Turn-Key Passive Entry/ Passive Start Solution

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Atmel® provides a passive entry/ passive start (PEPS) system with a complete set of basic building blocks, including hardware and software. This system allows designers to get more familiar with PEPS systems and Atmel's PEPS solution. The basic building blocks are a great help for engineers without experience in PEPS systems to shorten their development time, and time-to-market. The system demonstrates the principles of wake-up and ID screening, command and data, security authentication, and basic localization. It addresses application-related issues such as calibration at end-of-line, post-processing of RSSI (received signal strength indication), accuracy of the localization, and multiple key fobs. You can easily enhance this system for your own prototype development.

This article describes the complete Atmel PEPS system including the orientation-independent LF (low frequency) wake-up functionality. The system also provides key localization and one- or two-way RF communication. It includes immobilizer LF communication according to the Atmel open immobilizer protocol, and keyless entry functions with Atmel's secure rolling-code protocol. All functions needed for uni- and bi-directional authentication, key fob localization and field supply are also implemented by software.

General System Description

Atmel's PEPS system enables hand-free interaction with the vehicle (figure 1). It allows the driver to lock/unlock the vehicle doors and to start/stop the vehicle engine without performing any manual action either with the key fob or a mechanical key. Although the key fob still includes the conventional RKE (remote keyless entry) buttons, PEPS will pave the way to a more natural and convenient way to enter and start the vehicle while maintaining a high level of safety and security.

System Functions

The PEPS system provides the following car access functions: immobilizer, remote keyless entry, passive entry (PE), passive start (PS) and passive lock (PL). In addition, it also includes the following system configuration functionalities: a learning procedure for pairing vehicle and key fob, RKE rolling code synchronization, and end-of-line parameters (RSSI compensation, etc.).

When the driver approaches the vehicle, a secure wireless communication between the key fob and the vehicle control unit authenticates the fob. Bi-directional wireless communication authenticates the key fob and the vehicle in both one-way and two-way systems. In one-way RF systems the LF downlink serves to wake up the key and to receive commands as well as data for the authentication process. The fob then sends the response to the vehicle via RF uplink. In two-way RF systems the LF downlink only serves to wake up the key fob and to establish the RF up-/downlink. The bi-directional RF link handles the entire communication during the authentication process.

Vehicle LF antennas detect the key fob location and determine if the key fob is inside or outside the vehicle cabin. The system is flexible. You can adapt the position and the number of antennas to any type of vehicle.

Passive Entry (PE)

The passive entry function allows the driver to unlock the vehicle's doors without activating the key fob. However, some user action is needed to trigger the system such as approaching the door, or touching or pulling on the door handle. When the vehicle detects such an activity, it starts to search for the key fob outside the vehicle cabin. This is called localization. Once the fob has been authenticated, the doors unlock automatically.

