Wireless Power “*and Data*” Transfer (WPDT) in a single magnetic structure

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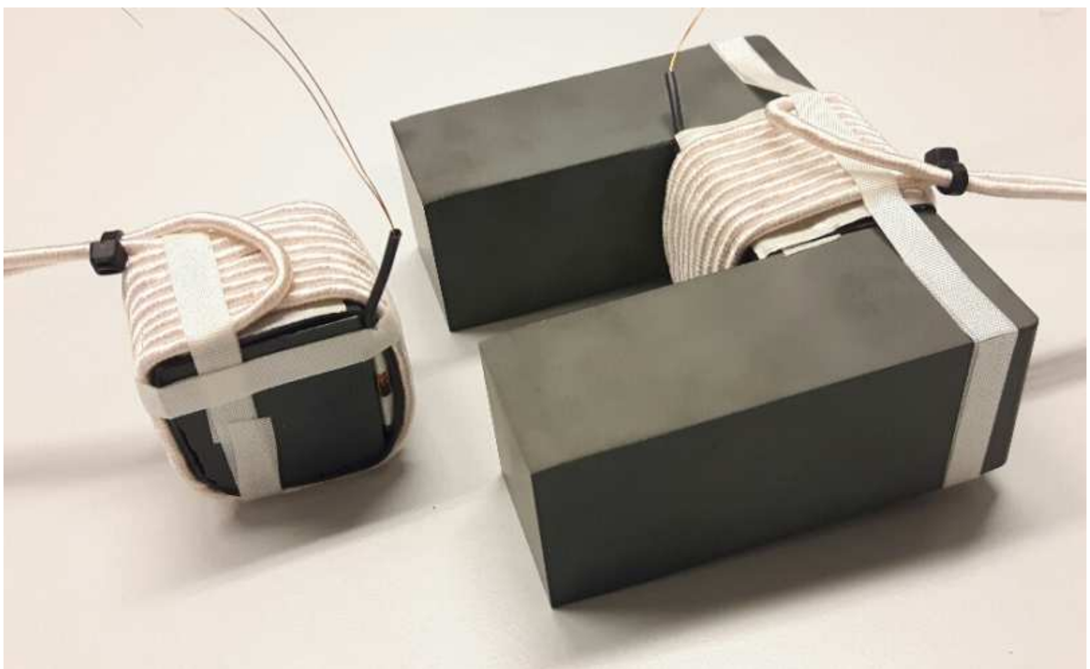

Contents

1. Problem description and the new idea

Due to several benefits, Wireless Power Transfer (WPT) has become more and more popular for charging of devices or transferring power in general [1]. Traditionally a cable does transfer the power from a source to the load. If this cable can be eliminated, and the energy can be transported in a different way (e.g. magnetically), it would have many advantages. Firstly, there will be no physical connection between transmitter and receiver, which results in more freedom of movement. Even charging or powering of vehicles while driving can become possible. Secondly, there is no longer a galvanic connection between transmitter and receiver, which eliminates the possibility of oxidation of contacts in charging plugs caused by moisture. Thirdly, charging cables can be lost, or damaged due to improper use.

Besides power transfer, most transmitters and receivers also interchange data. In a charging system, for example, the state-of-charge of the battery is send to the transmitter or how the payment should be arranged between user and supplier is communicated. Nowadays, this communication is typically done by techniques, such as Bluetooth, WiFi or with Power Line Communication (PLC). To establish rigid data transfer in a harsh EM-environment, with multiple users, and several suppliers of WPT technologies is challenging.

In this document a magnetic structure and the proof-of-principle set-up will be introduced, which is able to transfer power and data simultaneously. Both based on the principle of magnetic coupling.

2. Introduction

Fig. 1 shows the proposed set-up. At the bottom a typical set-up to transfer power via a magnetic structure is shown. It makes use of L1 and L2 and is based on the series resonant principle [2,4]. The DC input is transferred to AC by an H-bridge (S1...S4) and transferred to the secondary side where it is rectified (D1...D4). The used resonant power transfer frequency is 85kHz.

