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## **Taking Inductive Charging to mass production**

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### **Abstract**

Inductive charging offers a new level of convenience to owners of plug-in hybrids and electric vehicles; just park and come back to a fully charged car. Creating this innovative user experience requires many levels of advanced expertise for solving all the challenges in various aspects. Inductive Charging will change the future of charging technology. To create this future the industry has to go beyond demonstration models and feasibility studies. BRUSA has developed a unique “One Box” solution with a single Car Module and a single Ground Module for easiest vehicle integration and flexible Ground handling. With this system we also achieved mass production compatibilities. With innovative solutions we solved not only the conformity to standards, reproducibility, reliability, safety and robustness but also manufacturability at high yield rates.

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# 1 ICS1 BRUSA Elektronik AG`s first inductive charging system

The Inductive charging system of BRUSA Elektronik AG contains WLAN communication, a positioning system, foreign object detection, living object detection, functional safety and a highly efficient power transfer.

The actual system is able to be charged with 3,6kW mains power. The overall efficiency is around 87%. The possible displacement area is +/- 150mm lateral (Y-Direction), +/- 75mm in the driving direction (X-Direction) with 100...160mm ground clearance. It is even possible to charge up at to 180mm with reduced x and y displacement. The DC output voltage has a range between 170V - 440V DC.

## 1.1 System Overview

The system consists of two components:

The Car Pad Module (CPM) and the Ground Pad Module (GPM)

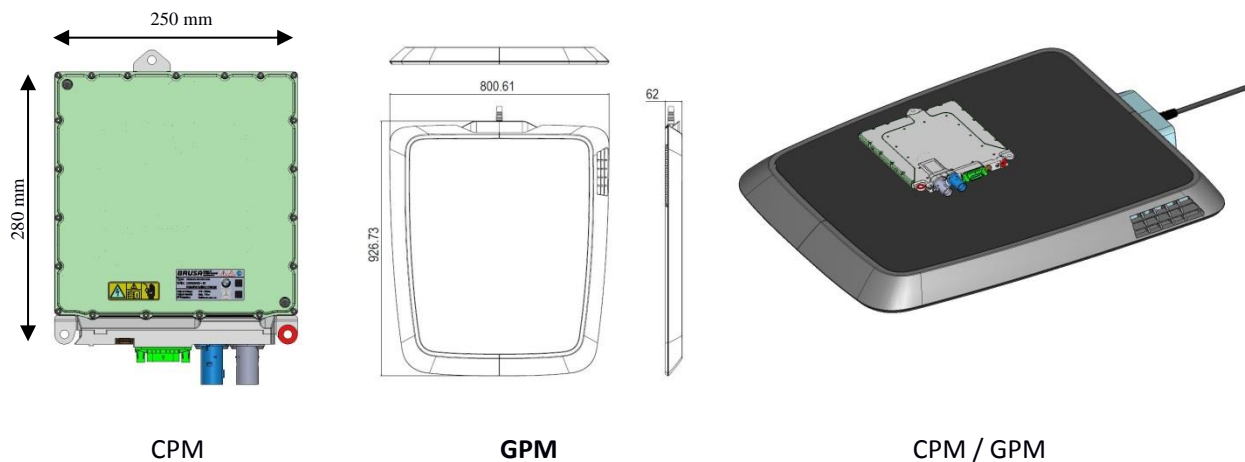


Fig. 1: Components of BRUSA's Inductive Charging System

All the power electronic and control units are integrated within these two parts. BRUSA Elektronik AG designed the system with a planar circular coil topology.

## 1.2 Way to mass production

The complexity of an inductive charging system is widely underestimated. The design of the magnetic coupling and corresponding electrical topologies is only one discipline. The positioning system, foreign object detection system and design of the product itself are as complex as the energy transfer.

After defining the physical layout of all systems (FOD, LOD, energy transfer, magnetic coupler, positioning) it took more than two years to get to the stage of a serial product. The definition of the magnetic coupler will only be the start of the development.

