How to Define the LF Driver's Key Parameters in Automotive PEPS Systems

Dr. Jedidi Kamouaa

Introduction

Because of the increased comfort and security they provide, passive entry (PE) systems have become standard in medium-class cars. Although they've been available for several years, they have become more popular recently as their increased level of integration lowers system costs. Today, the latest trend is toward passive entry passive start systems (PEPS) for medium-class vehicles, which are well established in the automotive high-end car market. This adoption of PEPS systems in medium and low-end markets is driven by an important system cost decrease, primarily due to the reduced number of coils per vehicle, which is the highest cost contributor.

Designing such PEPS systems is challenging and includes the following difficulties:

- Generation of high-drive current and, thus, the required low-frequency (LF) magnetic field to detect the key fob inside the vehicle and/or in the near vicinity
- Drive current regulation to allow reliable RSSI measurements
- Protection under thermal stress conditions and electrical diagnostics
- Reduction of electromagnetic radiation
- PEPS speed

The purpose of this article is to help designers understand how to define the key parameters of the LF driver, which is a key component in PEPS systems. Also, the piece will briefly explain how the LF driver technology will evolve in the future in response to the ever-increasing need to cut costs.

Principle of PEPS System Operation

A car key is powered by a small Lithium-Ion battery that supplies the key-fob microcontroller and its associated UHF transmitter/transceiver whenever the LF wake-up signal occurs. Often, however, the key remains in sleep mode to minimize current consumption and, thus, extend battery lifetime. A key wake-up is initialized by touching one of the vehicle's door handles or by a proximity sensor which causes the car (LF driver) to send a wake-up signal via the LF antenna located in the door handle. Each of the 3D LF receivers located in the key fob can be adjusted for sensitivity and resonance frequency to ensure a reproducible system design. If one of the key's 3D LF receivers detects an appropriated LF wake-up signal, an ultra-high frequency (UHF) identification response (ID response) is sent back to the car.

Once mutual authentication has been processed through the UHF channel, the car door opens. Up to seven (sometimes nine) LF antennas are used to determine whether the key is located inside or outside the vehicle prior to authorizing the engine start.

A PEPS system should also offer a special battery back-up mode that allows key fob controller operation via the LF magnetic field. All capacitors related to an LF antenna (mainly in the key fob) can be trimmed to the current resonant frequency to accommodate the tolerances of the components being used.

LF Antenna Driver System

Figure 2 shows the basic architecture of a PEPS system for a car sending a wake-up signal via the LF antenna. If the key's LF receiver has detected an appropriate LF wake-up signal, a UHF ID response is sent back to the car. Once mutual authentication has been processed through the UHF channel, the car door opens. Based on key fob sensitivity (1-2mVpp typically) and an antenna drive current of $1A_{peak}$, current systems can achieve a wake-up distance of one to two meters. Though it operates at the same LF frequency of 125kHz, the base station device is often separated from the LF driver device.