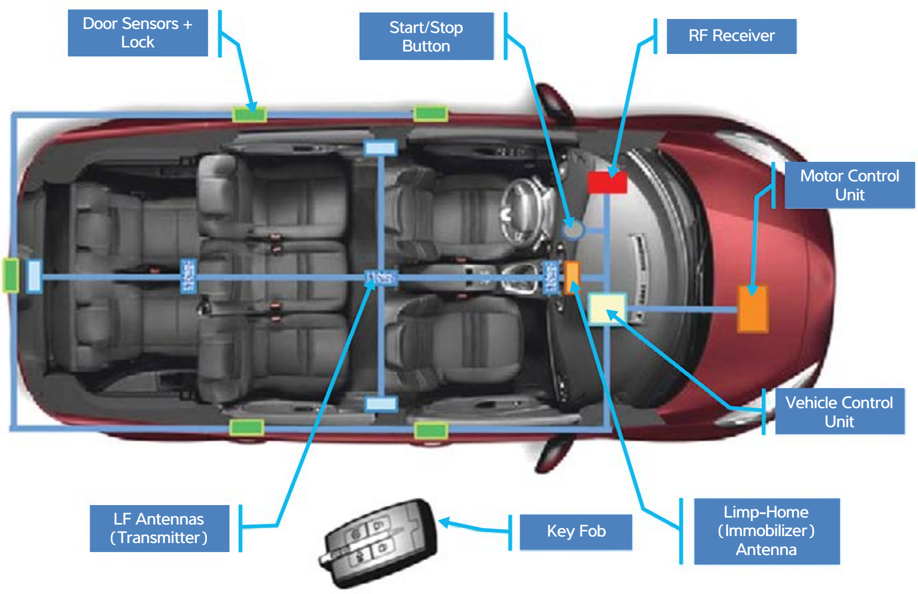

Figure 1. System Architecture

Passive Start/Stop (PS)

The passive start function allows the driver to start or stop the vehicle engine without activating the key fob. Replacing the lock cylinder, the start/stop engine button in the vehicle cabin activates the PS function. Once the driver pushes the start/stop button, the vehicle starts to localize the key fob inside the car.
The communication between vehicle and fob is almost identical to PE systems, except that PE systems search fobs outside the vehicle, whereas PS systems search for fobs within the vehicle cabin. If at least one paired key fob is localized inside the vehicle cabin, and has been successfully authenticated, the vehicle starts or stops the engine.

Passive Lock

The passive lock function allows the driver to lock the vehicle doors without activating the key fob. Prior to the introduction of PEPS systems, the driver locked the car doors by pressing a dedicated button on the key fob. With PEPS systems, a lock button or a sensor on the door handles eliminates the need for key fob manipulation. The driver only needs to push this button or touch the handle to lock or unlock the doors.

The vehicle system starts automatically to search the key fob outside and inside the car, and initiates key fob authentication. If at least one key fob is authenticated and localized outside the cabin and no paired key fob has been authenticated and localized inside the cabin, the vehicle locks its doors. Instead of keeping the doors unlocked if keys have been detected inside the cabin, it is also possible to blacklist those keys and disable them for the next passive entry request.

RKE

In addition to the lock and unlock function, you can include supplemental remote functions in the key fobs even with the PEPS system. When doing so, take care to avoid unwanted interaction between PEPS and RKE. For example, if the driver wants to lock the doors via RKE, the vehicle needs to check for active keys inside the vehicle cabin. If a paired key fob is detected inside the cabin, it must be disabled for the next passive entry request.

Immobilizer

The immobilizer function is an emergency procedure in case the passive start does not work properly or the key fob's battery is empty. It uses the same basic procedure as passive start but via short-range LF-to-LF communication. The LF field generated by the vehicle's base station supplies the key fob with power via antenna coupling. This magnetic field serves as bi-directional communication channel. See http://www.atmel.com/devices/ATA5580.aspx for more information on Atmel's highly secure, ultra-low-power AES-128 transponder with this immobilizer function.

Key Fob Wake-Up

In a hand-free PEPS system the key never knows in advance when a communication sequence requires the PEPS controller to actively respond to a request. An MCU that is permanently active consumes a lot of power and thus reduces battery lifetime. The Atmel MCU remains in sleep mode until a wake-up occurs. The highly sensitive 3-axis LF amplifier has a very low-power listening mode that constantly checks for a valid LF signal. Once it has received a valid LF signal containing the correct vehicle-specific wake-up ID, it generates a signal to wake up the PEPS controller.

Key Fob Localization

Localization is an important feature of any passive entry/passive start system. It detects if the key is near the vehicle, and, depending if it is a PE or a PS system, if the key is inside or outside the vehicle. A car has typically four to six LF antennas. These produce an LF magnetic field covering both the car interior and the car's vicinity. The key fob measures the LF signal level during the communication with the vehicle. It acquires the RSSI and sends it back to the vehicle, which analyzes the RSSI to determine the fob's position. As the spatial orientation of the key fob is unknown, the key fob uses three discrete antenna coils or one 3D-coil to determine the x-, y- and z-axes. The RSSI measurement accuracy depends on the hardware device and on the precise calibration of all key fobs during end-of-line manufacturing. Atmel's car access devices contain several technical innovations to assist in this critical process. For example, they measure all three axes simultaneously which reduces the overall RSSI measurement time.

