Wireless

Energy transmission

and efficiency:

A contradiction?

By Andreas Hagemeyer

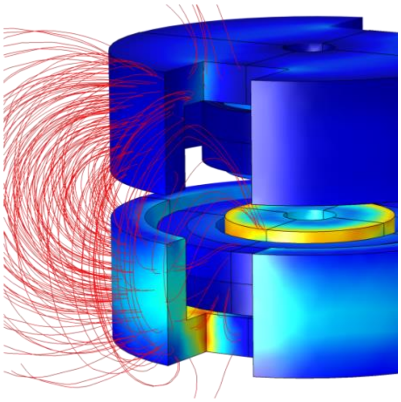

Image: Inductive energy transfer

Regardless of whether you use mobile devices such as smartphones and tablets or if you have applications that require dust, water or gas-tight charging: contactless energy transmission is clearly on the rise. But how can such a wireless charging process be realized efficiently?

M.Sc. Andreas Hagemeyer of FRIWO has dealt with this question and presents a suitable system. The key to success is: communication.

Wireless technology and its benefits

Lately the market increasingly offers wireless charging solutions. Instead of a conventionally wired power supply a charging station is used where the device is just placed upon. The required charging energy for the battery is transmitted via electromagnetic coupling, avoiding the connection of device and power source by conventional plugs. Sine this is quite convenient for the use, this technique is currently becoming very popular with users of mobile consumer devices like smartphones or tablets.

This technology still harbors another huge advantage: By means of electromagnetic coupling, the energy can be transmitted through electrically insulating materials over short distances. It allows the development of chargers and end devices with encapsulated housings to shut out dust, gas or water. Consequently, the use of wireless charging technology is highly interesting for applications in harsh environments, for example power tools, electric bikes or robots for vacuuming, wiping or lawn mowing. The aging of electrical contacts is accelerated by corrosion and pollution; hence lifespans can be significantly extended with the wireless technology. Even the industry can optimally benefit from wireless energy transmission since this technology, for example, is the answer to the problem of safe charging in hazardous areas.

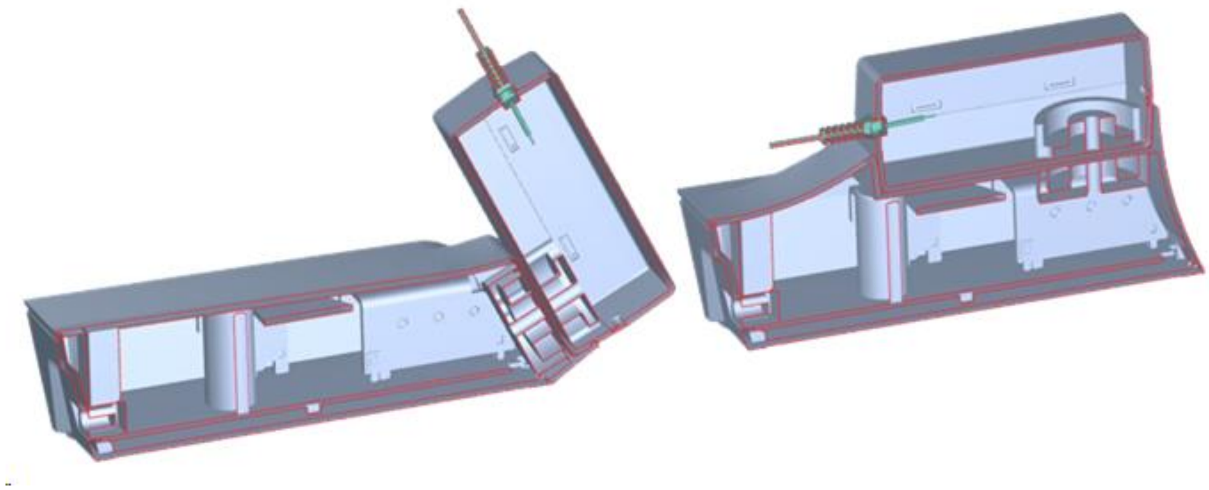

Image: Cross-section of charger and receiver of a possible application

The challenge: Energy balance

The benefits of this transfer technology are revoked by a poor energy balance. Energy is inevitably lost on the transmission route between charging station and device. Since the energy consumption of smartphones and tablets is relatively low, the higher consumption of wireless charging hardly affects the electricity bill. Increasing energy demand of the application, however, also boosts the energy loss on the transmission route. In order to profit from the wireless energy transmission without significant efficiency losses, an appropriate technical solution is required. FRIWO uses an innovative concept of energy and data transmission between charger and device which will be explained in detail later in this article. In addition, the various opportunities of such a system are described. First of all, a basic description of the wireless energy transfer is provided since it results in the need for parallel data transmission.

