data from the sensor are simultaneously transmitted to the WPT transmitter via the same coil.

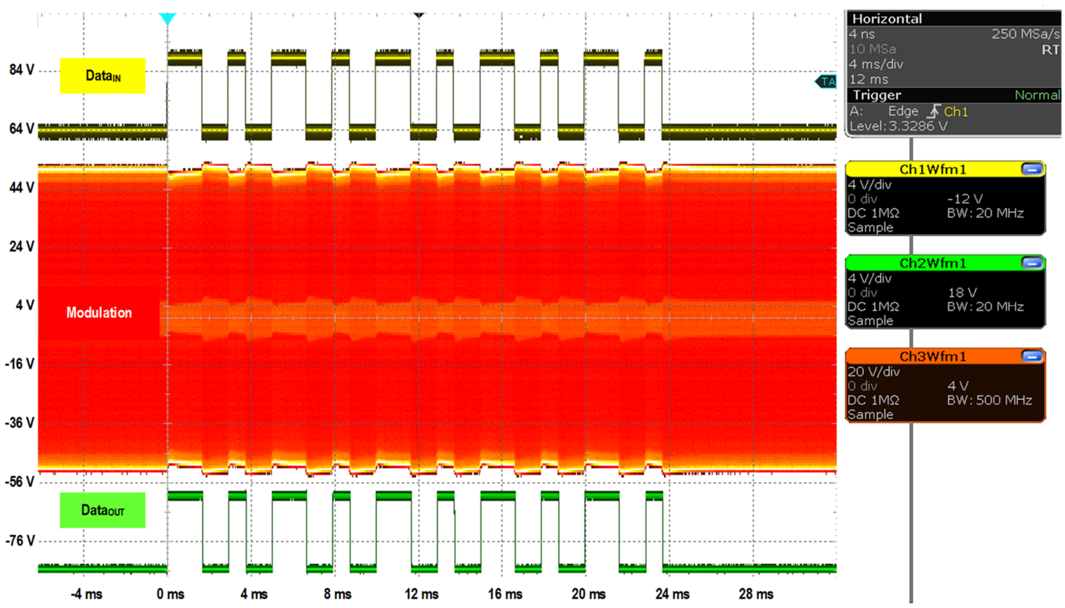

Figure 9: Data transmission from receiver to transmitter (U_{In} = 20 V, U_{Out} = 17 V, I_{Out} = 6 A, P_{Out} = 100 W)

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On the receiver side (data source), an additional capacitor is connected to the existing resonant capacitor by a switch. This switch is connected to the output of the UART of the microcontroller (see figure 10). An AM demodulator and the UART controller receive the data from the modulated signal at the transmitter coil. The data on the transmitter side can be shown at a LCD display (figure 12) or send out via an additional RF module to any kind of cloud service.