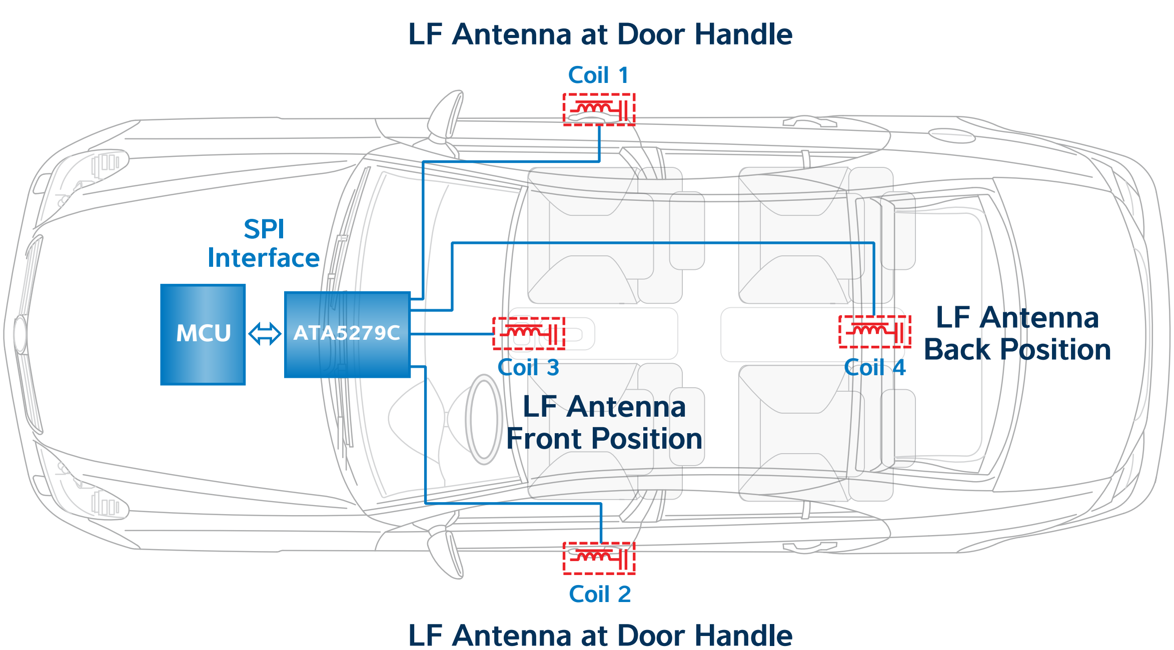

Figure 1. Automotive Application Example with Four Antennas

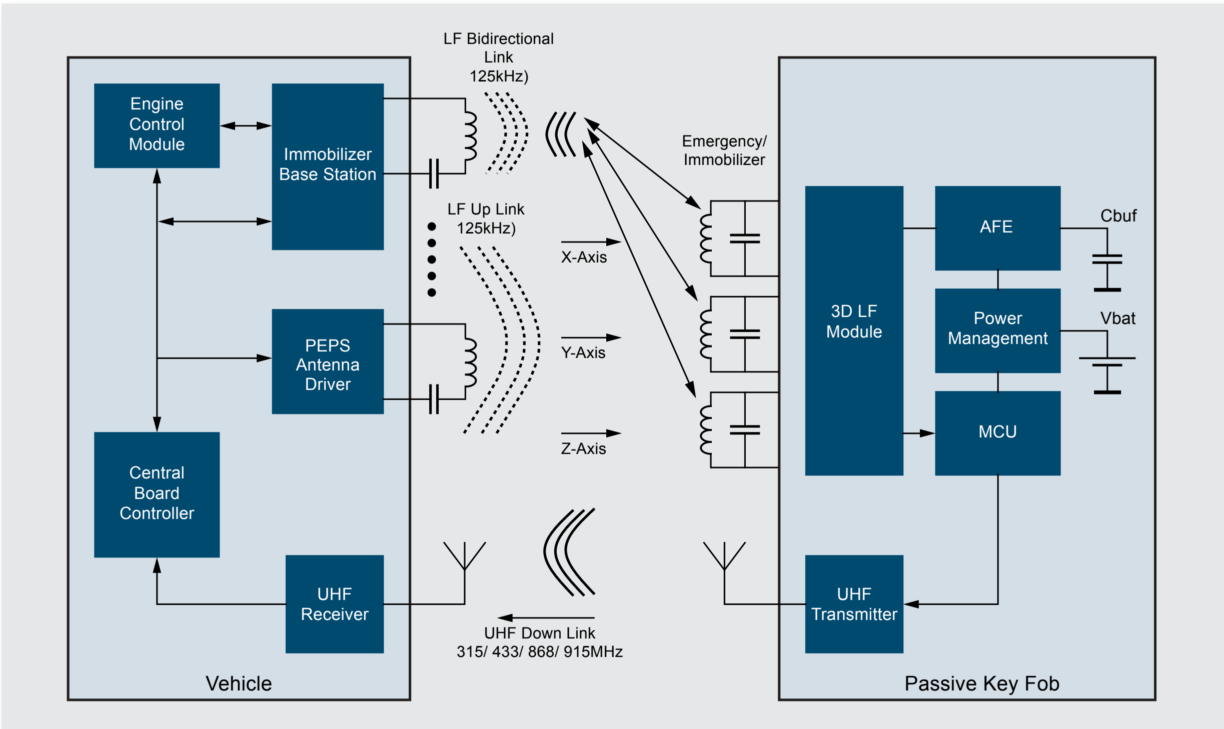

Figure 2. Basic PEPS System Architecture

To best match the PEPS system requirements, the Atmel® ATA5279C multi-channel LF antenna driver IC includes the following technical features:

- Three drivers with a peak current of up to 1000mA each and three additional drivers with 700mA of peak current each
- A boost converter to stabilize the antenna current independently from the battery voltage as well as from antenna tolerances
- A sinus wave 125kHz antenna signal to minimize harmonics radiation
- An antenna current regulation loop to allow stable RSSI measurement
- Programmable current in 20 steps required for RSSI field strength measurement
- An LF data buffer to reduce microcontroller data transmission tasks (limited microcontroller resources)
- Advanced fault diagnostics for driver and antenna indication
- Full protection against electrical and thermal overload
- An SPI interface suitable for bus structure designs
- Very low power consumption in power-down mode
- A small QFN48 7mmx7mm package

The ATA5279C IC operates alongside the Atmel ATA5791single-chip key fob controller featuring a typical sensitivity of $1mV_{peak\text{-}peak}$ integrating the RF transmitter.

There are several critical aspects for the LF antenna driver system design which need to be considered:

- Ability to generate sufficient magnetic field to detect the key fob inside the vehicle and/or in the vicinity of the vehicle. For this purpose, the boost converter is the best choice, allowing a high-drive current with the required voltage that can reduce the antenna size and, therefore, lower the cost of the overall PEPS system. The use of a boost converter implies further considerations such as filtering, alignment and thermal calculation, etc.
- A regulation loop of the drive current for reliable field strength and thus RSSI (receive signal strength indicator) measurement
- Protection under thermal stress conditions and electrical diagnostics

- Electromagnetic radiation
- The interface to the host microcontroller
- Thermal considerations

Figure 3 shows the principle of an antenna current regulation loop, and how the ATA5279C IC's boost converter is connected to the car battery.

