# Circuit and Antenna Design of a Simultaneous Wireless Power Transfer and Near Field Communication System


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***Abstract*—In this paper, different simultaneous wireless power transfer (WPT) and near field communication (NFC) systems are presented. Different methods to realize a simultaneous operation are discussed and the necessary design steps are described. For a power transfer up to 160 W, two Würth Elektronik (WE) WPT/NFC combination coils are used. For higher powers up to 200 W, an individual WPT/NFC combination design is developed by simulation and verified by measurement. Finally, the different methods to achieve the simultaneous operation are compared with each other and the advantages and disadvantages of each system are discussed.**



***Keywords—wireless power transfer, near field communication***


## I. Introduction

There are several ways how to implement data communication into a WPT system. One way is to use in-band communication, where the data and power transfer use the same frequency band. In this case, the data rates are limited to some hundred bytes, because of the low operating frequency of WPT of about 100-200 kHz. Another possible way to implement data communication into a WPT system is the use of NFC, which operates in the 13.56 MHz band. This communication standard enables data rates up to 848 kbit/s. Unfortunately, a simultaneous operation of WPT and NFC might cause interference, because the NFC can be disturbed by the WPT. Simultaneous operation means that the transfer of power and the data communication are operating at the same time. In a previous publication, the authors already presented a WPT/NFC system, but this system does not work simultaneously [1]. In the following, different ways how to realize simultaneous WPT/NFC are presented and a coil design for the operation up to 200 W is proposed.

### A. WE WPT/NFC Combination Coils

WE currently released two new WPT/NFC transmitter combination coils (article numbers 760308101312 and 760308101150), where each of the products combines a WPT coil and an NFC antenna mounted on a ferrite carrier. The two products are shown in fig. 1.

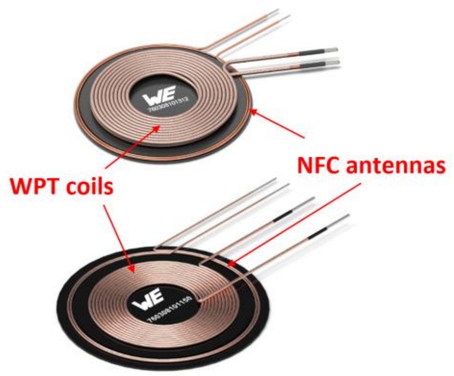


Fig. 1. WE-WPCC WPT/NFC transmitter combination coils (top: 760308101312, bottom: 760308101150).

The WPT coil of the part 760308101312 is compliant to the MP-A10 Qi design and the WPT coil of the part 760308101150 is compliant to the MP-A11 Qi design. In addition to these transmitter combination coils, WE also offers three receiver combination coils. All WE WPT/NFC products are listed in table 1.

TABLE I. WE WPT/NFC COMBINATION COILS

| WE part number | WPT @ 125 kHz | | NFC @ 13.56 MHz | |
|---|---|---|---|---|
| | $L_1$ [µH] | $Q_1$ | $L_2$ [µH] | $Q_2$ |
| 760308103305 | 8.8 | 30 | 1.4 | 47 |
| 760308102306 | 8 | 19 | 1.4 | 47 |
| 760308103307 | 7.8 | 19 | 1.6 | 47 |
| 760308101312 | 24 | 125 | 0.7 | 30 |
| 760308101150 | 6.3 | 100 | 1.2 | 80 |

### B. Setup of the Simultaneous WPT/NFC System

The setup of the WPT/NFC system, which is used in the following, is described by the simplified block diagram shown in fig. 2.