### 1.2.1 Power transfer

Fig. 2 shows the comparison between the power paths of a conventional on board charger and an inductive charger. The major difference is the reduced coupling factor in the galvanic separation. The inverter and rectifier are more complex on the inductive charging. There are some elements to reduce EMC and harmonics in the inverter.

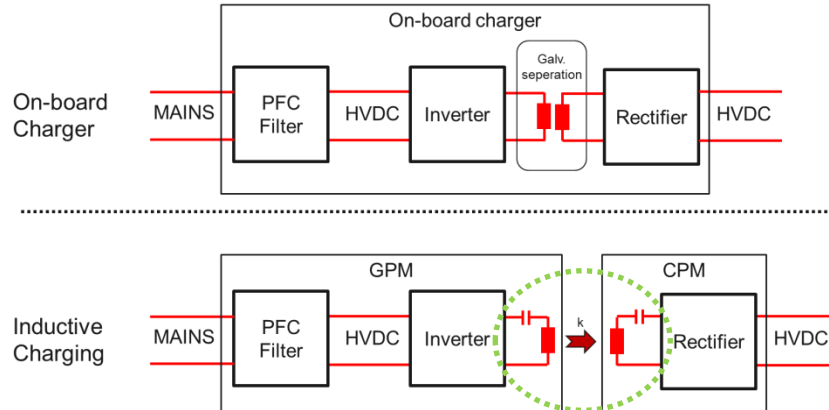


Fig. 2: comparison power path OBC vs. inductive charging

The efficiency of an inductive charging system is lower in comparison to a conventional on board charger due to the reduced coupling factor in the galvanic separation. Fig. 3 shows the reduction of efficiency over resonant coupling. As long as the coupling factor remains above 0.1 the efficiency drop caused by resonant coupling (marked green in Fig. 2) is lower than 5% in a real system. A PFC Stage has an efficiency of around 2-4%.

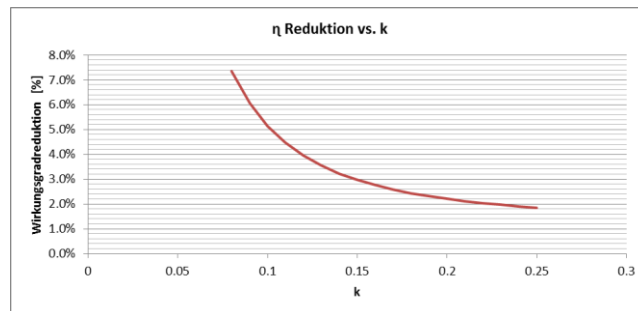


Fig. 3: Efficiency reduction over the resonance coupling vs. coupling factor

We build prototype systems with an overall efficiency of above 90%. For mass production additional elements have to be added in the power path to achieve a system with a very small CPM which will easily fit in the car and will be capable handling several different car integrations, a wide HVDC range, can deal with component tolerances and meets the EMC regulations. These additional elements lead to a decrease of the efficiency. The BRUSA Elektronik AG ICS GEN1 System has an overall Efficiency of 87% (50Hz Mains to HVDC) in serial production. Our first prototypes had an Efficiency of > 90% (50Hz Mains to HVDC).

One of the dominant parameters in inductive charging is the size of the CPM. The challenge was the small space in the underbodies of the plug-in hybrid car. This required a very small CPM size. A challenge for the automotive industry will be to find space in future plug in hybrid and electric vehicles for a larger CPM.