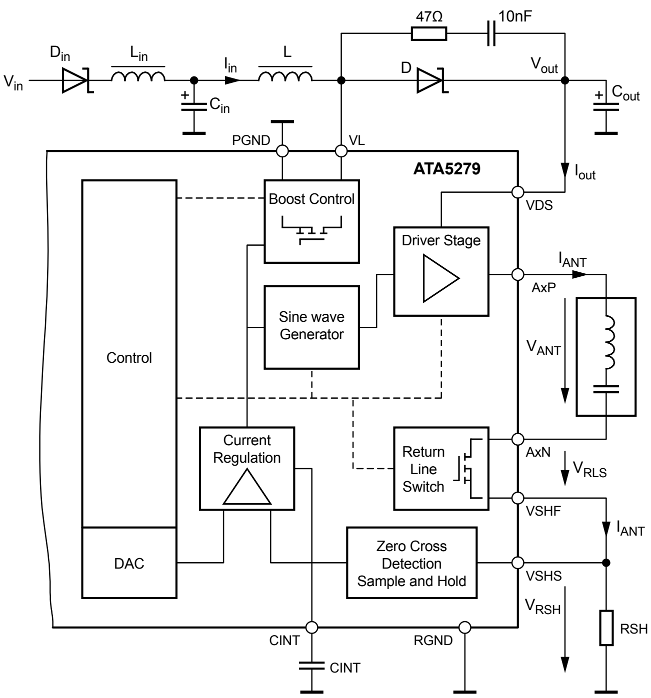

Figure 3. Principle of an Antenna Current Regulation Loop

Boost Converter

The boost converter operates in pulse width modulation (PWM) switch mode at a fixed frequency derived from the 8MHz resonator. For example, in the case of the ATA5279C device, this fixed frequency is 125kHz. The converter is able to generate an output voltage of up to 40V, providing the required supply voltage for the driver stage. The antenna current regulator provides the required control voltage for the boost converter in order to deliver the current set for the appropriate antenna. Thus, the current flowing through the antenna is fully independent of both antenna impedance and battery voltage.

In theory, the converter output voltage depends on the duty cycle (D) of the PWM control only. However, in real life the output voltage is reduced due to the losses of the affected components (NMOS, L, D, C) expressed by the efficiency factor η.

In continuous conducting mode (CCM), the output voltage is determined as follows:

$$V_{out} = V_{in} \times \frac{1}{1-D} \times \eta$$

$$D = 1 - \frac{V_{in}}{V_{out}} \times \eta$$

$$D = \frac{t_{on}}{T}$$

In the case of the ATA5279C IC, the boost converter is controlled within the antenna current regulation loop. Therefore, the duty cycle and the output voltage are automatically set to the required value in order to deliver the programmed antenna current.

a) Determination of the Boost Inductor

The inductance of the boost coil determines the ripple current through the inductance itself, the decoupling diode and the smoothing capacitor at the output (see the following formula):

$$\Delta I_L = \frac{1}{f} \times \left(V_{out} - V_{in}\right) \times \frac{V_{in}}{V_{out}} \times \frac{1}{L}$$

where:

- ΔI_L = ripple current
- V_{in} = input voltage
- V_{out} = output voltage
- f = frequency
- I_L = programmed current
- L = inductance

The output voltage VDS supplying the driver stage as well as the driver input signal is controlled by the current regulation. If the driver input signal is a sine wave, the boost inductor output voltage has to be increased according to the sine wave rail margin of typically 3V.

$$V_{out} = VDS = 2 \times \left[I_{ant\_p} \times \left(Z_{ant} + R_{Shunt} + 2 \times R_{DSon}\right) + 3V\right]$$

As a consequence, a higher inductance will (theoretically) smooth the ripple current Delta I_L and reduce the thermal load of the boost power transistor. An increased inductance, however, results in increased coil size and, as a result, higher system cost, adversely affecting the boost control stability that occurs, in particular, with low current loads at the boundary of CCM to DCM (discontinuous conduction) mode. This instability is attributable to an increased oscillation effect on the NMOS switch (V_L) if the converter switches to DCM operation. Also, undesirable emissions caused by those oscillations may conflict with EMC requirements.

Therefore, the selection of the inductor value needs to balance out low ripple current and stable boost converter operation. Regarding the ATA5279C device, Atmel recommends a selection of inductor values based on the specific load conditions of the driver (see Table 1).

Higher Load Range	Lower Load Range
25 to 40V	Up to 25V
47 to 100µH	22 to 47µH

Table 1. AT5279C Inductor Value Recommendations

b) Determination of the Decoupling Diode

Thanks to its low forward voltage drop and fast recovery time, a Schottky diode is the best choice to reduce power dissipation. As the switching losses can be ignored regarding conductivity losses, power dissipation as well as the peak current can be expressed as follows:

$$P_D \approx V_F \times I_{out}$$

$$I_{D\_P} \approx I_{out} \times \frac{V_{out}}{V_{in}}$$

c) Determination of the Output Capacitor Cout

The output ripple voltage can be expressed in two ways:

1. While discharging the capacitor during the conduction phase of the boost converter
($D = t_{on}/T = 1 - V_{in}/V_{out}$)

$$\Delta V_{out} = \frac{I_{out} \times D}{f \times C}$$

2. When generating a voltage drop at the impedance ESR of the capacitor caused by charging during the complementary time (1-D)

$$\Delta V_{out} = ESR \times \left(\frac{I_{out}}{1-D} + \frac{\Delta I_L}{2} \right)$$

