

# **PRIMOVE: First Affordable Automotive Wireless Charging System Starts Serial Production**

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## **Abstract**

This paper supplies a comprehensive technical and economic picture of the requirements of bringing wireless charging to an automotive mass product, using the inductive PRIMOVE charging system for electric cars as an example. This system overcomes all technical constraints to ensure an efficient, safe and automatic inductive charging process. Furthermore, the paper presents the advantages of an inductive charging system with a moving part in the ground coil in comparison to a solution with larger air gaps. Together with the interoperability between different power classes, these are key factors in leading to the PRIMOVE 3.6 kW charging system being a lean solution which is ready for serial production already today. Moreover, challenges when developing a wireless charging systems e.g. positioning or metal object detection will be described and the respective solutions will be presented. The need for a neutral standardization approach and an open dialogue and collaboration in the industry, e.g. an open coil design approach, as a key factor for the success of any new charging approach is pointed out. Finally, convenient and affordable e-mobility.

*Keywords: wireless charging, efficiency, infrastructure, industrialization, standardization*

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## **1. History and Background**

Since 2008, Bombardier has built up inductive power transfer experience in the fields of trams, buses, trucks and passenger cars. Due to its unique vertical integration, Bombardier Primove GmbH is able to provide its customers a one stop solution for all charging demands and all rail and road vehicles.

Initial tests for wireless charging were conducted on a tram at the Bombardier site in Bautzen, Germany, in 2009. In 2010, the first pilot project was launched in Augsburg, Germany, using a 800-metre track to perform extensive testing on a low-floor tram. As the wider potential of PRIMOVE technology became clear, a second pilot project was launched in 2011 to investigate further vehicle applications. This time, a PRIMOVE equipped bus was used to test dynamic charging on different road surfaces in Lommel, Belgium.

The gained knowledge about wireless charging was used to develop a solution for static charging at bus stops with 200 kW charging power. The first PRIMOVE 12 meter long e-bus has successfully served passengers in Braunschweig, Germany since March 2014. In December 2014, the world's first 18 meter articulated e-buses complemented passenger operations in Braunschweig. PRIMOVE equipped e-buses are also running in Berlin and Mannheim, Germany and in Bruges, Belgium as well as in Södertälje in Sweden.

Coming from rail and bus applications, putting wireless charging technologies into electric cars becomes the logical next step. Studies with 20 kW and 7.2 kW charging power with several OEMs have taken place from 2012 to 2014, using wireless charging systems without a moving part. In the beginning of 2015, PRIMOVE signed a nomination agreement with one of the world’s largest automobile manufacturers for the serial development of the PRIMOVE 3.6 kW inductive charging solution for e-cars. Together, the decision was taken to use a lifting device for the primary coil to achieve maximum efficiency, lowest electromagnetic field (EMF) and also to be able to use the same small onboard unit for cars with different ground clearances – the Z-Mover.

## 2. Challenges of Inductive Charging and PRIMOVE Implementation

### 2.1 Design Targets for the Coil Design

One of the major challenges for inductive charging is reaching high efficiency while keeping the electromagnetic stray field as small as possible. Taking this into account, PRIMOVE has chosen a DD vehicle coil and a three-phase infrastructure coil design. This combination ensures best efficiency behavior even when the car is not positioned accurately at the optimum parking position and allows for a small and lightweight vehicle unit.

As an example, Figure 1 is showing the measured DC to DC system efficiency, which has proven to be high and almost constant, even at low battery level for every car position above the ground coil.