Vehicle-Cabin LF Coverage

When defining the antenna placement within the car, insure that the most common locations of a key fob (such as seats) are covered. You can omit very untypical places such as under the roof. In most cases it is sufficient to place three antennas centered inside the vehicle to cover both vehicle sides (figure 2). The location, orientation, and amount of antennas vary depending on the car's size. To obtain constant field strength that does not exceed the cabin borders, you can adjust the LF power of each antenna individually.

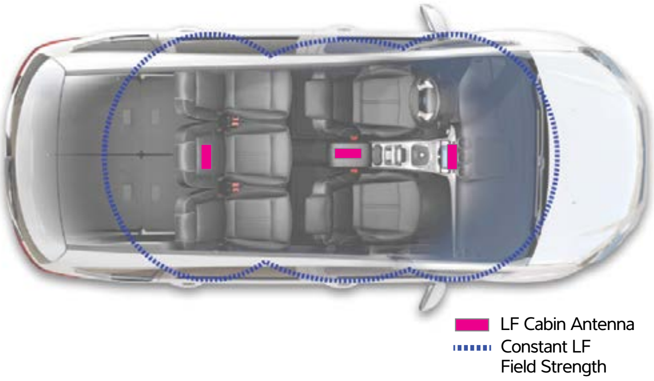

Figure 2. Inside Cabin Antennas

Vehicle-Outside LF Coverage

To design a passive entry function, you need to place the LF antennas close to the car's doors and trunk. A typical configuration is to place one LF antenna in each door and one in the trunk. With more powerful antennas having a higher driving current, only one antenna per side is required to cover both the front and rear door. In this case, place the antenna inside the "B" door pillar between the front and rear door (figure 3).

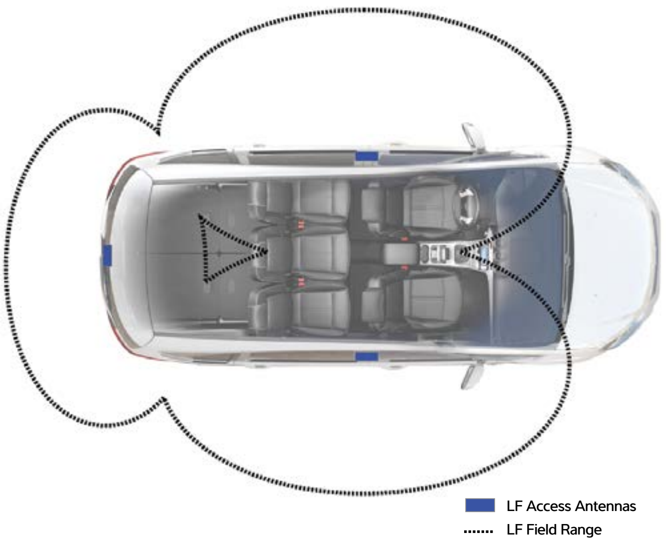

Figure 3. Outside Cabin Antennas

Trigger Sequence for Inside Localization

Passive start systems use only the cabin antennas for the inside localization process. The cabin antennas are activated one after another. The generated LF field covers the vehicle cabin as well as the perimeter close to the vehicle. The key fob measures the LF field RSSI of each vehicle cabin antenna trigger, and sends it to the vehicle. The vehicle gathers all RSSI values for further computation. They are either compared to an interior threshold or computed together to determine whether or not the fob is inside the vehicle cabin. The vehicle manufacturer must know the vehicle LF cartography to define the threshold value.

Trigger Sequence for Outside Localization

Passive entry, passive lock, and passive approach use an outside localization procedure.

Depending on the access strategy for PE systems, the chip activates one or more antennas (figure 4). There are several access strategies you can implement (see table 1).