Technical basics of wireless energy transmission

The most common way of wireless energy transmission over short distances is inductive coupling. In this case, a coil is implemented both on the transmitter and receiver side. The coil on the transmitter side is connected to an AC voltage source, generating an alternating magnetic field around the coil. If the receiver coil is located in the vicinity of the transmitter coil, the change in the magnetic field induces a current in the receiver coil. This supplies an electrical consumer on the receiver side with energy. The transmission parameters of such a system are depending on the coil design as well as on the positioning of transmitter and receiver coil. Since the position of the coils may not only differ from charging process to charging process but can also diverge during a charging process at any time, monitoring of the output parameters and a corresponding compensation of the deviations are essential. For the transmission of small outputs this can be done with a linear regulator which converts the excess power into heat at the expense of the energy efficiency. Higher outputs require a switching regulator since it significantly reduces losses. Both versions, however, need to be installed on the receiver side, i.e. in the mobile application. The increased space required for the charging electronics inevitably leads to an either increased overall size of the application or to a downsize somewhere else - sometimes even resulting in a capacity reduction of the battery. In times of highly compact mobile devices with maximum battery life, both alternatives are barely tolerated by the user.

FRIWO's concept circumvents these problems by having the deviation compensation of the output level occurring within the charging station. The compensation takes place in that part of the charging station which converts the applied voltage into a square wave voltage suitable for the inductively coupled transmission system. To illustrate the advantages of this approach, a first overview of the power transmission components is given.

The heart of the energy transmission is the coil system which transports the energy from the charging station to the receiver. Simplified, such a coil system can be considered a transformer. Half of the transformer, consisting of a primary winding and a transformer core half of ferromagnetic material, is located in the charging station. The second half, i.e. the secondary winding and another transformer core half, is located in the receiver. With this structure, energy can be transmitted over short distances through the air or through non-conductive materials, thus allowing the power to be transmitted through sealed housings.

The challenge: Magnetic propagation and leakage inductance

Since the energy is transmitted by a magnetic field, its propagation beyond the transmission system is inevitable. Compliance with defined limits of the relevant standards will avoid any hazard for users or impact on other technical appliances. For small transmission systems it is easy to comply with these limits but with increasing power the problems are growing too. The effects of the magnetic field, for example, lead to heating of electrically conductive materials in the vicinity of the transmission system. As far as temperature-sensitive batteries are concerned, this might cause problems. FRIWO's concept explicitly avoids flat coils and transformer cores. Instead, components for switch mode power supplies are used. These cores have a larger cross section for the same volume. Consequently, they are not suitable for flat designs. The larger cross section, however, positively impacts the magnetic core resistance and therefore reduces the electromagnetic emission beyond the transmission system.

