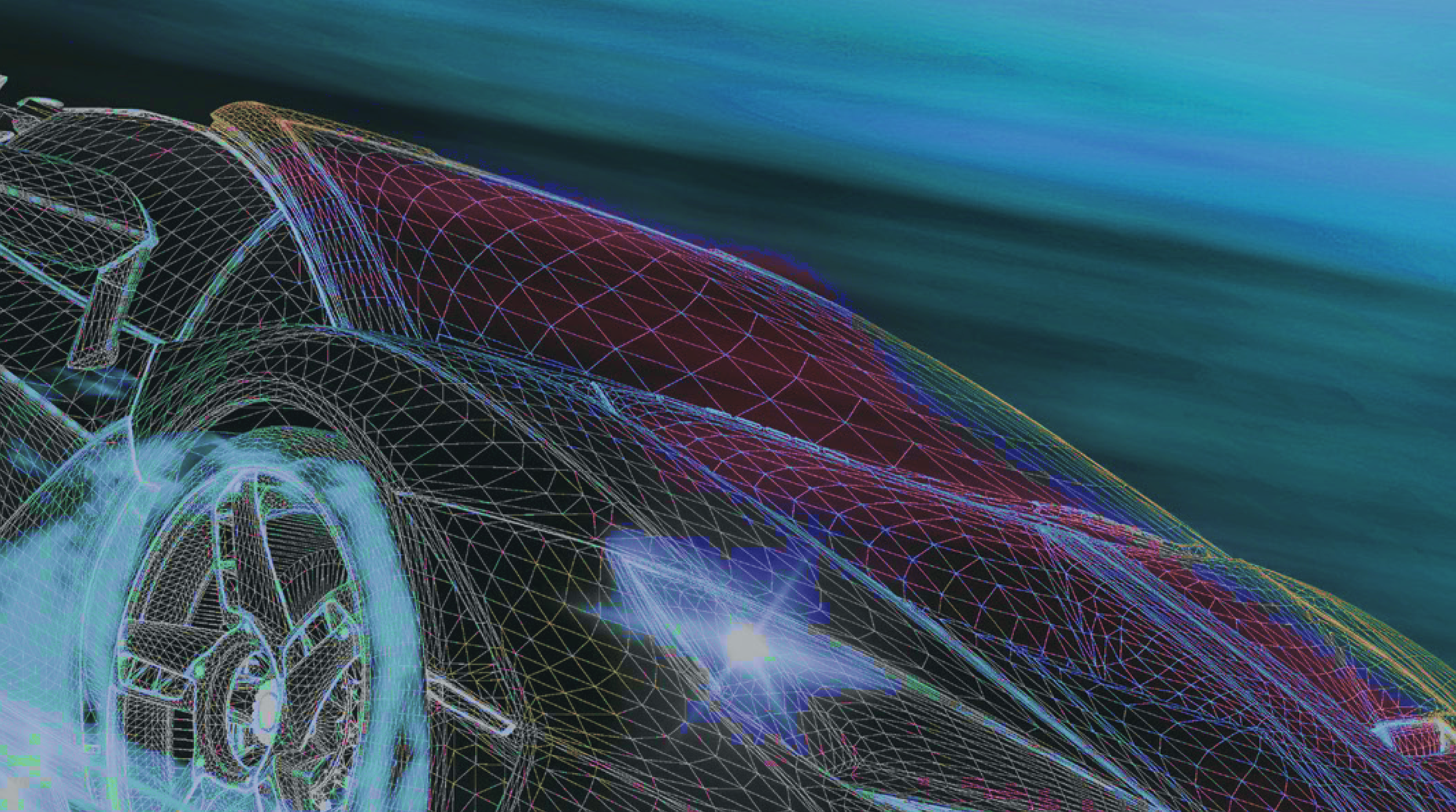


Ferrites in Automotive, EVS and HEVS

www.ferroxcube.com

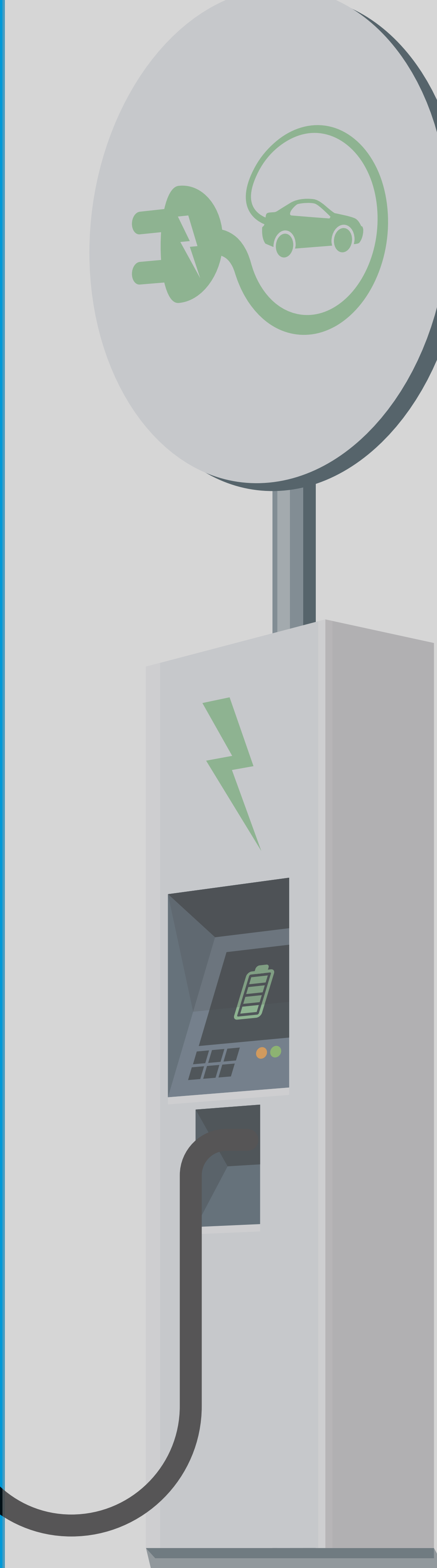
Automotive

- Low core losses at working frequency and temperature to achieve high efficiency
- Switching at higher frequencies allows size and cost reduction of the magnetic components
- Low profile shapes are recommended to build compact and modular designs

Formerly, a Philips Components company we now belong to the Yageo Group, one of the world's strongest suppliers of passive components. As a leading supplier of ferrite components, FERROXCUBE has manufacturing operations, sales offices, and customer service centers all over the world.

We supply one of the broadest ranges of high-quality, innovative products and place strong emphasis on miniaturization of magnetic functions. Ferrite components and accessories from FERROXCUBE are used in a wide range of applications, from telecommunications and computing electronics through consumer electronic products to automotive.

Power conversion in hybrid and electric vehicles has led to new technical challenges in the automotive field. When it comes to power conversion systems, magnetic design has a great impact not only on efficiency, but also on weight and cost. Ferroxcube offers a wide variety of cores for transformers and inductors in Automotive & e-Mobility, optimized for different conditions of frequency and temperature.