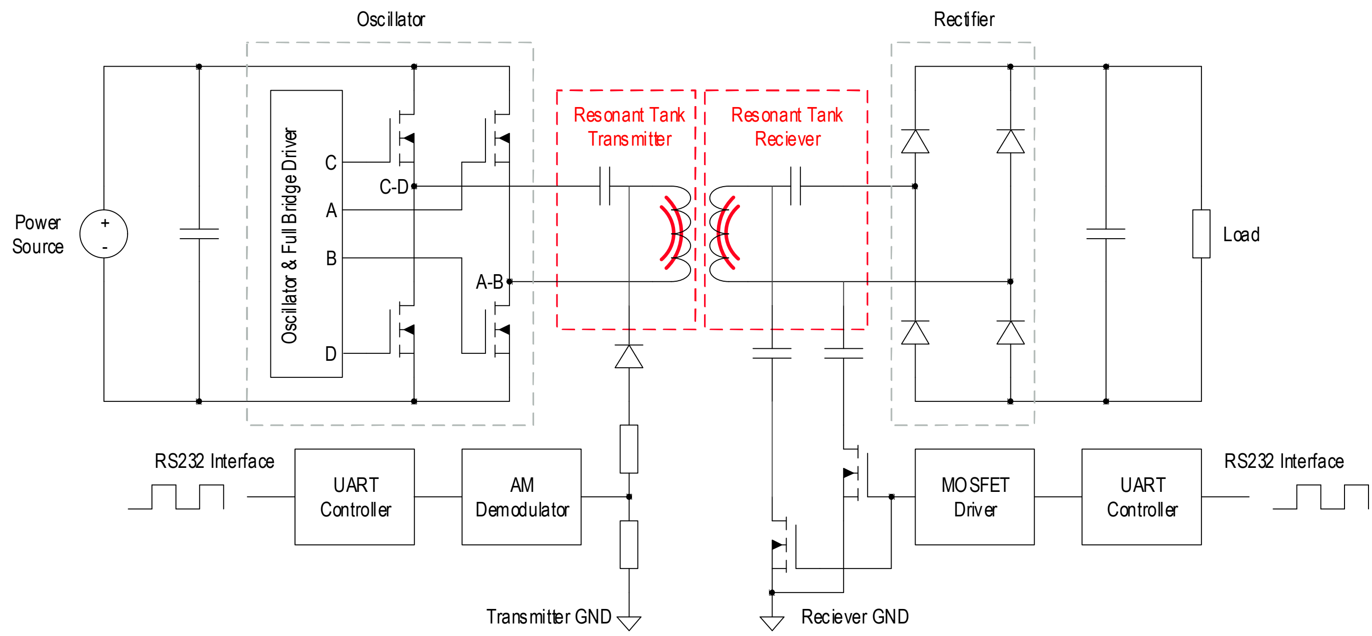

Figure 10: Principle of data transmission from receiver to transmitter

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4 Summary and measurement setup

With the circuit topology presented above, wireless transmission of very large amounts of power – several 10 kW – is possible. Both energy and data can be transmitted. The hardware developer can modify or extend the circuitry as desired or required to adapt it to the application. Since data can be transferred, regulating the output voltage is possible.

Along with the design of the circuits, the transmitter and receiver coils are crucial for high efficiency and the most compact design possible. Würth Elektronik eiSos also offers coils with the highest Q-factor in the respective design alongside its wide range of products. As a result, high inductance values can be achieved, allowing small resonance capacitors.

Furthermore, for higher power ratings, only HF stranded wire (less AC losses) and high-quality ferrite material (high permeability) are used. In practice, this means maximum efficiency with the best possible EMC properties.