Event	Access Level Selected	Access Antenna Used
User pulls door handle at drivers door (Antenna 1)	Vehicle looks for fobs on all access points	Antennas 1/2/3/4/5
	Vehicle looks for fobs on all access points except trunk	Antennas 1/2/4/5
	Vehicle looks for fobs on the same side as access point triggered	Antennas 1/2
	Vehicle looks for fobs on the access point triggered	Antenna 1

Table 1. Access Strategies

Protocol timing is one of the most critical parameters for PE systems. You should adjust the antenna trigger to get the fastest possible reply during passive entry. The antenna that covers the surround of the pulled door handle is activated first, since there is a much higher probability to locate a key fob next to the door triggering the passive entry process. The vehicle antenna activation sequence depends on the key fob location probability. For example, if the defined access level is "vehicle looks for fobs on all access points except trunk", Atmel

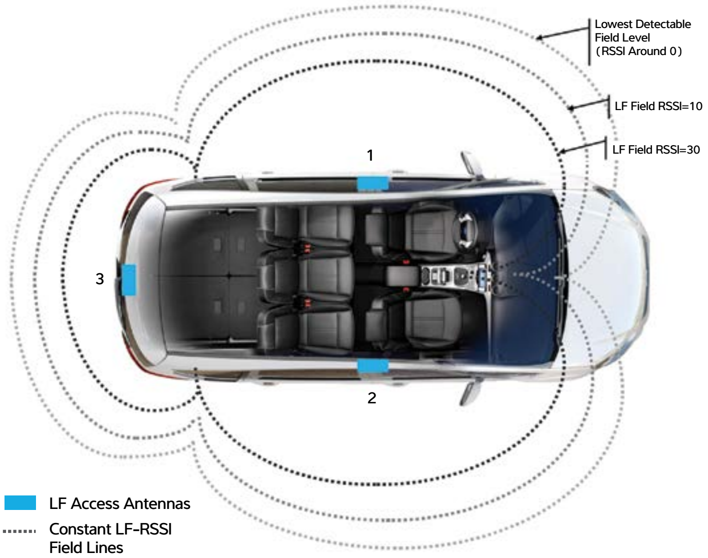

Figure 4. Thresholds for Outside Localization

pulling the driver handle initiates the antenna sequence 1 – 5 – 2 – 4 (driver door, passenger door, rear door left, and rear door right). If a fob successfully replies following antenna 1 activation, there is no need to check the other next antennas. Other functions such as passive lock, passive approach, or walk away do not require a specific trigger order sequence.

For each vehicle antenna trigger, the fob sends the measured LF-RSSI to the vehicle. Once enough RSSI values have been sent to the vehicle, the vehicle determines if the fob is located outside the vehicle cabin by:

- Checking if a fob has replied without checking a RSSI value as long as the fobs location is known from the previous action such as passive entry or walk-away.
- Comparing the RSSI value with an external threshold such as passive approach or walk-away. Different threshold values can be used to verify if the fob is located near or far from the vehicle. The vehicle manufacturer must know the vehicle LF cartography to define these threshold values.

At the end of this procedure there is a list of all fobs that have replied and that meet the outside localization criteria. However, the field generated by these antennas also covers part of the vehicle cabin. Fobs located within the car may send the same RSSI value as fobs located outside the vehicle. To address this issue, a good approach would be to create a list of all fobs found inside the vehicle before locking the vehicle and remove these fobs from consideration when performing the passive entry function.

Authentication

Protection against car theft or theft of property from vehicles is one point that requires special treatment in PEPS systems. Before a key fob can gain access to the vehicle or start the engine, the system requires a successful authentication between key fob and car.

The authentication process is based on Atmel's open-protocol AES 128-bit encryption. AES-128 is included as hardware module in the Atmel ATA5790N and ATA5791 PEPS controllers. During system configuration the vehicle and fobs exchange one or two 128-bit secret keys, depending on the authentication procedure. Both uni- and bidirectional authentication conform to the same challenge/response principals. In any case, it is always the vehicle that starts to communicate with a key fob.

Uni-Directional Authentication

In uni-directional systems, the vehicle authenticates the key fob. The vehicle generates a random number (Nonce) and transmits it via LF as challenge to the key fob. The fob encrypts the challenge and returns that via RF as response to the vehicle. The vehicle does the same and encrypts the Nonce. If the encrypted Nonce and the received response are identical, the key is authenticated and the door unlocks.