Introduction

Gear Up for Automotive Applications

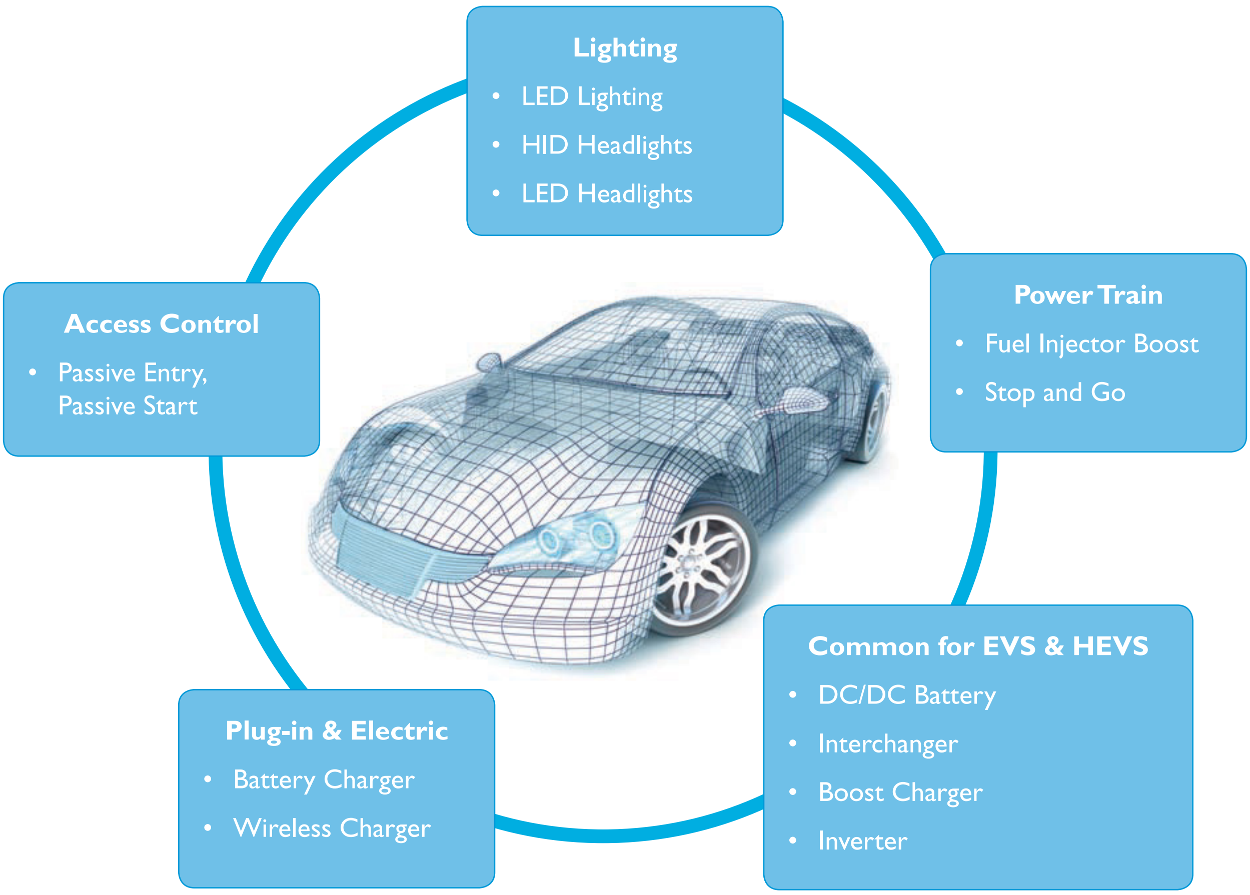
Power conversion in hybrid and electric vehicles has led to new technical challenges in the automotive field. Currently, high voltage batteries supply the power to the motor as well as to other electronic devices. Several stages and types of energy transformation are required.

When it comes to power conversion system, magnetic design has a great impact not only on efficiency, but also on weight and cost. Applications of ferrites in hybrid and electric cars are countless. This application note shows the variety of Ferroxcube's shapes, sizes and materials that can be combined to achieve the highest efficiency in a power conversion system design for hybrid and electric vehicles.

As a leading innovator in ferrite-ceramic technology, Ferroxcube offers advanced material in a wide variety of core shapes for transformers and inductors in automotive and electronic vehicle applications. Our products are optimized for different conditions of frequency and temperature. Recommended shapes, sizes and grades are intended to support the main design considerations.

Requirements for Automotive Applications

- Low core losses at working frequency and temperature to achieve high efficiency
- Switching at higher frequencies allows size and cost reduction of the magnetic components
- Low profile shapes are recommended to build compact and modular designs