Both calculations imply a high-capacitance value to reduce the ripple voltage. However, because PEPS applications require a fast start-up time, the capacitance value needs to be low. Therefore, the best trade-off between these two diverging requirements needs to be found. Also, the capacitance value must match the resulting ripple current:

$$I_{C\_RMS} \geq I_{out} \times \sqrt{\frac{D}{1-D}}$$

d) Determination of the Input LC Filter

The use of an inductor at the boost converter input facilitates the suppression of the ripple current in the input capacitor C_{int}. The required inductance depends on the individual application and the EMC requirements. The input inductor is generally similar to the one used for the boost converter.

The input capacitor provides low impedance that prevents any interaction with the car battery supply voltage. It is important, however, to ensure that the rms ripple current of the selected capacitor is higher than the equivalent rms of the boost inductor ripple current ΔI_L

$$I_{Cin\_rms} = \frac{\Delta I_L}{\sqrt{3}}$$

e) Determination of C_{int}

The ATA5279C IC's internal current regulator is similar to a trans-conductance amplifier that provides sink/source output currents at the C_{int} pin. Typically, the capacitor C_{int} is connected to ground so that the regulator integrates the voltage over time. The resulting voltage at the C_{int} pin supplies the internal control for the driver as well as for the boost converter unit.

Selection of the C_{int} capacitor involves a trade-off between the rise time and the overshoot antenna current. It is rather difficult, however, to calculate or simulate this value because the dynamic behavior of the antenna regulation loop also depends on the antenna's Q factor and the boost converter circuitry. Therefore, direct physical measurement is recommended.

Reduction of Radiated Antenna Harmonics

Even though the power dissipation of the driver stage exceeds that of a driver with a square wave output, a sinusoidal antenna signal minimizes the radiated harmonics and, thus, both effort and cost to achieve EMC approval.

Antenna Regulation Loop

The antenna current is regulated by the boost driver voltage VDS, the current of which is primarily independent of the battery state and antenna tolerances. Given the fact that PEPS systems require an accurate field strength measurement, the regulated antenna current (and, thus, the field strength) can be programmed via SPI in 20 predefined steps from 50mA to $1A_{peak}$.

Interface to the Host Controller

To avoid overloading the host controller, the ATA5279C IC contains a 128-bit data buffer that is organized in 16 bytes. All driver-related commands and data are stored and processed by the FIFO buffer. During operation, the status is continuously monitored. An interrupt to reload the buffer via SPI can be executed within 2Mb/s.

Electrical Diagnostics and Protection under Thermal Stress Conditions

All ATA5279C driver connection lines (AxP) and return lines (axN) are monitored during operation (see Figure 5). In case of a short circuit to battery supply or to ground, or if an antenna is shorted, the power stages switch to shut-down mode to protect themselves from damage. In addition, the temperature sensors on the NMOS driver stages shut down if the temperature exceeds 145°C. At the same time as the shutdown, an interrupt request is triggered and the shutdown cause is stored in the fault register.

In addition, an advanced diagnostic mode allows the AxP and AxN outputs to be loaded by switchable DC current sources (see the gray area in Figure 4). During this diagnostic mode, the driver stages remain in high impedance. The diagnostic mode also allows the current switches and the digital level state of the selected AxP/ AxN stages to be set so they can be read via a status request. This mode as well as the related test structures can be used to indicate any antenna-line interconnection faults.