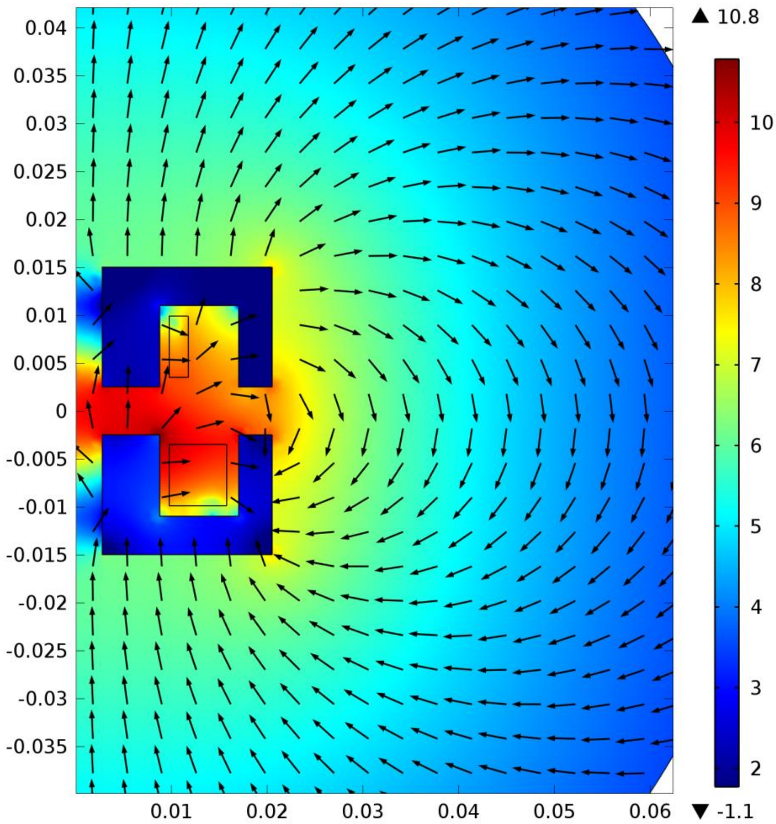

Image: Ferromagnetic cores protect the environment from electromagnetic emission

The distance between the transformer cores results in an increased leakage inductance of the transmission system. Field-theoretically speaking, this means that a part of the magnetic flux, generated in the primary winding, does not pass the secondary winding and has therefore no impact on the transmission. The leakage inductance is influenced by the design of the coils. Decisive factors are the radius of the windings, their positioning as well as shape and size of the transformer core. This opens up good optimization opportunities, although the leakage inductance of such a transmission system cannot be fully compensated.

Circuit design for contactless energy transmission with resonant converter

Even with this inherently lossy system a high efficiency of the entire system can be achieved by picking a matching circuit design. FRIWO use a resonant converter, a circuit design which is also used in conventional power supplies and chargers. In addition to the transmission system (the transformer), the main components form a circuit to generate a square wave voltage and a capacity. The capacity is a capacitor forming an LC resonant circuit together with the transformer. If the frequency of the square wave voltage is chosen near the resonant frequency of the LC resonator, the voltage applied to the transformer and the passing voltage will be increased.

If the frequency of the rectangular voltage is chosen near the resonant frequency of the LC resonator, the voltage applied to the transformer or the voltage passing through the transformer will be increased. This is caused by oscillating energy between resonant capacity and transformer. To use this effect, the transformer must have a leakage inductance by design. In conventional power supplies with resonant converters this inductance is deliberately generated by corresponding core designs and winding techniques. This allows, for example, a transmission system with an output of 150 W and an efficiency of up to 90 %. The efficiency measured refers to the entire system, i.e. from outlet to recipient.

The switching concept described is also suitable for adjusting the voltage-current characteristics which are particularly important for chargers. These characteristics ensure that the battery is charged up to the final charge voltage with a constant current. As soon as the final charge voltage is reached, the power supply switches to constant voltage mode, reducing the charging current accordingly. This works as follows: The resonant converter operates in constant voltage mode with a fixed frequency. Once the maximum output current is reached, a controller increases the switching frequency causing it to move away from the resonant frequency. This results in an output drop putting the power supply in a constant current mode.

During the manufacture of conventional power supplies with resonant converters, the output voltage is trimmed to a fixed value. The output current is measured within the power supply and passed to the controller. Contactless energy transfer, in principle, contains the same components; only these are divided into two separate and insulated housings. Due to the monovariants of a contactless energy transfer, the schematic structure of the system may change as already mentioned, for example by different placements of the energy receiver on the charging station. Changes of charging stations or receiver sections are likewise conceivable. Due to the continuous changes in the charging system, output voltage and/or output current deviate inevitably from the desired values. Information about the deviation can always be obtained from the energy receiver, but to effectively intervene with the controller the information should be available with the charging station.

Near field data transfer allows communication between energy transmitter and receiver

To compensate deviations of output voltage and output current, FRIWO use a near field data transfer which notifies the energy transmitter about the respective deviation in the receiver. In addition, the data transfer offers more possible applications and benefits. Transmitter and receiver can exchange a variety of information and interact accordingly. After successful charging, the energy receiver, for example, can put the charging station in a power saving mode. Even the data transfer can ensure a safe operation: In case of failures like excess temperature or defective cells, the battery management can either reduce the charging process or abort it. In addition, authentication options are given to ensure a perfect match of charging station and energy.