Automotive Application Matrix

	Function	Material Grade	Preferred Core Shape	Characteristics
Access Control				
Passive Entry Passive Start	On-board antenna	3C90, 3C91, 3C95	Long Bar	Temperature stability
	Key antenna XY axis	4A11, 4A5	Small bar	
	Key antenna Z axis	4A11, 4A5	Drum	
	Key antenna 3D coil	4A11, 4A5	Multiwinding core	
Lighting				
LED Daylight, Signaling & Convenience	Inductor in the LED driver	3C95, 3C92 4F5 (in development)	Drum cores	High saturation
LED Headlights	High Power Inductor in the LED driver	3C92, 3C97 3F36	Low profile compact mid size	Low losses, high saturation
HID Headlights	A transformer to generate high voltage for ignitor	3C92, 3C97 3F36	Compact planar or mid size cores (Planar E32, RM8, PQ20..)	Low losses, high saturation
Power Train				
Fuel Injector Boost	A boost inductor for the DC/DC converter to generate overvoltage	3C92	PQ32	High saturation
Stop and Go	A boost inductor for the DC/DC converter to generate overvoltage	3C92, 3C97	PQ, RM, EE	High saturation, low loss
EV & PHEV battery charger				
EMI filter	Common mode choke	3E10, 4S2	Mid-large size toroids	
PFC	Inductor	3C92	PQ35, RM14	High saturation
DC/DC converter to battery voltage	Transformer provides isolation between grid and automotive	3C95, 3F36	Planar and compact sizes: ER41	
	Inductor	3C92, 3F36	Planar and compact sizes: ER41	
	IGBT isolation transformer	3C95, 3F36	Small EP or planar	Low losses
Wireless Charger	Emitter coil (ground unit)	3C90, 3C95	Large plates	Temperature stability
	Receiver coil (vehicle unit)	3C90, 3C95	Large plates	Temperature stability
Auxiliar DC/DC to drive IGBT's circuitry	Inductor	3C95	Planar ER23	Low loss
Current Sensing	Current transformer	3E27	Toroids	High perm., temp and B stable
	Hall sensor	3E27, 3E10	Toroids	High perm., temp and B stable
HEV, EV, PHEV				
DC/DC bidirectional HV battery to 12V battery	Transformer provides isolation between HV and low voltage	3C95, 3F36	Planar and compact sizes: ER41	Low loss
	Inductor	3C92, 3F36	Planar and compact sizes: ER41	High saturation
Auxiliar DC/DC to drive IGBT's circuitry	Inductor	3C95	Planar ER23	Low loss
Current Sensing	Current transformer	3E27	EP, toroids	High perm., temp and B stable
	Hall sensor	3E27	Gapped toroids, UU, custom	High perm., temp and B stable

Ferrites for advanced automotive electrical systems

Access control: Passive Entry Passive Start (PEPS)

Passive Entry Passive Start systems are based on 2 frequencies: a UHF data carrier that transmits encrypted codes and a low frequency (125-134 kHz) signal that starts the transmission, waking up the key when the driver touches any of the doors. These low frequency signals are emitted by ferrite antennas located in several places in the car (sides, front and back) to ensure full coverage around it, and also in the driver key. The car emitter antennas are powerful enough to induce a current in the key receiver antenna to wake it up, starting the communication protocol.

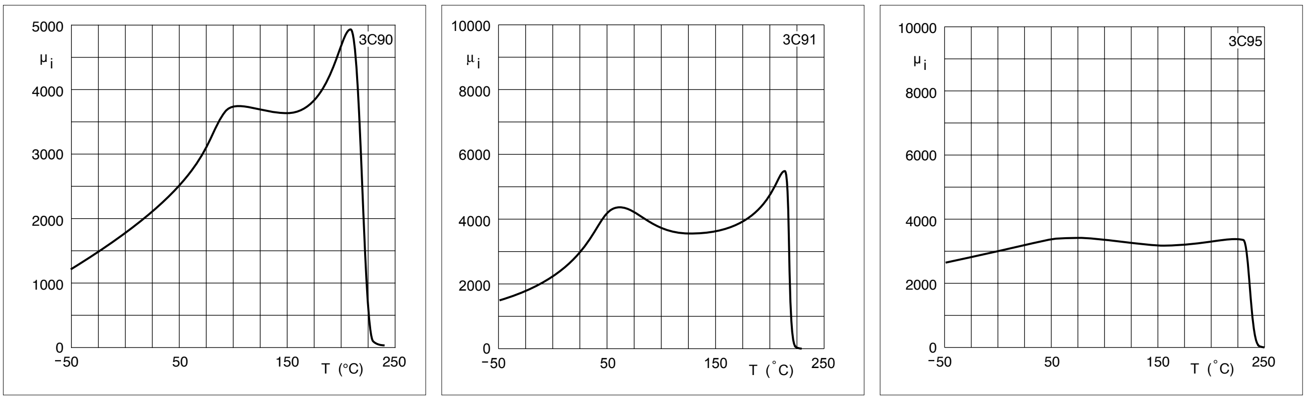
The antennas are based on a resonant LC circuit tuned at 125 kHz according to:

On board antennas

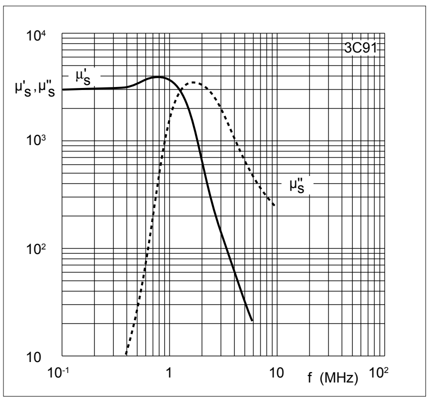
The most common shape for this function is a rectangular bar ranging 60 to 90 mm long. Tight tolerance on inductance is needed to keep constant and reliable tuning. This can be achieved by:

- Low spread on mechanical dimensions of the ferrite cores, easing the winding process. Ferroxcube has capabilities to machine all sides of the product.
- Thermally stable material. Ferroxcube 3C95 material offers optimal temperature stability

Optimal antenna sensitivity strongly depends on ferrite material loss factor. Ferroxcube provides several solutions with high Quality Factor (Q factor): preferred materials are 3C90, 3C91 and 3C95.



Initial permeability as a function of temperature



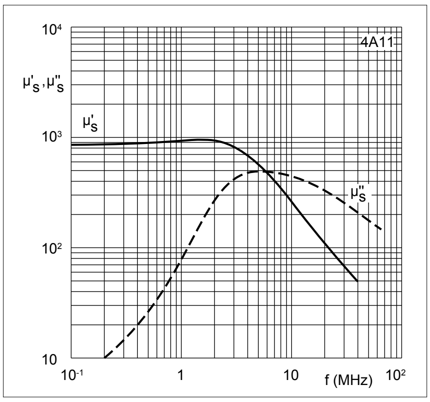
Complex permeability as a function of frequency

Key antennas

The key needs 3 antennas, one for each axis, in such a way that doesn't matter what the position of the key is, so that, the field will be detected.

The antennas have to fit in the thin credit card sized key, thus a low profile is a must. The most common shape is a rectangular bar 10 mm long. The Z axis is sensed with a low profile drum core.

The preferred materials are high resistivity Nickel Zinc enabling the possibility to wind directly on the core. Ferroxcube preferred materials are 4A11 and temperature stable 4A5 (in development).