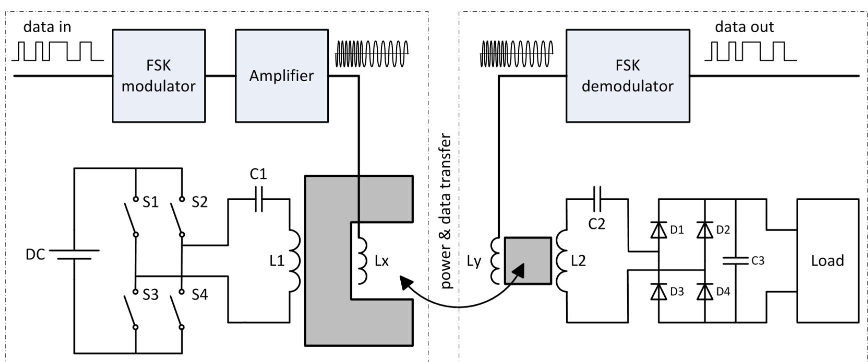

Fig. 1: Used set-up for wireless power transfer power and serial data transfer

With two extra communications windings (Lx,Ly), which are both also integrated in the same magnetic structure, a communication path between primary and secondary is created. The primary serial input data (top part of Fig. 1) is transferred to two different sinusoidal frequencies 1MHz and 2MHz, which represents the digital “0” and “1” state respectively (i.e. so-called FSK modulation [3]). At the secondary side, an FSK demodulator reconstructs the serial data. This document describes the:

1. design and construction of the magnetic structure;
2. design and construction of the demodulator;
3. achieved results from a proof-of-principle;
4. next research steps that are needed to come to a so-called “Pilot Scale validation in a relevant environment”, which roughly equals TRL-5 level.

3. Proof-of-principle

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The construction of the magnetic structure, which is used in the proof-of-principle, is described in this chapter and is based on the described idea in the patent. Other equipment, such as the (de)modulator to prove the data transfer, and the used power electronics are also shortly described.

3.1 Magnetic part

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Fig. 5 and Fig. 6 show the complete magnetic part, which consists of two communication inductors (Lx, Ly, shown in Fig. 3), two power transfer inductors (L1, L2) and two cores. Fig. 4 shows the magnetic structure with the communication inductors only.

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Fig. 3: Communication inductors Lx, Ly

Fig. 4: Position of the comunication inductors on the core

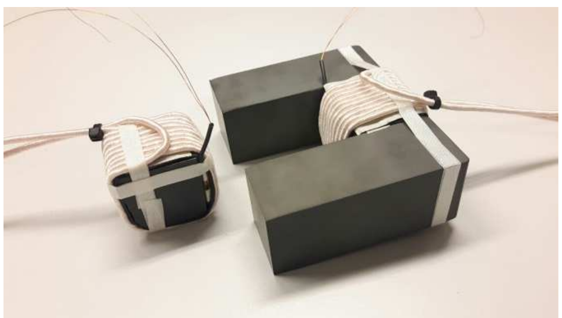

Fig. 5: Complete set-up with communication (Lx,Ly) and power inductors (L1, L2)

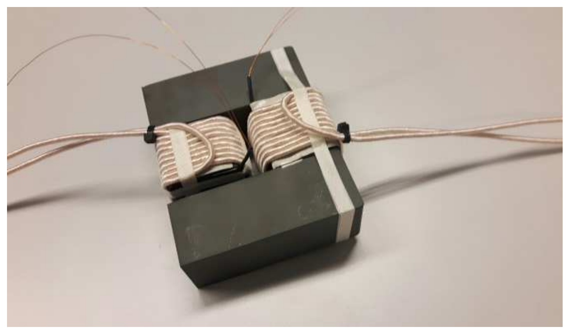

Fig. 6: Complete coupled set-up with communication and power inductors

Fig. 3, 4, 5 and 6 shows the construction of the inductors around the both cores. The secondary side (i.e. the block core) can be placed in numerous positions within the primary U-core, where the ideal coupling is shown in Fig. 6. Both Power transfer windings (i.e. L1, L2) and communication windings (i.e. Lx, Ly) simultaneously generate fluxes. However, the axis of the communication flux generated by the inductor Lx is perpendicular to the axis of the power inductor. So, the coupling factor between L1 and L2 and Lx and Ly is sufficient to transfer power and data respectively.