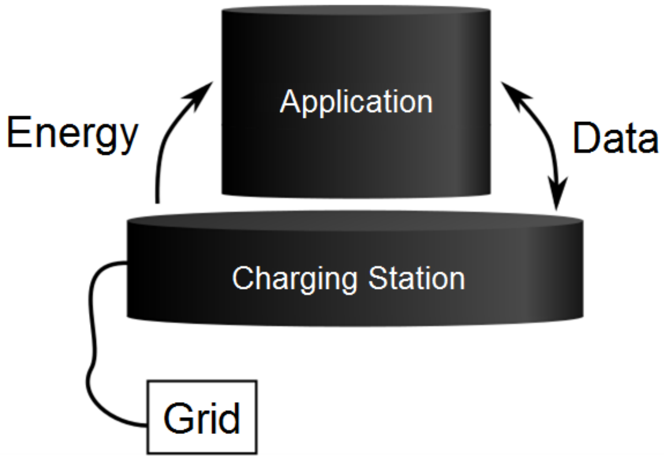

Image: Parallel data transfer in a contactless energy transmission system

To enable controlling and monitoring of output parameters, data transmission with lowest possible latencies and a secure connection between charging station and energy receiver is required. To tackle this challenge, FRIWO rely on a proximity transmission system which allows a connection over just a few centimeters. This system ensures that a connection can be established only between charging station and the addressed energy receiver. False interconnections to adjacent transmission systems or open channels are excluded. Since no sender or receiver addresses have to be transmitted, the data exchange protocol can be reduced. Consequently the required computing power is low, allowing the use of more cost-effect microcontrollers.

Antenna structure and antenna geometry as key to efficiency

In order to keep the required data transmission power low, a shortest possible distance between both antennas would be beneficial. The antenna structure employed by FRIWO allows the transfer via thin film to the center of the energy transmission system. The antenna structures printed on film are placed between energy transmission coil and housing wall. Compared to the housing walls, these films are quite thin and have therefore a somewhat negligible impact on the distance between the energy transmission coils.

This way, the antenna placement necessary for data transmission requires only little space in the overall system.

Since both the energy and the data transmission use inductive coupling, spatial overlaps would generate inductive crosstalk if no protective measures are taken. To prevent this, FRIWO use a specific antenna geometry for data transmission. With the aim of sufficient decoupling of both transmission systems, a corresponding method for coil designing has been found. This method avoids the use of filters which has the advantage of implementing a data transmission subsequently into a non-contact system without affecting the energy transmission. The elimination of filters also has a positive effect on the transmission efficiency.

The system antennas are provided with a wiring which modulates the data to be transmitted. This circuit can be connected directly to a microcontroller and differs from direct wiring only in latency (less than 5 µs) and in potential separation. With such a configuration data can be transmitted bi-directionally at a rate of 1Mbit/s - regardless of whether the power transmission is active or not. The data transmission rate is more than sufficient for an effective parameter control during charging, and also provides reserves for the exchange of further data.

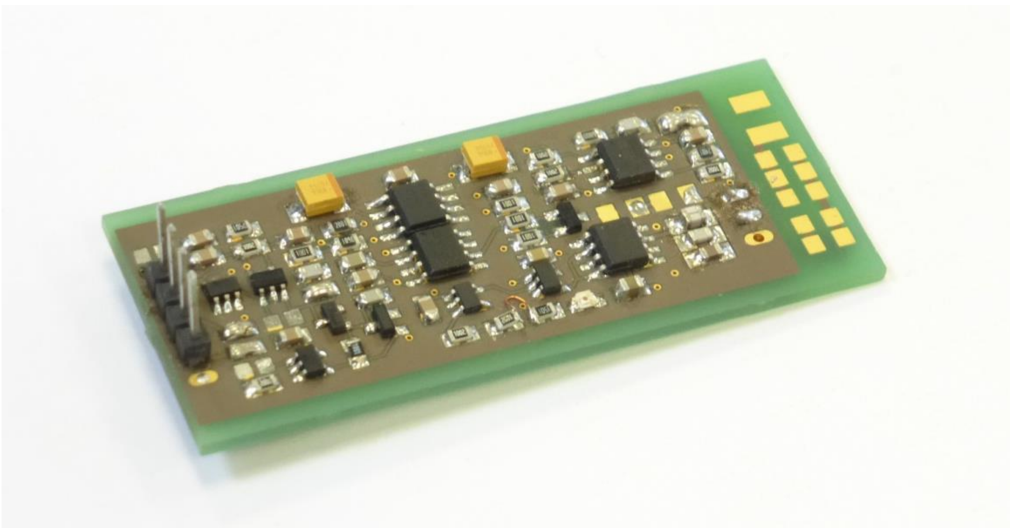

Image: Communication module for data transmission

Conclusion

Contactless energy transmission and efficiency are no contradiction. With the use of a parallel data transmission, an efficient non-contact energy transmission is just a question of the right system. A system like the one described provides many advantages beyond efficiency increase, only some of which have been mentioned. The data transmission used does not only allow an efficient contactless charging for high-capacity devices but also expands the range of applications by its communication possibilities.

The author

M.Sc. Andreas Hagemeyer has been working for FRIWO since 2008. He has studied electrical engineering at the Technical College of Oldenburg/Germany (B.Eng.) and at the Duisburg-Essen University (M.Sc.). In the course of his work for FRIWO he became involved with the design and optimization of contactless energy systems.