Bi-Directional Authentication

The bi-directional procedure offers increased security compared to uni-directional authentication. The fob authenticates the vehicle before replying, and in a second step, the vehicle authenticates the fob. Both steps use different secret keys.

The vehicle generates a Nonce, encrypts it using secret key 1 to get *Nonce*, and sends both via LF to the key fob along with a command to indicate that bidirectional authentication is used. The fob encrypts the Nonce with secret key 1 and compares it to *Nonce*. If both are identical the vehicle is authenticated to the key fob. Then, the key encrypts this first encryption result by using secret key 2, and sends it as response via RF to the vehicle. The vehicle performs the same procedure and compares its own result with the received response. If these are identical, the fob also is authenticated to the vehicle, and the doors unlock or the vehicle starts.

As this procedure requires additional data to be exchanged and two encryption steps, it takes slightly longer than the uni-directional authentication.

If the timing requirements for passive start are less critical than for passive entry, you might use bi-directional authentication for passive start systems, and uni-directional authentication for passive entry systems.

Communication Interfaces

A PEPS system communicates bidirectionally via three different communication channels:

- Bidirectional, short-range (4 to 5cm) LF communication
- Unidirectional, medium-range (about 2 to 3m) 3D-LF communication
- Long-range (10 to 30m) RF communication, both one- and two-way RF

Short-Range LF Communication

The short-range bidirectional LF communication serves for immobilization according to the AES-128 protocol and for system configuration. In learning or pairing mode, it transfers the authentication data(i.e. secret keys, or communication parameters) from the car to the key where the EEPROM stores this data. In both cases the circuit operates independently from the battery. The ATA5272 base station applies the magnetic field that supplies the circuit with power for bidirectional communication.

Medium-Range LF Communication

The medium-range LF interface within the key fob consumes extremely low power in listening mode. It permanently checks if a vehicle requests to wake up the key PEPS controller. This interface consists of 3 channels equipped with three separate orthogonal antenna coils or one 3D-coil in case of unknown spatial key orientation. Triggered by a user action such as touching the door handle, the ATA5279C LF driver in the vehicle sends LF commands to initiate the search for an associated key. If a key wakes up, it replies using the RF channel.

Long-Range RF Communication

Both RF configurations need an anti-collision method. Standards prescribe that a PEPS system must support up to eight key fobs (four with one-way RF) simultaneously. If more than one key replies at the same time, the receiver within the car can not decode the signal. The time domain method can avoid such collision. The engineers assigned time slots to each fob and also a fob index to each key during configuration. This way, the keys can determine in which time slot they need to respond, and no two fobs are allowed to emit at the same time. This is called anti-collision functionality. The Atmel anti-collision method is designed so that the first time slot is assigned to every key. In case there is only one key near the car, the vehicle receives the reply faster. If more than one fob is present, four to eight slots assigned to individual keys following the first common time slot. In addition, the vehicle can modify the sequence of fob replies by using the fob index.

One-Way RF

Atmel's ATA5791 single-chip PEPS controller with a fully-integrated fractional-N PLL (phase-lock loop), VCO (voltage-controller oscillator) and a 315/433MHz loop filter performs the one-way RF communication. In addition to the RF transmitter function, the IC contains the immobilizer circuit and the 3D LF receiver.

Two-Way RF

The 2-way-RF communication requires two ICs in the key fob: the ATA5790N PEPS controller without RF transmission function, and the ATA5831 RF transceiver. With one 24.305MHz crystal, the ATA5831 operates at 315MHz, 433MHz, 868MHz, and 915MHz frequencies.

Atmel Evaluation Kits

Car Access Reference System (CARS)

The car access reference system (CARS) demonstrates all functions of the aforementioned PEPS system. The body control computer emulation uses an ATmega2560 on a base board and application boards plugged on top.

The PC-GUI comes up with a start screen. It visualizes the individual design steps and enables you to modify parameters. The software allows easy modifications and adaptations to customer needs.