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3.2 Data (de)modulator

To prove the principle the experimental set-up, shown in Fig. 7, has been build. The serial data is modulated with two function generators. The first one, a BK-4052, is programmed to generate an arbitrary 16 bits serial data stream (in this case "A70C"$_{hex}$) at different bit rates. In this case, a bit lasts 50µs, so the transmission speed becomes 20 kbit/s. The data signal is frequency modulated by a TTI-TG5011 into 1MHz for a "0" (T_0=1µs) and 2MHz for a "1" (T_1=0.5µs). This results in 50 and 100 times higher FSK-modulation frequency in comparison to the bit rate respectively [6].

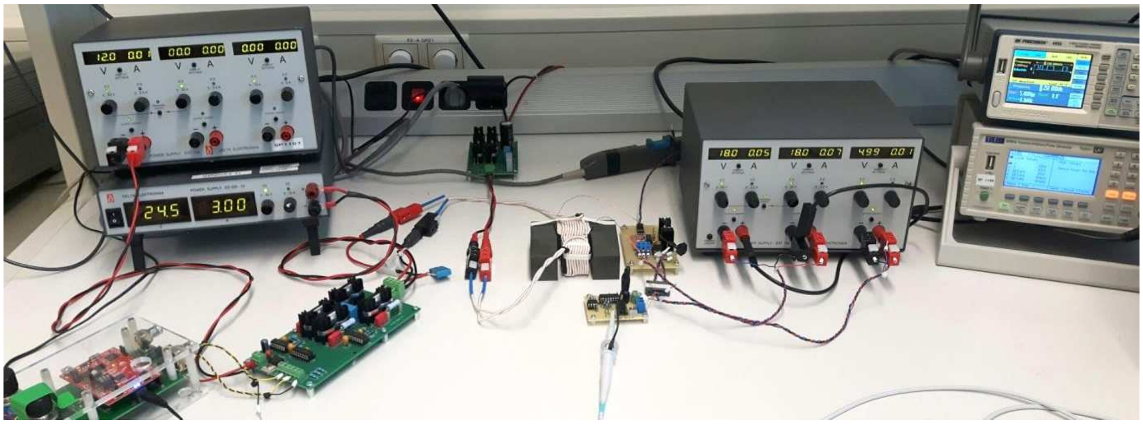

Fig. 7: Proof-of-principle set-up with (Left): power supplies for auxiliary and transferred power; power electronics controller and H-bridge; (Middle): Magnetic structure with FSK-demodulator and amplifier; (Right): FSK-modulator build-up with two function generators

The FSK-modulated signal is amplified and fed to the transmission winding *Lx*. At the secondary side the FSK signal is transferred to BFSK and fed into a PLL-VCO combination [5, 6], which reconstructs the digital data stream. The HF-amplifier and demodulator is shown in more detail in Fig. 8.

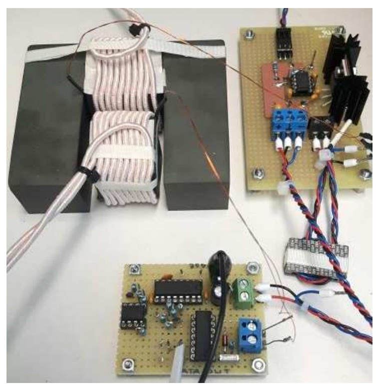

Fig. 8: Magnetic structure with HF-amplifier and demodulator

The sketched schematic of the demodulator is depicted in appendix A. It should be noted that with this particular set-up a half-duplex serial communication channel has been created from the primary to secondary side.

3.3 Power electronics

Fig. 1 shows the power electronics, which consists if an H-bridge at the primary side, L1. At the secondary side, L2, it is equipped with a straightforward HF-rectifier, which is resistively loaded. Both schematics are depicted in Appendix B. The primary power winding as well as the secondary, are SS (series-series) compensated, as described in [2, 4]. The DC-bus of the H-bridge is fed at 30Vdc and the draws 3.5Adc, which results in an output power of approximately 100W.

4. First measurements

The results obtained from the described test set-up are shown in this chapter. By coupling the magnetic parts, as shown in Fig. 6, the power- and data transfer is directly established. In the first paragraph of this chapter, the data transfer is analysed, and the second paragraph investigates the transfer of power and data simultaneously.

4.1 Data transfer

Fig. 9 shows the data communication with the magnetic parts coupled as depicted in Fig. 6. The four top signals shows the serial input/output data, and the send/received FSK signals at 200µs/div. A single bit lasts 50µs as expected, which results in a data transmission speed of 20 kbits/s.