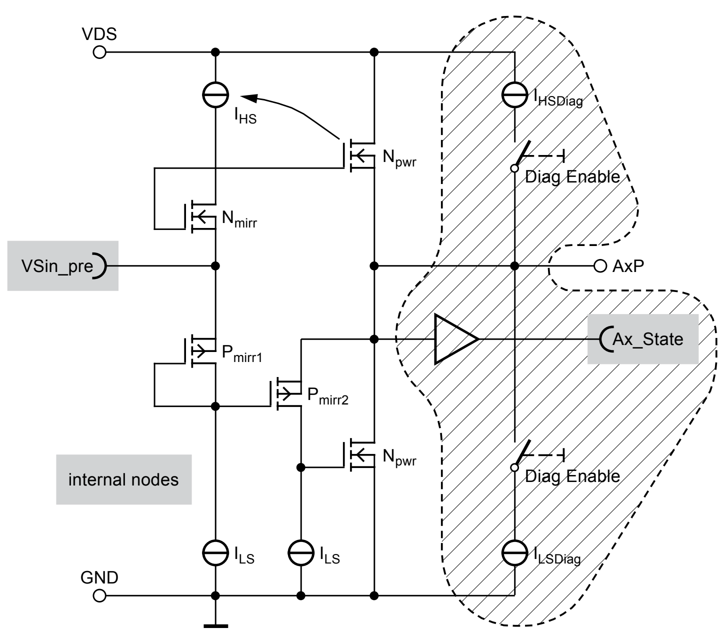

Figure 4. Principle of AxP Driver Arrangement

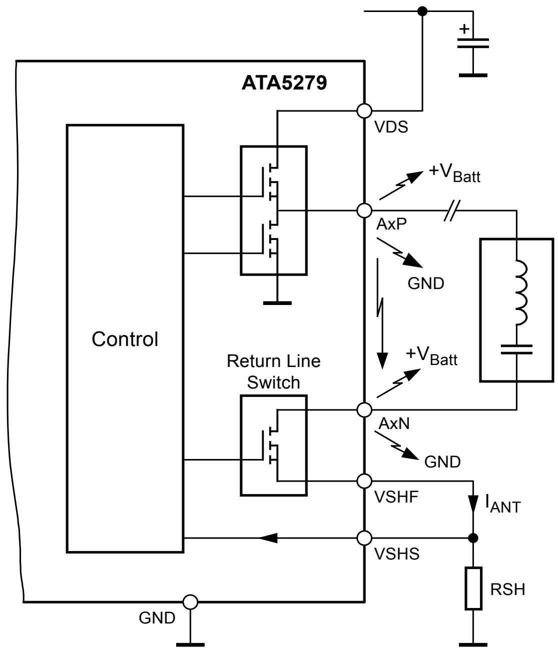

Figure 5. Fault Scenario Schematic

Fault Scenario, e.g., at Driver 1	Driver	Fault Register Code	Detected by	Meaning of Fault Code /Criteria
Normal operation	Switch on	00	-----	No fault
Open antenna	Switch off	28	RSH	Missing return line signal during modulation, no zero cross detected via VSHS
Short circuit A1P- A1N	Switch off	22	HS	Excessive current through high-side transistor, parameter 4.1 > ;0.88 A;
Short circuit A1P - VBatt	Switch off	21	LS	Excessive current through low-side transistor, parameter 4.2 > ;1.1 A;
Short circuit A1N - VBatt	Switch off	24	RSH	Excessive positive voltage on VSHS detected, parameter 6.2 > ;1.25 A ;* RSH (1Ω)
Short circuit A1P - GND	Switch off	22	HS	Excessive current through high-side transistor, parameter 4.1 > ;0.88 A;
Short circuit A1N - GND	Switch off	30	RSH / Temp	Missing return line or temperature shut-down

Note: For multiple detection of a steady channel fault (e.g., in a running loop), the channel must be changed before the fault register can be reset by sending the Reset Fault Status command.

Table 2. Fault Scenarios

Determination of the Thermal Model

Driver stage activation and the boost transistor (when integrated) are the main sources of thermal load in LF driver devices. PEPS operation typically lasts a few milliseconds only, so it is unlikely that the thermal overload will cause damage. At the same time, the ATA5279C IC includes a temperature sensor monitoring function that protects the device from being damaged in the event of an unusual operation scenario. To avoid thermal shutdown and to extend the lifetime of the device, the designer should consider and use the worst-case trigger scenario (protocol length and repetition rate) as a basis to estimate the margin to the thermal shutdown and vice versa.