Complex permeability as a function of frequency

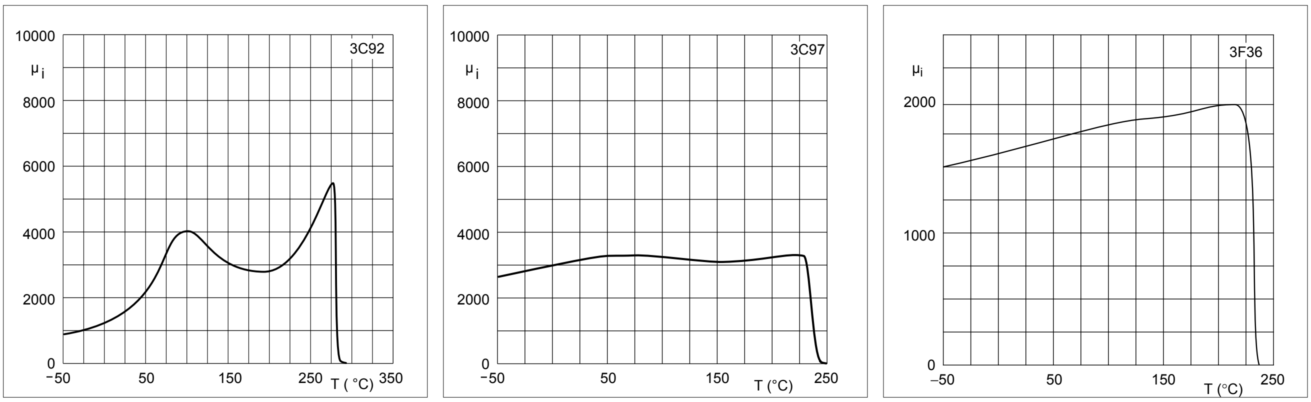
Lighting

New developments in lighting technology have improved strongly the efficiency of the systems, reducing the consumption and increasing the lifetime when compared with traditional incandescent lamps. But these technologies, including LED and HID lamps require specific power conversion systems using current controlled LED drivers or igniters in the case of HID.

LED drivers use an inductor to store the energy on the DC/DC converter. There are several solutions depending on the power:

- Low power LED's (daylight, signaling) use very common power inductors. Ferroxcube offers drum cores in 4F5 material exhibiting high saturation flux and low losses (in development).
- Headlights: due to the higher power, it is preferred to use high efficiency materials and shapes. Ferroxcube 3C92 exhibits the highest saturation flux (460 mT at 100°C), while 3C97 has low loss at all temperatures. For high switching frequency (>400 kHz) 3F36 is the optimal choice. The preferred shapes are compact PQ20 or RM8 cores and also planar cores.

HID igniters use a high frequency transformer to boost the voltage for the high voltage generator generator. Same materials materials and shapes are preferred: 3C92 due to its high Bsat, 3C97 for low losses and thermal stability and 3F36 for >400 kHz operation and thermal stability, using PQ, RM and planar cores.



Initial permeability as a function of temperature

Auto stop and start boost converter

Fuel consumption can be optimized using auto stop and start systems that shut down the engine while the car is stopped and in neutral. When the clutch is pressed, the engine starts quickly again using a high power starter motor. During cranking the battery voltage drops from 12 Volts to 10 or even less. A boost DC/DC converter keeps a stable supply to all electric systems (air conditioning, radio, lights…) preventing them from switching off during this drop.

Ferroxcube offers several materials suited for the inductor in this boost DC/DC converter: 3C92 with its high Bsat (460 mT at 100°C) and 3C97 with low loss at every temperature are specially suited for operation below 400 kHz. Common shapes are PQ, RM and E cores.