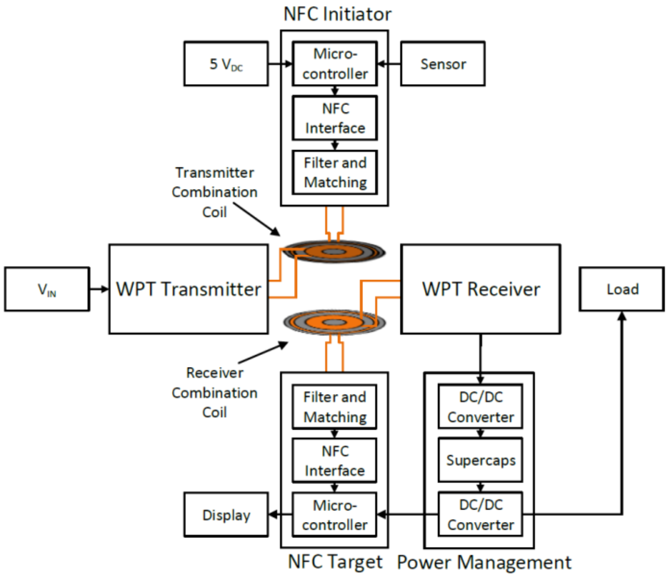


Fig. 2. Simplified block diagram of the used WPT/NFC system.

Based on this setup, the different methods to achieve the simultaneous operation of WPT and NFC have been developed. For the WPT transmitter and receiver parts, we use two different versions.

In the first version, the WPT transmitter and the WPT receiver parts of the WE 200 W development kit (article number 760308EMP) have been used. The WPT transmitter comprises a full bridge inverter plus peripherals, which is described in [2]. On the receiver side, a synchronous rectifier plus peripherals is used. The in-band data transmission, which is implemented in the WE 200 W development kit, has been deactivated in this project, because the NFC part is used for the communication.

In the second version, the WPT transmitter and receiver are built up with Royer converters, which are described in [3]. Compared to version one, the options to control the circuit are reduced significantly.

At the output of the WPT receiver, a power management is necessary. It consists of two DC/DC converter and super capacitors. For each of the DC/DC converters, the WE power module reference board (WE part number 178003) has been used.

The NFC initiator is based on the microcontroller board Arduino Mega 2560 with the microcontroller ATMega2560 from Atmel. For the NFC interface an Adafruit PN532 NFC/RFID controller shield, based on the PN532 chip set from NXP, is used. The included NFC antenna, matching and filtering circuit were removed and a self-made output NFC circuit for filtering and matching was connected on the initiator and the target side. The schematic of the NFC output circuit is shown in fig. 3. The matching process and the used matching and filtering board is described in [4]. As a data source the Adafruit VL53L0X time of flight (TOF) distance sensor was implemented. The NFC target is based on an Arduino Uno Rev. 3 with the microcontroller ATmega328P from Atmel. To visualize the transmitted data the RGB LCD shield kit display from Adafruit is added. It shows the distance measured by the TOF sensor in millimeter.

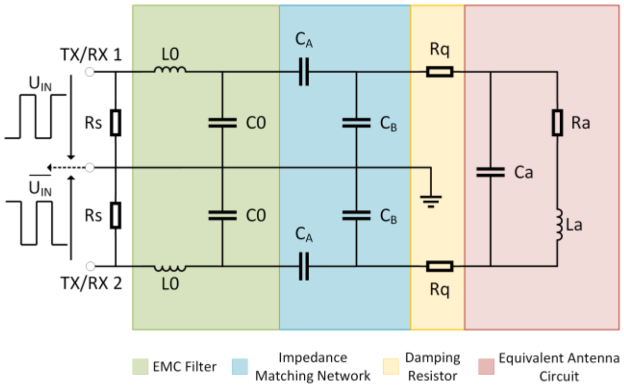


Fig. 3. Differential output NFC circuit. [4]

On the transmitter/initiator and receiver/target side, the same WE combination coils have been used (760308101312 or 760308101150).

## II. Methods and Results

### A. Near Field Communication Part

The NFC standard ISO/IEC14443A is used, which has a data rate of 106 kbit/s and uses an ASK 100 % modulation and a modified miller coding for the communication from initiator to target and a load modulation with sub carriers with Manchester coding for the communication from target to initiator.