Thermal Model Determination of the Device Mounted on the PCB

The calculation of the LF devices' thermal behavior implies the definition of a simplified thermal model. The ATA5279C IC's power dissipation sources are located in different chip areas. Each source is connected to an individual thermal resistance R_{thjc} (thermal resistance junction case) having the same value. The thermal capacity C_{thjc} can be ignored because the time constant (around 4ms) has only minor impact compared to that of the device package. The combined power dissipation $P_{boost} + P_{driver}$ flows through R_{thca} (thermal resistance case-to-ambient) and is then absorbed by the PCB. Thus, the final heat slug temperature is determined by the total power dissipation multiplied by the thermal resistance Rthca and the duty cycle plus the ambient temperature (see the formula below).

$$T_{Heatslug}(t) = T_{amb} + n_{duty} \times R_{thca} \times (P_{Boost} + P_{Driver}) \times \left(1 - e^{-\frac{t}{\tau ca}}\right)$$

To estimate the margin to the thermal shutdown, it is important to calculate the junction temperature as shown below:

$$T_{Junction}(t) = T_{Heatslug} + (P_{Boost} + P_{Driver}) \times R_{thjc}$$

However, the calculation of the temperature increase does not help in obtaining a real temperature profile while sending the LF data pattern (0 and 1) because it assumes an average operation based on one duty cycle. By applying the analogy of thermal and electrical behavior, the temperature rise can be simulated by a standard PSPICE tool.

PEPS Speed

The communication protocol between the car and the key, the corresponding baud rate and the amount of services/functions determine the overall PEPS timing, i.e., the speed. For example, a protocol that drives several LF antennas simultaneously ensures a faster PEPS system. However, several issues may arise depending on the complexity of the localization algorithm:

- Field cancellation that renders the key fob detection impossible
- The resulting field does not reflect the absolute key fob position
- A high-current drive generates excessive heat and instability in the driver stage
- A cost-effective and highly integrated LF driver solution is not viable compared to a discrete solution

For advanced localization, these issues are difficult to overcome so that driving only one coil at a time may be a good compromise.

Future LF Antenna Driver Trends

Driven by the need to achieve cost savings—in particular for passive start systems—car makers are expecting the LF driver to also perform the immobilizer backup function. This requires the immobilizer and the LF driver function to be merged. Therefore, multiplexing one of the antennas and thus reducing one coil (a major cost contributor) is possible. This allows the immobilizer base station coil in the steering lock cylinder to be removed. The resulting car architecture change will lead to significant cost savings that will further increase PEPS adoption. Strategy Analytics is anticipating annual demand for PEPS systems of almost 19 million units by 2016 while also forecasting passive start systems to accelerate faster and reach 26 million units by 2016.

Car manufacturers also want to have LF drivers charging while driving wireless mobile devices.

This entails several technical innovations:

- Merging the immobilizer base station into the LF driver allows multiplexing one of the antennas.
- Multiplexing one of the LF antennas requires operation at a low coupling factor within a range of 1% to 2% and a highly sensitive LF base station receiver since the LF antenna is located up to several meters away from its base station.
- Enhanced and complex state machines that offer flexible immobilizer protocols and self-polling schemes, autonomous operation to lower the host controller resources for reduced power consumption. Programmability of an embedded microcontroller provides

higher flexibility but it is more expensive, slower and consumes more power than a state machine.