ATAK51003-V1: One-Way Multi-Channel Passive Entry

This kit is for second-generation PEPS systems and contains reference designs for the ATA5782 and ATA5791. It uses the AES-128 open immobilizer protocol (RF and LF). You can operate it via PC GUI or in standalone mode. For 3-channel operation, three frequencies are available (433.47MHz, 433.92MHz, 434.35MHz). Single-channel application is also supported with the ATA5774C.

ATAK51002-V2: Two-Way Multi-Channel Passive Entry

Similar to the one-way kit, this kit serves for second-generation PEPS systems and uses the Atmel AES-128 encryption. The included reference designs are based on ATA5831 and ATA5790N. It uses the AES-128 open immobilizer protocol (RF and LF). Designed for multi-channel operation, the RF frequency ranges 315 MHz to 956 MHz. Again, you can operation it via PC GUI or in standalone mode.

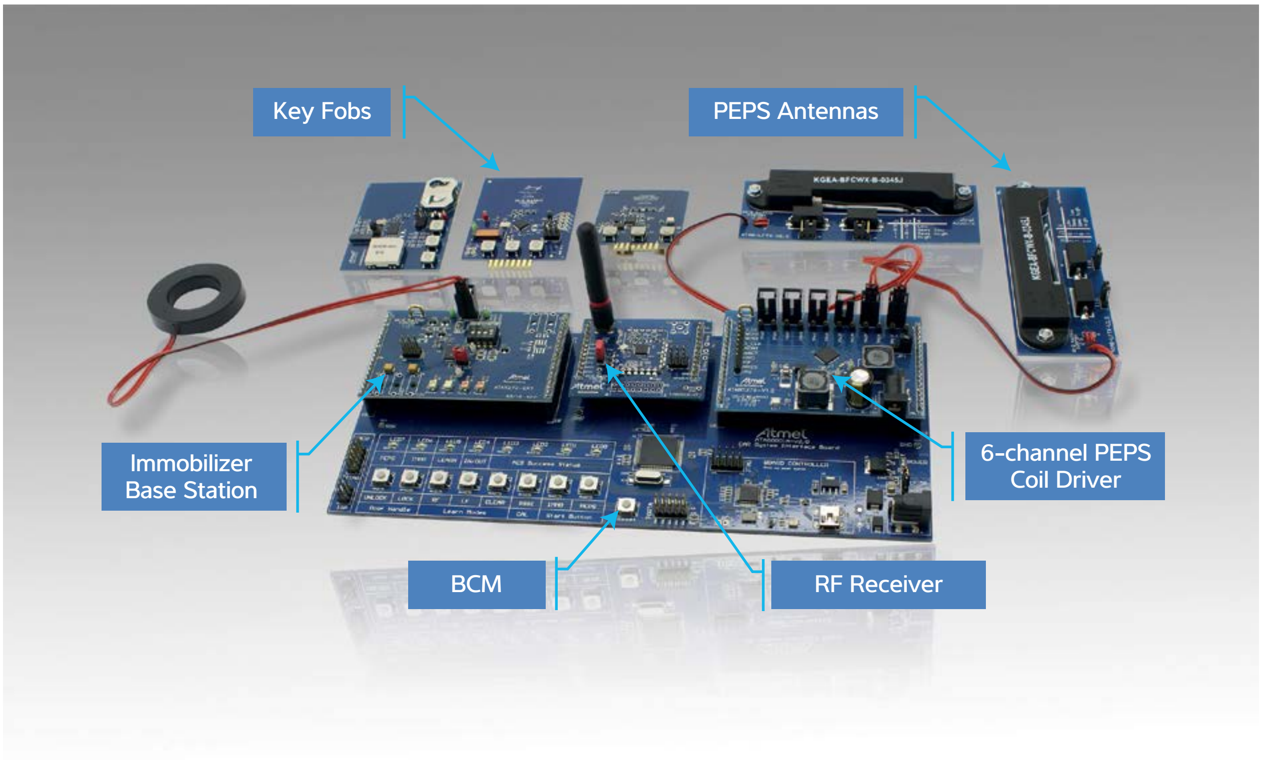

Figure 5. ATAK51003-V1 One-Way Multi-Channel Passive Entry Kit