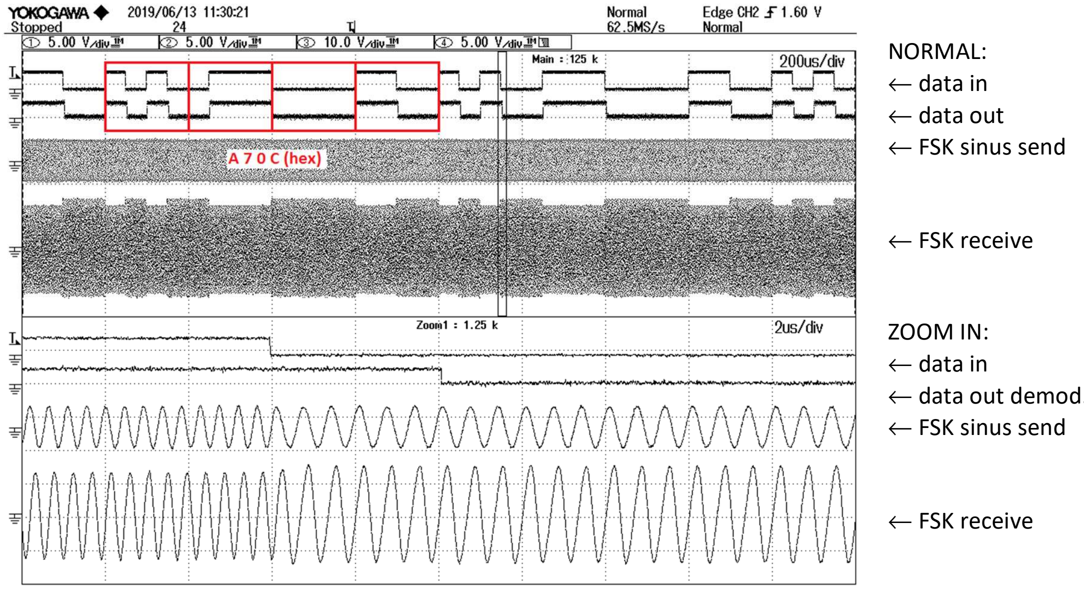

Fig. 9: Send and receive data across magnetic WPDT set-up at no-load. (Top figure signals: data in, data out, FSK modulated sinewave send, received modulated FSK signal, (200µs/div.) Bottom figure: zoom-in of data transition equal to top figure, (2µs/div.)

At the bottom of Fig. 9, the same signals during a single data transition are depicted (at 2µs/div.). During the falling transition (i.e. from “1” to “0”) the frequency decreases from 2MHz to 1MHz, and the demodulated signal follows 4µs later.

Fig. 10 shows the same type of measurement, however now with the Phase Comparator Pulse (PCP) output [5, 6]. This signal is filtered at 500kHz and is a measure for a properly locked PLL. After roughly 10-15µs the PPL is locked, which is represented by a high level of PCP (i.e. “1”).