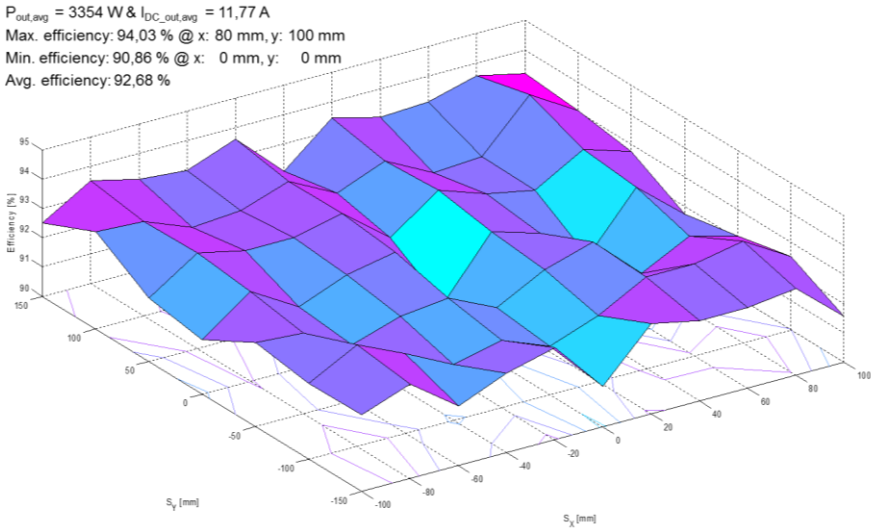


Figure 1 Efficiency at low battery voltage level

### 2.2 Onboard Coil Design

Besides the design targets from chapter 2.1, thermal losses should be minimized in order to reduce the cooling efforts which lead to PRIMOVE choosing a DD vehicle coil design. Figure 2 shows the vehicle coil design presented in 2015 at the Deutsche Kommission Elektrotechnik Elektronik (DKE) GAK 353.0.1

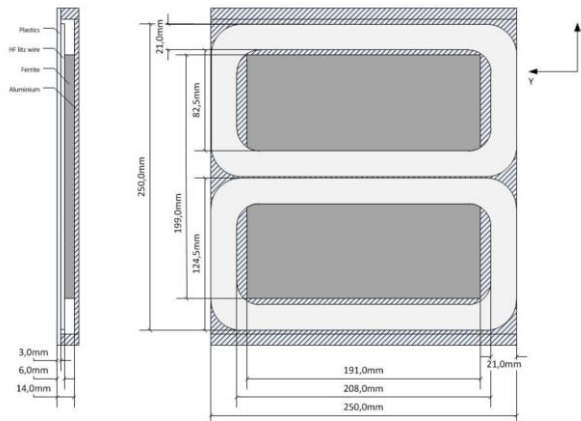


Figure 2 Magnetic layer of the vehicle coil

For the WPT1 power class (3.6 kW), this design plays an important part in allowing for full-power-charging at high ambient temperatures without additional cooling efforts like water-cooling or forced air for the onboard unit.

### 2.3 Infrastructure Coil Design

Enabling the design targets of minimized EMF and high efficiency in misaligned positions, a three-phase coil design for the infrastructure has been chosen, allowing for the magnetic field to be very consistent and controllable. Figure 3 shows the infrastructure coil design presented in 2015 at the Deutsche Kommission Elektrotechnik Elektronik (DKE) GAK 353.0.1

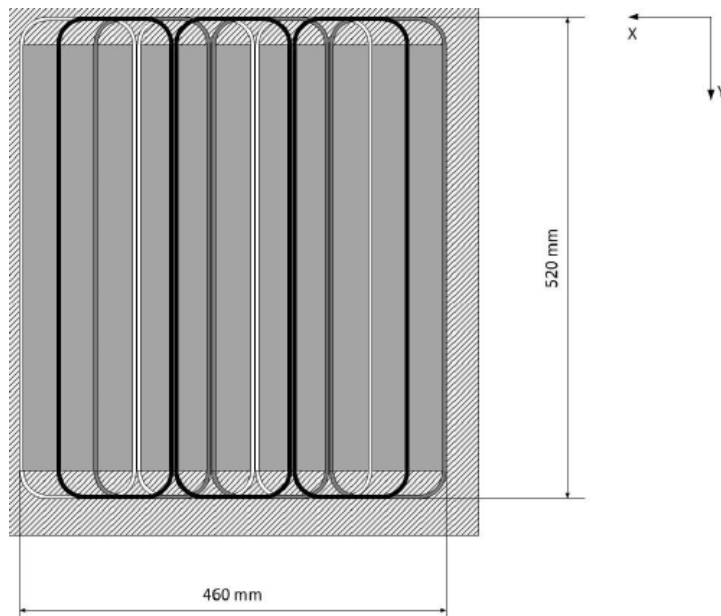


Figure 3 Magnetic layer of the infrastructure coil

Another positive aspect of using this topology for the primary device is that power transfer for different onboard coil designs like unipolar or multipolar can be assured.