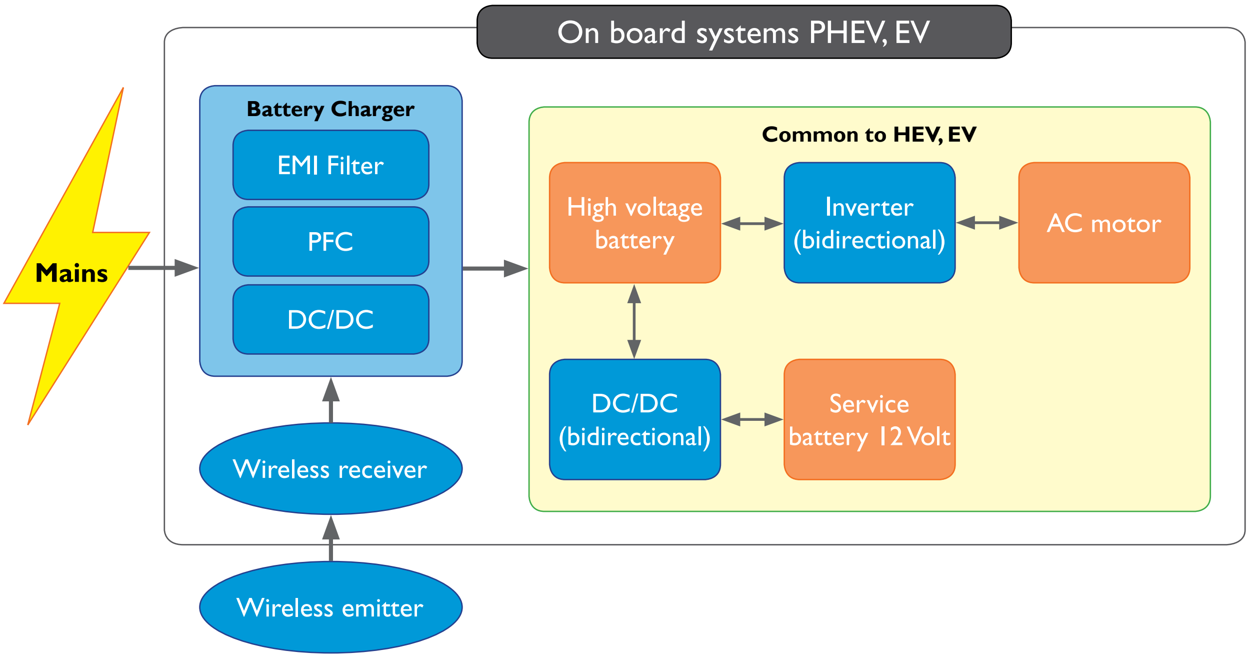
Fuel injector boost converter

Fuel distribution in the cylinder can be improved when the injectors are started with a short overvoltage. This overvoltage can be accomplished using a DC/DC boost converter which is managed by the injection driver. Ferroxcube offers 3C92 high saturation material in PQ26 and other shapes for optimal operation of the converter.

Ferrites for hybrid and electric cars

Electrical power conversion on hybrid, plug in hybrid and electric cars is one of the key parameters on the car autonomy and efficiency. Electrical power is generated, stored and consumed at different levels and even frequencies. Each of the conversion steps uses ferrites for different functions: energy storage, filtering, shielding, galvanic isolation or transformation.

Ferroxcube provides high end cost effective solutions for all those functions, supporting customers on optimal design when needed.



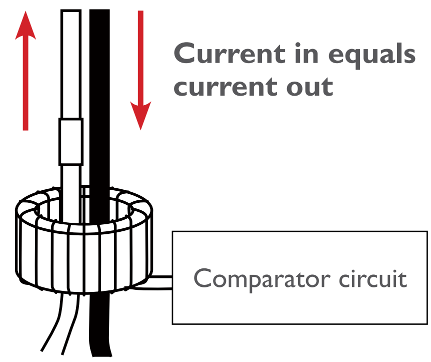
Grid connected battery charger

This unit transforms the power from the grid to high voltage DC to be stored in the vehicle battery. The power ranges from 3 to 20 kw (or even more) depending on the charging speed. Generally the system consists of 3 units:

- EMI filter: common mode chokes prevent EMI noise going to the grid. Ferroxcube provides high permeability and extended bandwidth toroids in a full range of sizes. Optimal materials are 3E10, 3E27 for low frequency (below 20 MHz) EMI suppression and 4S2 for high frequency (up to 300 MHz).
- Power Factor Corrector: high saturation 3C92 with distributed airgap cores are optimal for this function. Custom design is commonly used to fit the core in the housing.
- DC/DC converter to battery voltage: commonly a boost converter with galvanic isolation. The preferred materials are 3C95 (low loss at wide temperature range, <400 kHz) and 3F36 (low loss, >400 kHz) on both the inductor and transformer using planar or PQ cores. Switches can be isolated as well using small EP or EFD cores.

Ground fault interrupter

High permeability cores (3E10, 10k permeability) can be used for detection of current leakage to ground. When there is a mismatch between line and neutral the secondary winding generates a signal proportional to the mismatch, which can be used to stop the charging.



Wireless charger

Inductive wireless chargers enable the possibility of charging the car without plugging it to the grid. Safety is one of the major benefits: the vehicle is completely isolated from the grid, allowing the possibility of transferring high power without the need to have a low resistance ground connection.

The charging coils are "shielded" with ferrite tiles to drive the field to each other. Ferroxcube can provide tiles in a wide variety of sizes and thicknesses on 3C95 low loss wide temperature material and also in cost competitive 3C90.