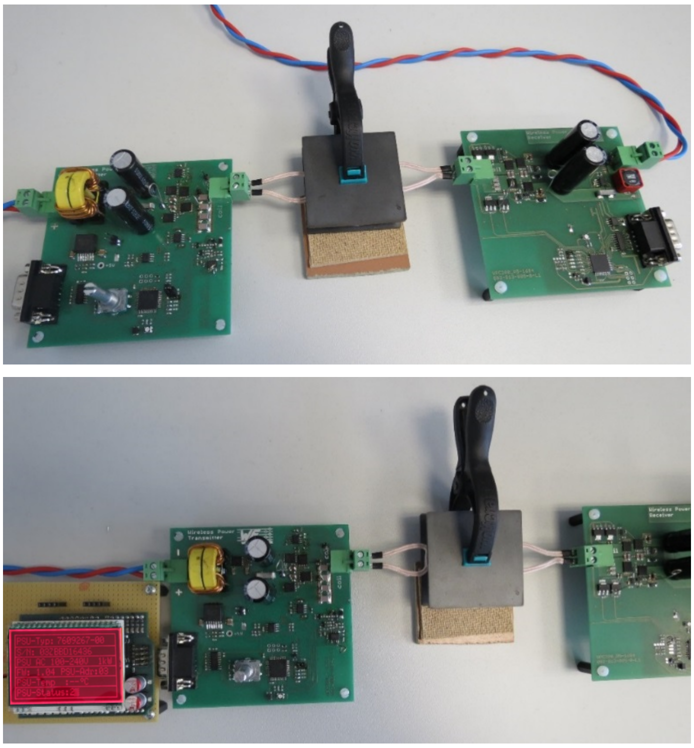

Figure 12: WPT Transmitter and WPT Receiver

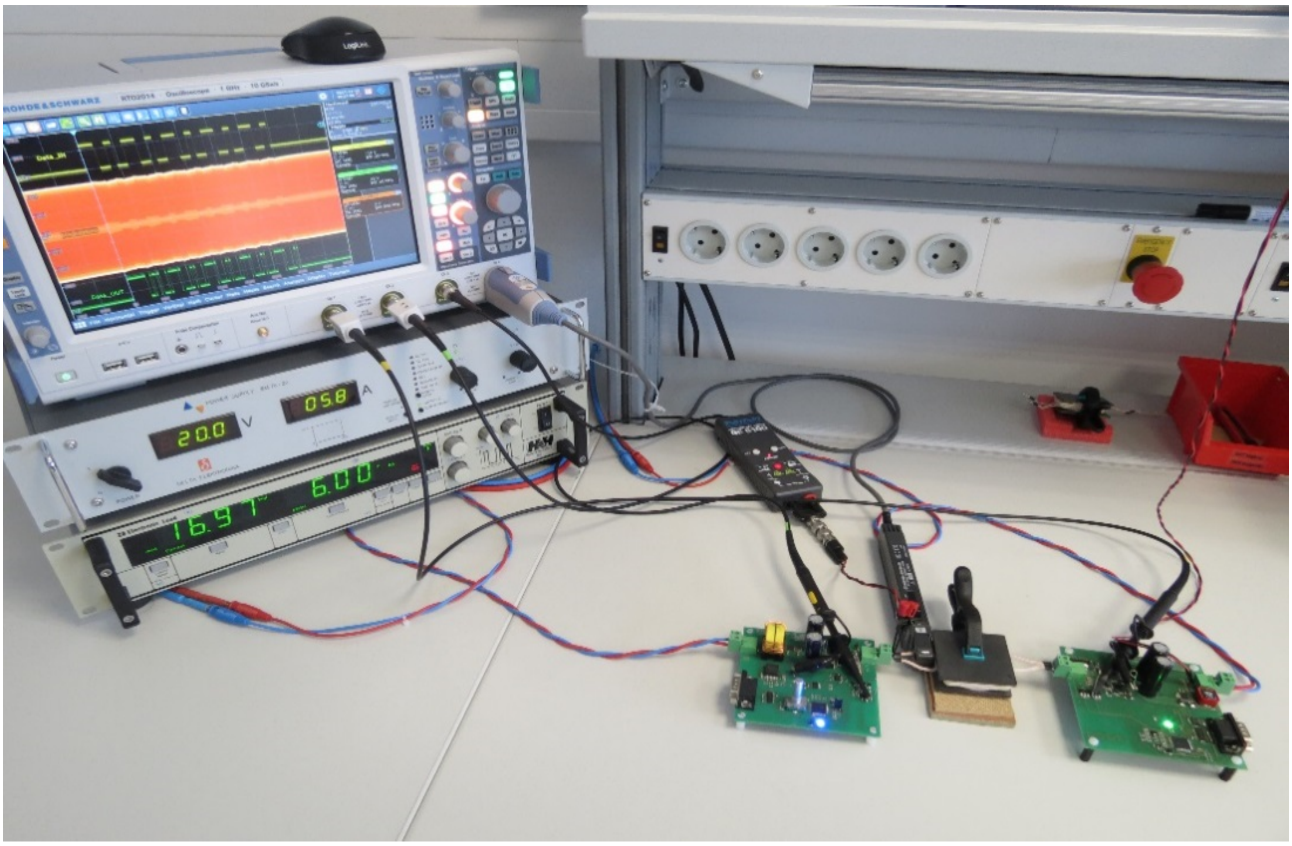

Figure 11: Measurement setup

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