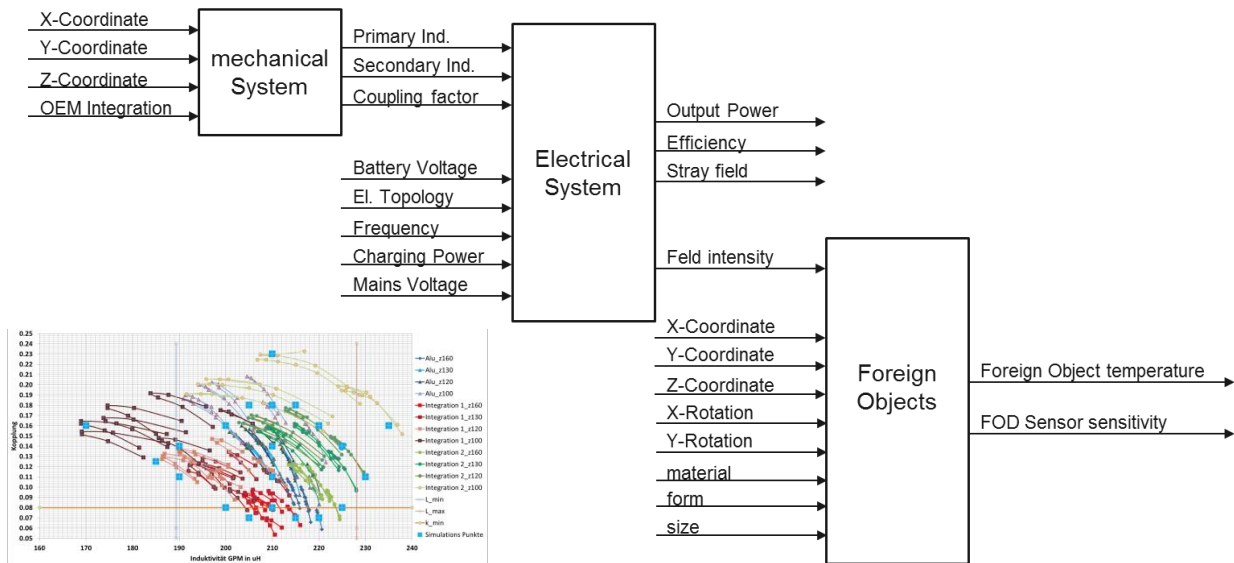


Fig. 4: Design complexity inductive charging

The dominant difference between a conventional OBC and an inductive charging system is the variance in the galvanic separation. The OBC has only to scope with the following complexity:

- input mains Voltage
- Output DC Voltage
- Variance in demand charging power

To handle this three dimensional problem, the working frequency can be chosen freely as long as a corresponding EMC filter can be built. An inductive charging system on the other hand has to cope with the following and is far more complex:

- input mains Voltage
- Output DC Voltage
- Variance in demand charging power
- Variance in coupling factor depending on park position
- Variance in primary inductance depending on park position
- Variance in secondary inductance depending on park position
- Variance in primary inductance depending on car integration (car underbody)
- Working frequency is only allowed in a very small range due to by EMC regulations

This problem has 7 dimensions instead of 3. The problem becomes even more complex when the component tolerance of all elements within the power path are added. In the BRUSA GEN 1 system there are 12 elements (capacitance or inductance) which act in the power path. Caused by the rectifier on the CPM the acting value of some of these elements is changing depending on charging power and battery voltage.

BRUSA has invented the so called “double capacitor” system. On the CPM side, this is a small but very important invention in the area of inductive charging, because it reduces the variance in load impedance.

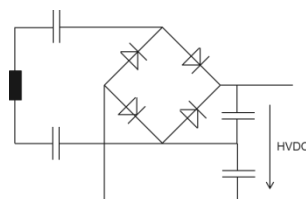


Fig. 5: double capacitor system invented by BRUSA

### 1.2.2 Energy transfer

The BRUSA System is capable of transferring power over a coupling range between 0.08 to 0.25 coupling factor. The coupling factors of GEN1 are shown in Fig. 6. For the purpose of efficiency, charging above 0.1 coupling is recommended. At 180mm ground clearance the BRUSA system still has areas where the coupling factor is above 0.1.