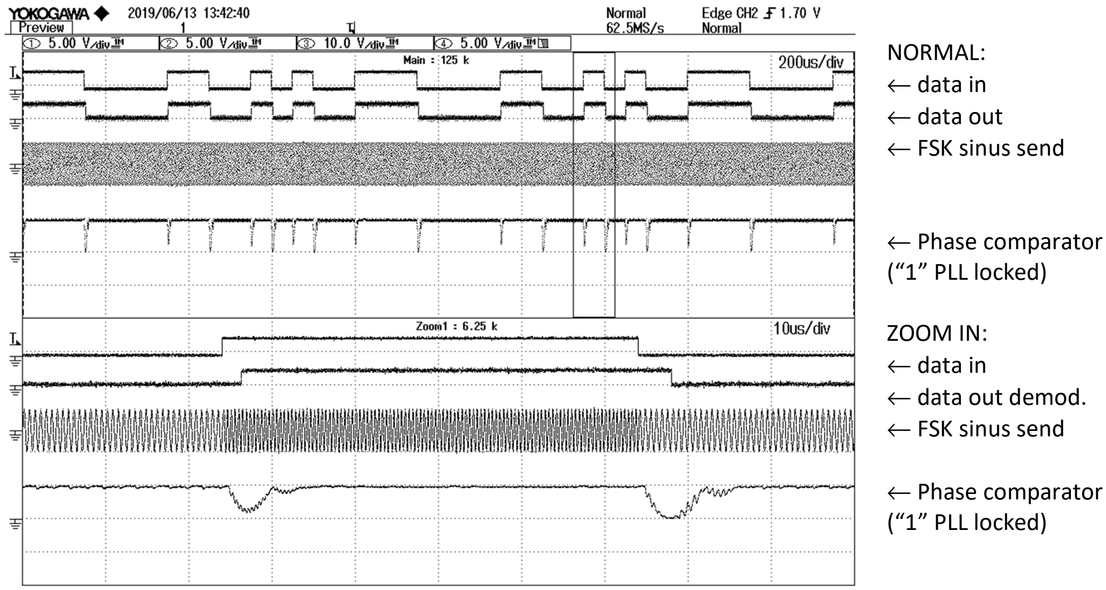

Fig. 10: Send and receive data across magnetic WPDT set-up at no-load. (Top figure signals: data in, data out, FSK modulated sinewave send, PLL phase comparator output, (200µs/div.) Bottom figure: zoom-in complete data transition equal to top figure, (10µs/div.)

4.2 Simultaneous data and power transfer

Fig. 11 is in principle equal to Fig. 9. However, now the data and the power are transferred at the same time. Also in this situation, the magnetic parts are coupled as depicted in Fig. 6 (i.e. closely and at an angle of 0°, see next paragraph). Again, a serial data stream of "A70C"$_{hex}$ is transferred, but now also with a transferred power of approximately 100W (i_{L1} = 3.9A_{RMS}).

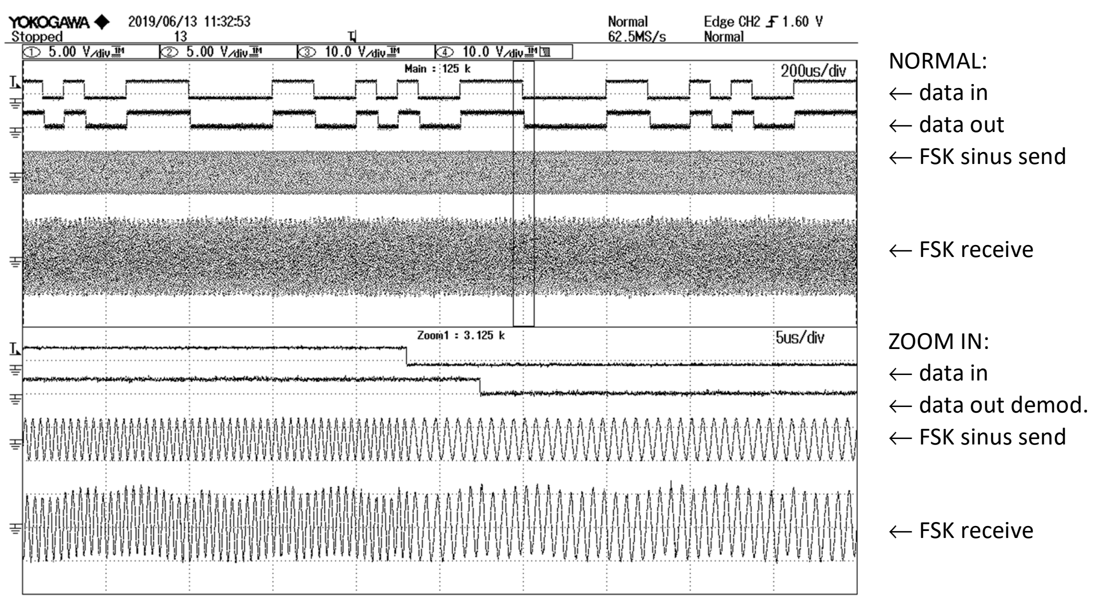

Fig. 11: Send and receive data across magnetic WPDT set-up at a power transfer of 100W. (Top figure signals: data in, data out, FSK modulated sinewave send, received modulated FSK signal, (200µs/div.) Bottom figure: zoom-in of data transition equal to top figure, (5µs/div.)

Due to the second flux (i.e. "3a" in Fig. 2b caused by the transferred power) and a coupling factor "$k_{1,y}$", which is not exactly zero, the transfer frequency of 85kHz can be clearly seen in FSK-receive signal. However, the disturbance is minimal, and is it still possible to transfer the data without errors at 20kbit/s.