Two different programs have been developed, one for the WPT part and one for the NFC part. The program for the WPT part deactivates the standard in-band communication of the 200 W Kit. The NFC program is based on an example delivered by Adafruit. The included reader/writer mode and card emulation mode are used. The receiver acts as a passive NFC target like a key card. First the NFC initiator sends a request to write on an NFC target in fixed time intervals. If an NFC target is in range it answers the request and allows the initiator to write on it. As written data the sensor values of the TOF sensor are used. Now the receiver can send the written data to the display. The workflow of the NFC software is visualized in fig. 4.

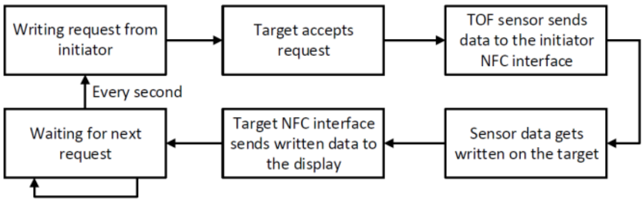


Fig. 4. Workflow of the NFC software.

### B. WE WPT/NFC Combination Coils

To estimate the influence of the WPT transmitter coil on the NFC antenna and vice versa, the variation of the coupling factor k on distance between the transmitter and receiver have to be determined. Not only the coupling of the transmitter and receiver coils have been measured, but also the lateral coupling of the coil and antenna of a single carrier (e.g. the article 760308101150). The coupling factors vs distance between the combination coils get simulated with ANSYS Maxwell from ANSYS Inc.. In the second step the simulation gets verified by a measurement with an LCR meter.

For the determination of the coupling factor k, the inductances $L_1$ and $L_1$' have to be measured. $L_1$ is the inductance of the transmitter coil or initiator antenna in the presence of the open receiver coil or target antenna. $L_1$' is the inductance of the transmitter coil or initiator antenna in the presence of the shorted receiver coil or target antenna. Both measurements are done for distance steps of 1 mm from 1 mm to 20 mm distance. The inductance was measured at 125 kHz. The coils were adjusted with a variable spacer. The setup of the coupling measurement setup is shown in fig. 5.

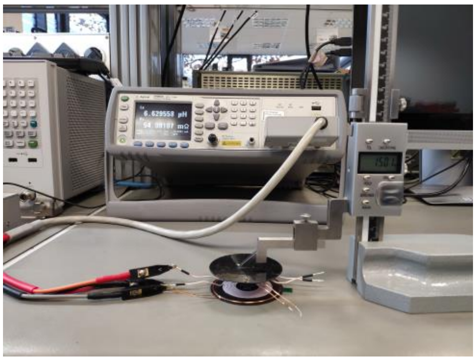

Fig. 5. Coupling measurement setup.

With $L_1$ and $L_1$' the coupling k can be calculated using eq. (1).

$$k = \sqrt{1 - \frac{L_1'}{L_1}} \tag{1}$$

### C. Simultaneous WPT/NFC Systems

After the coupling is known, the influence of the WPT signal on the NFC frequency band has to be analyzed. This is done with the measurement of the current waveform in the WPT Tx coil creating the magnetic field, and the waveform of the induced voltage in the NFC Rx antenna. The waveforms are analyzed with an oscilloscope using fast Fourier transformation (FFT). A distance of 10 mm between the combination coils is chosen. If the WE 200 W development kit is used for the power transmission, a specific operation point has to be chosen. The 200 W development kit can have a triangular or sinusoidal current waveform at the WPT Tx coil, dependent on the operation point. A sinusoidal waveform is chosen, because it has less harmonics that can interfere with the NFC frequency band. To approximate this operation point eq. (2) can be used [5].

$$R_L = \frac{\pi^2}{8} \cdot L_2 \cdot \omega \cdot k \tag{2}$$

$R_L$ is the load resistance on the receiver side, $L_2$ is the inductance of the WPT Rx coil, $\omega$ is the angular operating frequency of the system and the coupling factor between the WPT Tx and WPT Rx coil. The load resistance of the test system is realized by an electrical load. The formula is only an approximation, so the switching frequency of the 200 W development kit has to be varied a bit until a sinusoidal waveform is achieved at the WPT Tx coil.