- Thanks to their low cost, passive entry passive start and/or passive start systems combined with RKE (keyless entry systems) are expected to grow faster than the PEPS market.
- Leading silicon vendors aim to reduce the number of drivers to three or four and to limit overheating in their devices. External drivers or multiplexing techniques could be proposed to address PEPS applications requiring six to nine antennas.
- On-going sensitivity improvement of the key-fob controller towards 200μ$V_{peak-peak}$ or lower also allows the drive current to be reduced, thereby limiting overheating in LF driver devices.
- As wireless power charging operates at the same (or almost the same) LF frequency, the implementation of a dominant wireless charging protocol into the LF driver allowing the use of the same PEPS LF antennas could enable significant cost saving while adding new features and enhancing value for automotive OEMs.
- The implementation of near field communication (NFC) interfaces that enable communication with mobile phone devices and computers will add new features such as payment services.

A silicon integration example is given in Figure 6. This figure shows an LF driver IC that includes a state-of-the-art immobilizer base station block. Thanks to its high sensitivity of 100μ$V_{peak-peak}$, the key fob controller enhanced with RF transmitter functionality allows for LF distances of up to 8m, thus enabling new applications/features such as approach lighting and/or automatic walk-away detection.

Conclusion

This article examined the key technical parameters of LF driver devices, and discussed how these can be defined for the Atmel ATA5279C LF driver, a widely used device for automotive car access applications. The article also explained how LF drivers will evolve to become a key PEPS device in response to the ever-present need for integration and cost reduction while enabling new applications such as wireless power charging for mobile devices or connectivity through NFC with NFC-enabled devices, etc. Forthcoming developments will encompass both LF drivers together with the key fob functionality at an optimized level of integration.

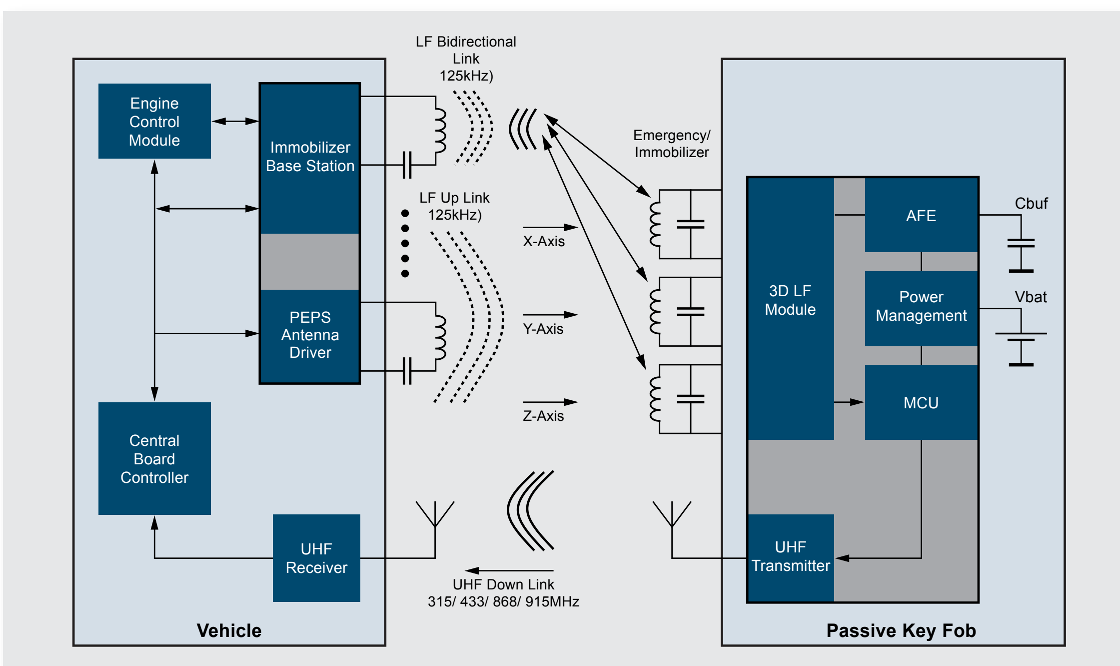

Figure 6. Advanced PEPS System Architecture

Atmel Corporation 1600 Technology Drive, San Jose, CA 95110 USA **T:** (+1)(408) 441-0311 **F:** (+1)(408) 487-2600 | **www.atmel.com**