4.3 Communication errors

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4.4 Freedom of movement of the I-core

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5. Next research steps

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6. Conclusions

This report shows:

- That simultaneous Wireless Power & Data Transfer (WPDT) in a single magnetic structure, which consists of a separate transmitter and receiver is possible
- A proof-of-principle that transfers simultaneously:
    - 100W at 85kHz and
    - 20kbit/s. in half-duplex FSK-mode
- That by coupling transmitter and receiver, power as well as data transfer is directly established
- That the freedom of movement of the mechanical coupling, obtained in this “proof-of-principle”, is roughly XX mm
- Next research steps to increase the rigidity of this device

References

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Appendix A: FSK- demodulator

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Appendix B: Power electronics

Schematic and PCB of the used Power Electronics (H-bridge and HF-rectifier)

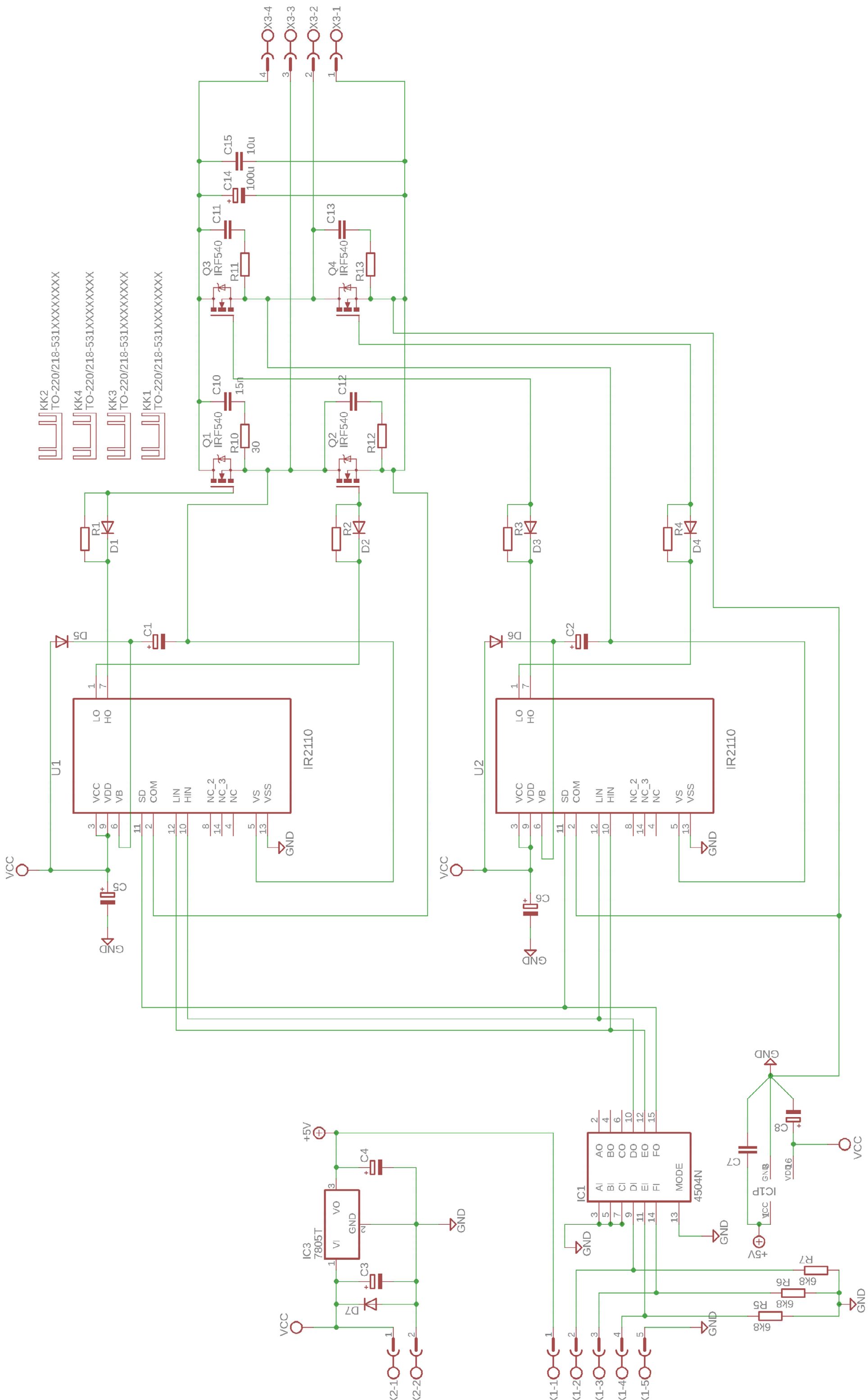

Fig. B1: H-bridge schematic

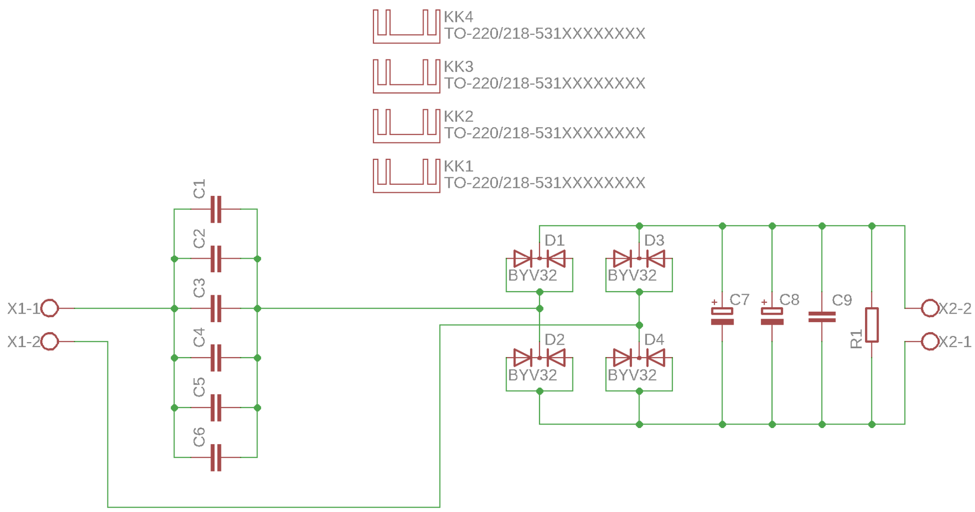

Fig. B2: HF-Rectifier with resistive load (not shown)

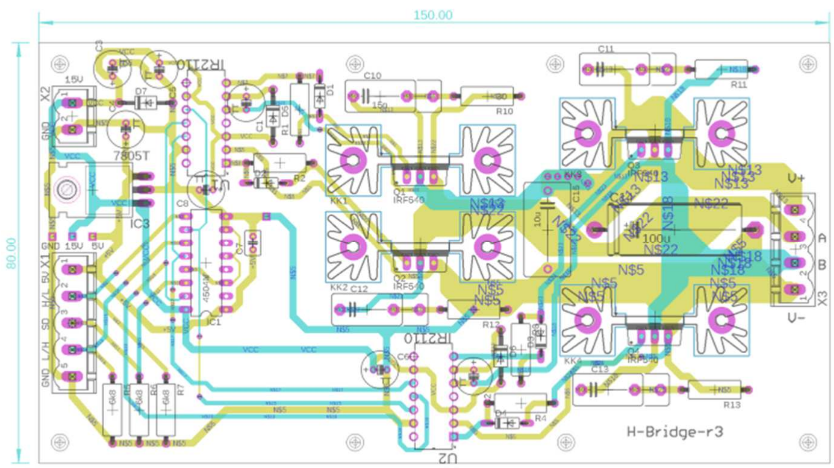

Fig. B3: H-bridge PCB

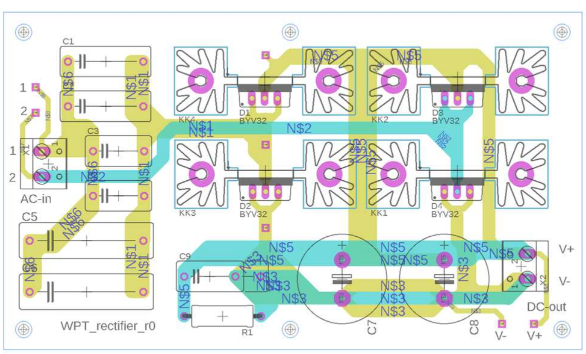

Fig. B4: HF-rectifier PCB