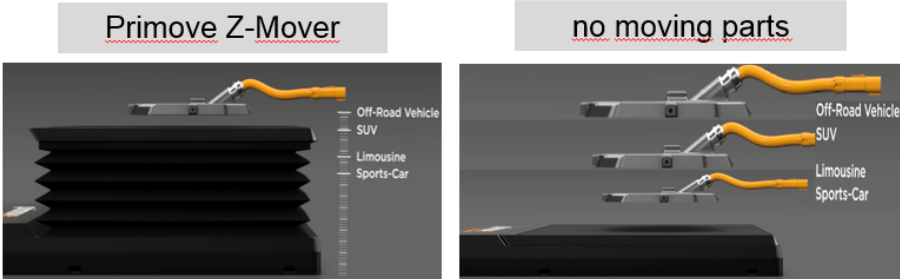
## 2.4 Reducing the Air Gap

Due to the fact that 80 to 90 % of the EV charging is taking place at home or at work, inductive charging should be designed to serve this need. The smallest possible electromagnetic stray fields as well as the highest possible efficiency are going to play an important role for the end-customer, as a lower efficiency leads to the charging of the electric vehicle being more expensive.

The best and most simple way to achieve this, is using a lifting device to raise the primary device closer to the car – the PRIMOVE Z-Mover. Advantages for the OEMs are the elimination of variants as well as a small and lightweight onboard coil. Savings on magnetic material, power electronics and safety systems are significantly higher than the additional cost for the lifting mechanism.

In Table 1, the benefits of a reduced and constant air gap in comparison to systems with variable airgaps can be seen.

Table 1 Comparison between Z-Mover and systems without a moving part



One system fits every vehicle	+	-
Efficiency	+	-
Lowest EMF	+	-
Costs	+	-
Packaging	+	-

Moreover, this approach leads to a decreased total cost of ownership for Tier I, OEMs and car owners starting even at small power classes and cars with low ground clearance. This advantage increases with higher charging power and ground clearance, because the savings on magnetic materials are increasing.

## 2.5 Easy Interoperability between Infrastructure, Car and Power Classes

Figure 4 illustrates the cross interoperability between ground and vehicle coils for 3.6 kW and 11 kW. This means, that an e-car equipped with a 3.6 kW inductive charging system will be able to charge on a 11 kW charging pad and vice versa, leading to maximum flexibility for car manufacturers as well as end customers. This also applies for cars with different ground clearance.

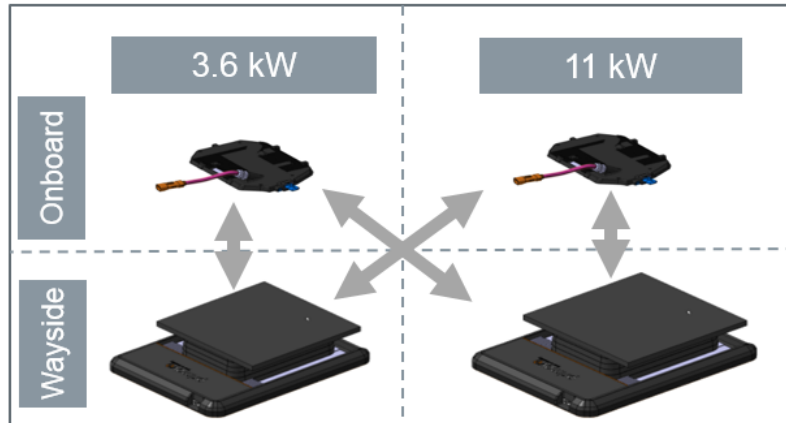


Figure 4 Interoperable for different power classes and car types

### 3. Not Only Power Transfer

A robust power transfer is only the beginning. This section will describe further challenges when developing an inductive charging systems for electric cars as well as the respective solutions.