As second option for the power transmission, Royer converters are used at the transmitter and receiver side. The advantage of using Royer converters for the power transmission compared to the WE 200 W development kit is the greater simplicity of the circuit and that there is no microcontroller needed. The disadvantages are the reduced possibilities to control the circuit due to the missing control circuit. The operation frequency of the Royer converter is determined by the resonance tank during the 200 W development kit is driven by a PWM signal. At the 200 W development kit, a series-series resonant tank compensation is used. For the Royer converters, a parallel-parallel resonant tank compensation is used. The different compensation techniques and resonant tank calculations are described in the WE "Trilogy of Wireless Power Transfer" book [6].

### D. Time Multiplex Procedure

An alternative of the simultaneous operation of WPT/NFC, which is described in the previous section, a so-called time multiplex procedure can be used. Time multiplex means that the WPT is switched off during the NFC operation while the NFC target is supplied by a pre-loaded super capacitor. The whole system, which is shown in fig. 2, operates in the time multiplex mode as follows:

1. Super capacitors at the output of the WPT receiver are loaded for 5 seconds with a DC-to-DC converter. The converter is supplied by the WPT receiver, which receives the power from the WPT transmitter wirelessly.
2. The 200 W transmitter deactivates the power inverter and sends a message to the NFC initiator microcontroller.
3. The microcontroller receives the message from the transmitter and activates the initiator.
4. The initiator transmits the data from the TOF sensor to the target, while the target is supplied by a second DC-to-DC converter, which is supplied by the pre-loaded super capacitors.
5. After the data transmission from initiator to the target is complete, a message is sent to the WPT transmitter microcontroller and the whole NFC system is switched off.
6. The microcontroller of the WPT transmitter receives the message and activates the power inverter, which transfers power to the WPT receiver for 5 seconds and loads the super capacitors again.

To bridge the NFC target six super capacitors with 3 F in series were used. Detailed information about dimensioning the capacitors can be found in [7].
All of these steps are repeated again and again, so that the WPT/NFC system seems to work simultaneously from an outside point of view. The workflow for the software to realize the time multiplex procedure is shown in fig. 6.

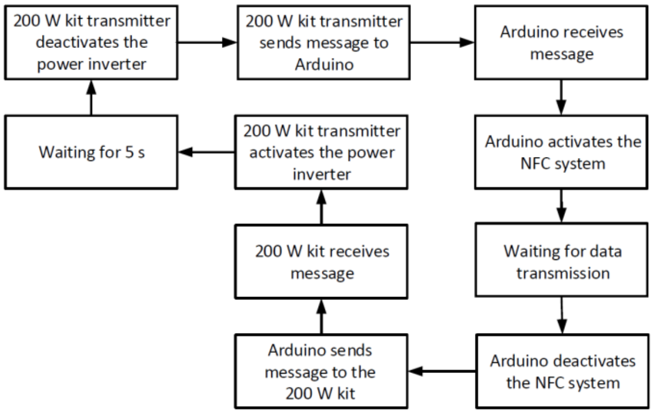


Fig. 6. Workflow of the software to realize a time multiplex procedure.