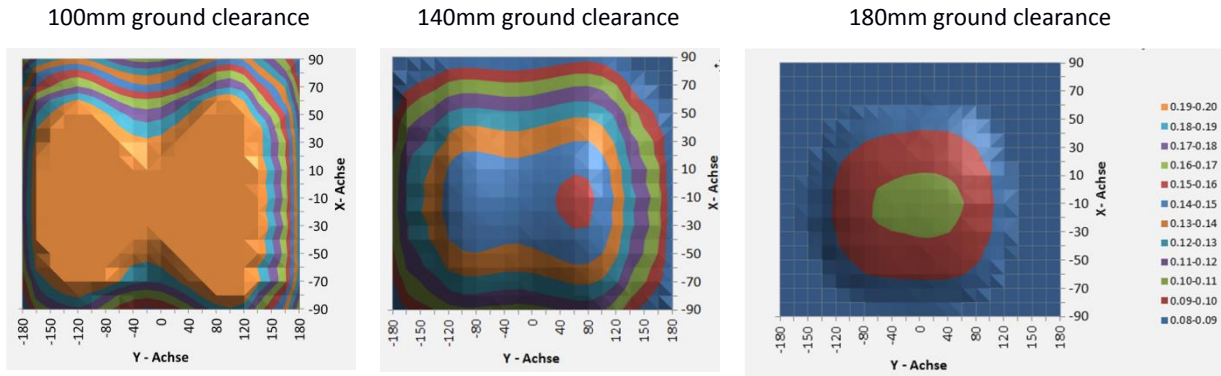


Fig. 6: coupling factors of BRUSA's Inductive Charging System

### 1.2.3 Higher Z, Higher Power

With a bigger sized CPM it is possible to charge in higher Z - regions. If the CPM is increased by 20mm in each direction the 140mm coupling factor values can be expected at 160mm Z height.

Brusa designed and built systems with 7,2kW input Power within the same CPM Size as the 3,6kW, but water cooled. We also build test systems with 11kW and 22kW.

### 1.2.4 WLAN

It is defined within the standardisation process that WLAN has to be used for communication purposes. At the moment there are no AECQ 125C WLAN Modules available on the market. We have solved this by developing our own WLAN module.

### 1.2.5 Positioning

The BRUSA positioning system is capable of supplying measurement coordinates within a nearby position and can measure the distance between CPM and GPM at far distances. With external antennas to the CPM it is possible to receive coordinates within a 2m range.

### 1.2.6 Standardisation

There is still a lot of work to do with respect to standardisation. For instance, the standardisation process should generate a document which includes all necessary information to develop a GPM independently to building and designing the corresponding CPM. This means that multiple and very important decisions have to be made to achieve a functional charging system to be able to charge the cars of our leading customers we have to fine tune several technical parameters like positioning signal intensity, receiving sensitivity and damping.

At the moment the standardisation documents do not contain these details. Not even the physical layout from the positioning system.

For interoperable systems such common standards will be needed to make this technology successful in the future. From BRUSA's perspective currently only 10% of the required definitions have been made to build such an inter-operable system.

For this reason BRUSA had to develop its own propriety solution.

### 1.2.7 IP

Inductive charging is a new technology in which hundreds of challenges have to be met. Additionally the market promises a huge potential in volume. This leads to an exorbitant number of patents. Some are not very useful. BRUSA developed its own technologies and did not use any information from other players or patents. Unfortunately, there are there some patent trolls on the market which like to gain control of the market by using very smartly placed but scientifically and technically useless patents.

### 1.2.8 Safety

To achieve a safe system it is not only sufficient to implement some ASIL functions. An analysis of the inherent safety has to be made. During a risk analysis of foreign objects it was very difficult to start an open fire. We did not manage to start a fire with a paper clip in an 85 kHz magnetic field with 6mT. Even by blowing air at the glowing paper clip or with several different kinds of papers. We did only managed to get the paper glowing but could not ignite the paper itself. Some players say that a fire can be started with a paper clip. We have not been able to achieve this. It can only be done with an additional fire accelerant.