#### 3.1 Highly Accurate Automatic Positioning System

The most visible aspect to the customers of automatic wireless charging systems is the positioning process. The comfort of not-needing to plug-in your car should not be disturbed by a complicated way of placing your vehicle coil at the right spot above your infrastructure unit. Therefore, the parking process must be automated or at least guided. Main challenges when installing a positioning system are delivering long range data in order to start the automatic positioning process at the needed distance as well as sending highly accurate signals for the final parking-position. Furthermore, it is important that both do work independently from environmental conditions like different road materials.

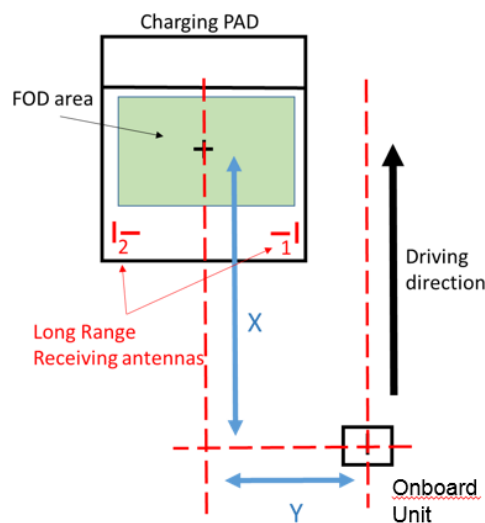


Figure 5: Positioning System

For the long range positioning, PRIMOVE uses two x- and two y-antennas to receive the signal sent by the onboard unit. The inductive sensor-board with multiple short range antennas of the FOD-System (foreign object detection) is used for highly accurate positioning data for the near field.

For increasing the quality and filtering the signals, additional data provided by the vehicle can be used. All antennas as well as the needed software algorithms are placed and handled inside the inductive charging system, leading to low integration efforts for the car manufacturer.

### 3.2 Foreign Object Detection

The most important safety system of the inductive charging unit is the detection of foreign metal objects. Objects like coins or screws getting in the area between primary and secondary coils will get very hot because of the strong magnetic fields and thus represent heating and even burning hazards.

To avoid this, the system must automatically shut down in case a metal object is located between the coils. The PRIMOVE FOD system is based on measurements on three different frequencies in adequate distance to the 85 kHz power transfer frequency. Thanks to the Z-Mover, the area to be monitored is reduced as the air-gap is significantly smaller with the wayside coil being lifted towards the vehicle, so that also very small objects, even when sticking to the car’s underbody, can be detected.

### 3.3 Cooling Concept for the Infrastructure Device

Since the infrastructure device is exposed to the public as soon as the parked car departs, strict limits regarding the surface touch temperature apply, even when high ambient temperatures occur and full charging power is requested. In combination with the required ingress protection for outside-mounting under all weather conditions, this is a challenging task to fulfill, especially when power electronics and the coil unit are mounted in the same housing as a one-box-solution.

The PRIMOVE Z-Mover uses a closed air cooling circuit inside of the primary device’s base-plate. The heat from the electronic hot-spots gets distributed evenly over the big base-plates’ surface, allowing for an optimized heat dissipation. Due to the closed channel, no air exchange with the environment takes place to ensure ingress protection IP69k.