### E. *WPT/NFC Combination Design for Powers up to 200 W*

Before designing a new high power combination coil an operation point has to be defined. For the chosen operation point the highest WPT Tx coil current has to be determined, which does not disturb the NFC. This can be done with an already existing combination coil. In this paper the WPT coil current was determined with the 760308101150 combination coil from WE with 10 mm distance. The measured coupling factor is 0.42 between the WPT coils.
With the Royer converter a transferred power of 163 W, with a WPT Tx coil current of 7.1 A was possible without interference in the NFC frequency band. The maximum transferable power is limited by the size of the WPT system and the coil size in this case. With the 200 W development kit 54.5 W transferred power could be achieved, with a WPT Tx coil current of 6.7 A. The influence on the NFC frequency band is much higher in comparison to the Royer converter. Higher power levels disturbed NFC significantly.
For the high power combination coil a thicker litz wire for the WPT coil is chosen to prevent high temperatures during operation. As a result, the WPT coil is wound around the NFC antenna. The WPT coil should have a similar inductance as the WPT coil of the 760308101150 combination coil, around 6 µH. Two assumptions are needed to estimate the new WPT Tx coil current. First, the coupling factor between the new WPT coils is higher than the one of the 760308101150 combination coils due to the larger area. Second, the higher coupling factor results in lower WPT Tx coil currents for the same transferred power. A WPT Tx current of 10 A was chosen, so power levels over 100 W are possible. An approximation can be done to estimate the needed coupling factors between the WPT coils and the NFC antennas as shown in eq. (3).

$$k = \frac{6.7\,A}{10\,A} \cdot 0.42 = 0.28 \tag{3}$$

To find the geometry for the combination coil where the coupling factors between the WPT coils and the NFC antennas do not exceed 0.28, ANSYS Maxwell is used. The distance between the WPT coil and the NFC antenna and the number of turns of the WPT coil are varied. As a result, we get a matrix with inductance values and coupling factors for every geometry. In this paper a distance of 16 mm between the WPT coil and NFC antenna and four turns using a litz wire with 2.6 mm diameter and an inner diameter of about 90 mm for the WPT coil are chosen. A quadratic ferrite carrier has been used with a thickness of 1 mm and a side length of 15 cm. The inductance of the coil has a value of about 6 µH. With the prototype of the high power combination coil, shown in fig. 7, 190 W can be transferred with the 200 W development kit with an efficiency of 80 % and 10 mm distance. The WPT Tx coil current is 11.6 A and no communication errors in the NFC could be noticed. One important aspect to note when building a new combination coil, is the changing self-resonance frequency of the NFC antenna. The higher the coupling factor between the WPT coil and the NFC antenna coil the smaller is the self-resonance frequency. In the worst case this can lead to a failure of the NFC. The self-resonance frequency should be far above 13.56 MHz. As a rough guideline, the maximum operation frequency should not exceed 50 % of the self-resonance frequency. So, for an NFC application the self-resonance frequency of the antenna should be in the range of 30 MHz.

Fig. 7. Prototype of the high power combination coil.

### F. *Summary of the Design Steps to Realize the Simultaneous WPT/NFC Operation*

To achieve a simultaneous WPT/NFC operation for higher powers, the following steps are required:

1. Definition of an operation point or operation range.
2. Measurement of the coupling factor between the WPT coils.
3. Measurement of the highest possible WPT coil current without influence on the NFC frequency band.
4. Approximation for the required coupling factor between the WPT coils and the NFC antennas.
5. Simulation of different combination coils geometry to achieve the desired inductance and coupling factors.
6. Check if the self-resonance frequency of the NFC antenna is in the range of 30 MHz.

## III. Discussion and Outlook

In this paper two different methods for a combined system with WPT and NFC were presented. The currently used time multiplex procedure can be used for every WPT system. However, for applications that demand secure data communication without power transfer interruption this method needs large capacitors or batteries to bridge the interrupted power supply. Another option is the simultaneous operation of WPT and NFC. The best results can be achieved with WPT systems which have a sinusoidal WPT coil current waveform. With the used Royer converter 163 W could be transferred with the combination coil 760308101150 from WE without measurable influence on the NFC frequency band. The 200 W development kit achieved 54 W with the same combination coil due to the higher interference in the NFC frequency band in comparison to the Royer converter. This could be increased with a new high power combination coil.

The high-power combination coil can be built up with a few steps and can be scaled for different power levels. With this combination coil the 200 W development kit could transfer 190 W without measurable influence on the NFC frequency band. In future WE will continue its work on systems with simultaneous WPT and NFC to determinate detailed design rules for combination coils.

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