Bidirectional battery charger

This unit exchanges energy between the high voltage battery (commonly 200 or 400 Volts) to the service battery (12 Volts). This unit is an isolated DC/DC buck boost converter handling 3 kw.

The preferred inductor materials are 3C92 and 3C95 for the transformer. Shapes are generally planar magnetics which can be easily paralleled and connected to a heat sink, but other shapes are also available.

Auxiliary power supplies

Auxiliary power supplies are used to power the Electronic Control Units (ECU) and the switching circuitry. Power can be obtained from either the high voltage battery, or from the service battery, and reliability is a must for safety reasons. The preferred material is 3C95 using small or mid size cores (planar ER32, PQ20).

Current sensing

It is possible to use ferrite cores for current sensors in 2 different ways:

- Current transformer: only applicable to AC lines. The secondary supplies a current proportional to the measured current on the primary. The materials are 3E27 and 3E10 on small EP cores or toroids.
- Combined with a Hall effect sensor. The sensor is located in the core airgap. Both AC and DC currents can be measured. The preferred materials are 3E27 and 3E10 on gapped toroids or E cores.

Preferred Materials

Power conversion materials: Low frequency

- Low frequency: <300 kHz
- Thermal stable: 3C95
- Cost effective: 3C90

Symbol	Conditions	Value			Unit
		3C90	3C91	3C95	
μi	25°C ,10 kHz , 0.25 mT	2300 ±20%	3000 ±20%	3000 ±20%	
μa	100°C, 25 kHz, 200 mT	≈ 5500	≈ 5500	≈ 5000	
Bsat	25°C ,10 kHz ,1.2 kA/m	≈ 470	≈ 470	≈ 530	mT
	10°C ,10 kHz ,1.2 kA/m	≈ 380	≈ 370	≈ 410	
P_V	100°C, 100 kHz , 100 mT	≈ 80	≈ 40	≈ 40	kw/m^3
	100°C, 100 kHz , 200 mT	≈ 450	≈ 300	≈ 290	
ρ	25°C, DC	≈ 5	≈ 5	≈ 5	Ωm
T_C		≥ 220	≥ 220	≥ 215	°C
Density		≈ 4800	≈ 4800	≈ 4800	kg/m^3

Power conversion materials: High frequency

- High frequency: >300 kHz
- Improved temperature performance

Symbol	Conditions	Value	Unit
		3F36	
μi	25°C ,10 kHz , 0.25 mT	1600 ±20%	
μa	100°C, 25 kHz, 200 mT	≈ 2400	
Bsat	25°C ,10 kHz ,1.2 kA/m	≈ 520	mT
	10°C ,10 kHz ,1.2 kA/m	≈ 420	
P_V	100°C, 500 kHz , 50 mT	≈ 90	kw/m^3
	25°C, 500 kHz , 100 mT		
	100°C, 500 kHz , 100 mT	≈ 700	
ρ	25°C, DC	≈ 8	Ωm
T_C		≥ 230	°C
Density		≈ 4750	kg/m^3

EMI suppression materials

- 4S2: High frequency EMI suppression
- 3E27: High Tc, low frequency EMI suppression
- 3E10: Low frequency, high impedance EMI suppression

Symbol	Conditions	Value			Unit
		3E10	3E27	4S2	
μi	25 °C; ≤10 kHz, 0.25 mT	10000±20%	6000±20%	≈ 850	
Bsat	25 °C; 10 kHz, 1200 A/m	≈ 460	≈ 430	≈ 340	mT
	100 °C; 10 kHz, 1200 A/m	≈ 270	≈ 270	≈ 230	
tanδ/μi	25 °C; 30 kHz; 0.25 mT	≤ 5 x 10^{-6}			
	25 °C; 100 kHz; 0.25 mT	≤ 20 x 10^{-6}	≤ 15 x 10^{-6}		
η_B	25 °C; 10 kHz; 1.5 to 3 mT	≤ 0.5 x 10^{-3}			T^{-1}
ρ	DC; 25 °C	≈ 0.5	≈ 0.5	≈ 10^5	Ωm
T_C		≥130	≥150	≥125	°C
Density		≈ 5000	≈ 4800	≈ 5000	kg/m3

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