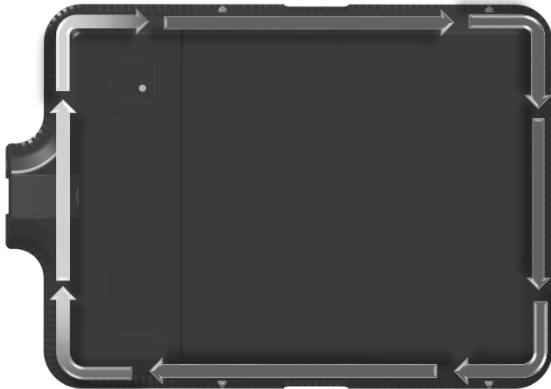


Figure 6:closed cooling circuit infrastructure device

## 4. Neutral Standardization for Industry-wide Participation

### 4.1 The Need for an Open Coil Design Approach

Currently, international standardization activities are leading to publications of the magnetic interface between the infrastructure- and the vehicle-devices with the help of mechanical drawings of specific coil designs, which may be coupled to patents. To allow to give freedom to operate for the supplier industries on the one hand but also the car makers, a more open magnetical interface description becomes inevitable.

In July 2015, PRIMOVE already presented [3] an Open Coil Design Approach for SAE Standardization which will be explained in the following section

### 4.2 PRIMOVE Open Coil Design Approach

The main principle of the PRIMOVE open coil design approach can be seen in Figure 7. Independent of ground coil size or ground clearance, the open coil design approach describes the magnetic flux that has to be captured in the appropriate surface of the vehicle coil.

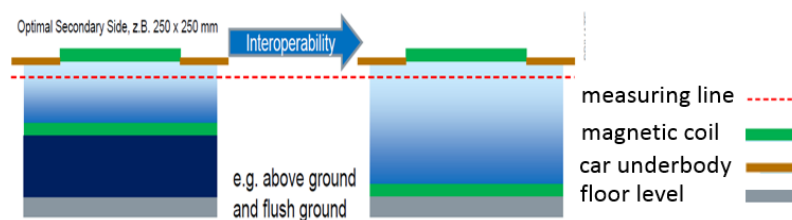


Figure 7 Position of magnetic interface just below vehicle coil

The following key principle [3] is foreseen:

- Usage of a reference block to capture electro-magnetic field below secondary coil
- This allows to „capture“ the primary field received in an „average“ secondary coil
- Using of the data from reference block measurements to achieve interoperability

The key point of this principle is to enable every supplier to design freely and thus leaving more room for future innovations.

### 4.3 Material Efficiency

In order to guarantee a cost optimized, affordable system for the end customer, PRIMOVE sees a need for considering a material efficiency threshold in the standardization because only then it is possible to compare the material impact and thereby the costs of several systems.

Table 2 compares the magnetic material amounts of the PRIMOVE system to the current coil designs of the Society of Automotive Engineers (SAE), showing that the need for high-cost magnetic material is by far lower with the PRIMOVE Z-Mover.

Table 2 Usage of magnetic materials for 3.6 kW inductive charging

	PRIMOVE Z-mover 3.6 kW		SAE reference 3.6 kW	
	amount litz-wire	amount ferrites	amount litz-wire	amount ferrites
Primary Coil (infrastructure)	1.22 kg	2.80 kg	4.07 kg	3.13 kg
Secondary Coil (on-board) Z1 ground clearance	0.40 kg (independent from Z-class)	1.02 kg (independent from Z-class)	1.13 kg	1.26 kg
Secondary Coil (on-board) Z2 ground clearance			1.63 kg	1.75 kg

Shown are the Values for 3.6 kW charging power. For higher power classes, bigger differences will occur, giving a system with lifting device even higher savings on expensive magnetic materials.

## 5. Conclusion

The previous sections have underlined that the PRIMOVE charging system for electric cars is market-ready, combining high efficiency, low cost and a system that fits every vehicle height. This provides the car manufacturer with a high degree of freedom when installing the system into the car while keeping cost low.

Finally, convenient e-mobility.

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## Author



**Andreas Fockers** is responsible for Automotive Sales at Bombardier Primove. In 2012, he finished his studies at the Ruhr-Universität Bochum with master-degrees in sales engineering and in mechanical engineering. Before he joined Bombardier Primove, Andreas started his career as sales representative for customized electric drives. Since Jan. 2016 he is the account manager for Bombardier PRIMOVE's first OEM customer for inductive charging going into serial production.