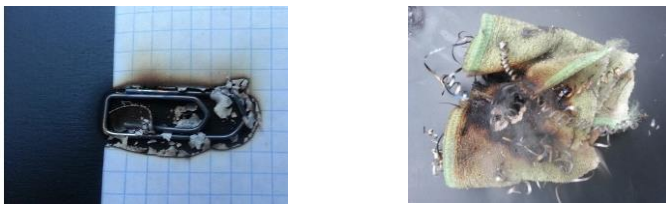


Fig. 7: examples experiment risk analysis fire

The direct influence of the magnetic field can be very dangerous for people with implants. Tests proved that up to 200W Heat dissipations are caused within an implant by placing it on top of the ground pad. For this main reason BRUSA highly recommends a living object detection system in the area with the highest magnetic field.

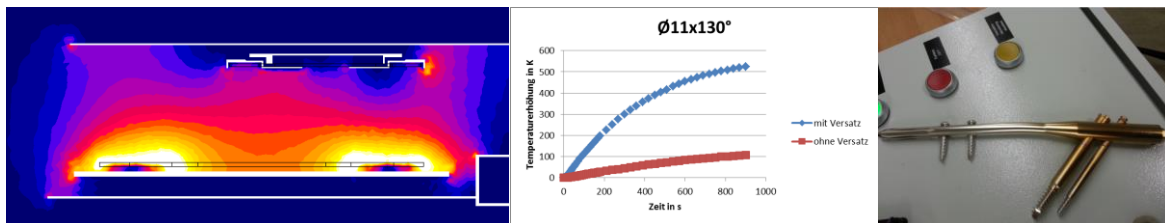


Fig. 8: experiment implants heating

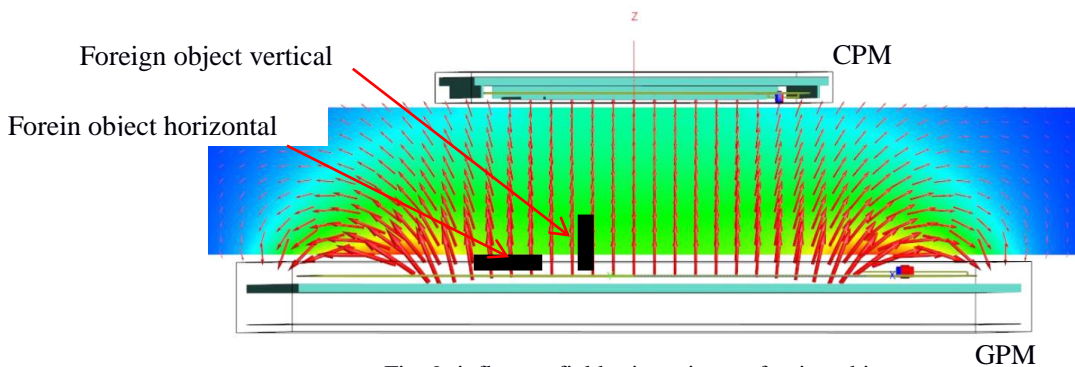


Fig. 9: influence field orientation on foreign objects

Different Materials with identical geometry will influenced differently by the field. For instance, a steel plate will reach its highest temperature if the field lines penetrate the material longitudinally. An aluminium plate if the field lines hit the material orthogonally to the largest surface.

## Authors



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Born in 1985 in Switzerland. 2007-2011 Study MSE electrical engineering at HSR Rapperswil. Since 2011 at BRUSA as Senior Hardware Developer and System Architect in the Management Business Unit Charging Systems. He has already worked for four years in the area of inductive charging and is therefore one of the pioneers in the development of inductive charging systems.