

by Youbok Lee and James B. Nolan

Microchip Technology Inc.

ENSURING SMART PASSIVE KEYLESS ENTRY TRANSPONDER IS RELIABLE

The challenging task for a passive keyless entry system design engineer is reliably detecting the base station command in any possible operating condition while still maintaining all other design parameters, such as battery power usage and the physical size of the antenna. To achieve this goal, the transponder needs to have a high input sensitivity, ability to detect input signals with low modulation depth, multiple input channels to detect signals from different directions, ability to enable or disable input channels depending on input signal and application conditions, and programmable wake-up filter to operate the transponder in a low-power mode until it receives valid input signals.

The passive keyless entry (PKE) transponder is a mainstream option for high-end vehicle models, and is becoming available in common vehicle models as well. The advantage of using the PKE transponder is that the user can access

his or her car by having the transponder on his or her person, which eliminates the need to press the transponder button. As the owner approaches his or her vehicle, the base station unit inside the vehicle communicates with the person's transponder

automatically, and unlocks the doors if the transponder is valid. As people begin to rely more on the PKE transponder, the reliability of the system is becoming an issue. The system will fail if the two units are not correctly communicating. Most of the failures are due to a weak input-signal level at the transponder. The challenging task for PKE system design engineers is detecting the base station command reliably in any possible operating condition while still maintaining all other design parameters, such as battery power usage and the physical size of the antenna. This article discusses the requirements for a reliable PKE transponder using a new smart transponder device.

SYSTEM REQUIREMENTS

The PKE system consists of the base station and transponder units. Figure 1 shows an example of a PKE system. The base station unit transmits commands using 125 kHz, whereupon the PKE transponder receives the

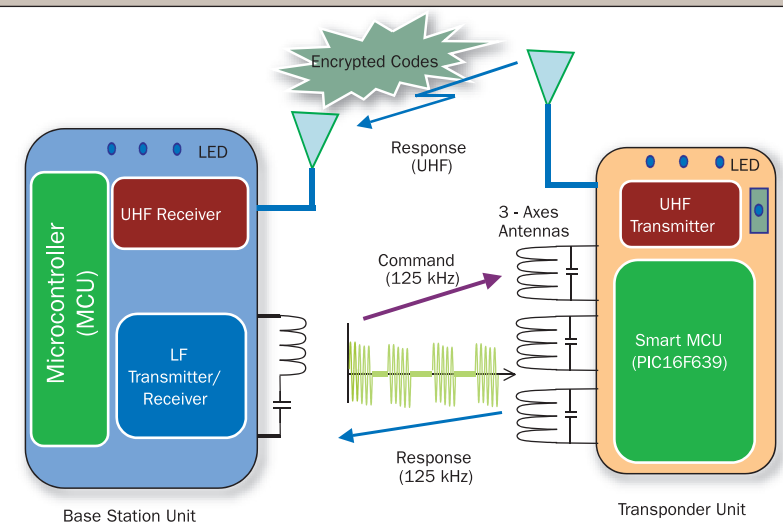


Figure 1. Example of passive keyless entry system.

REQUIREMENTS

Small size and low cost

Inexpensive bidirectional communication

Bidirectional communication distance: > 2 meters

Work in all ranges within maximum range

Minimum antenna directionality

Long battery life time

SOLUTIONS

A microcontroller (MCU) that has digital and analog front-end circuits in a single package.

Use 125 kHz for the base station command and UHF for response.

High input sensitivity of the transponder to detect the weak signal: ~ 3 mVpp

High input modulation depth sensitivity: 12%

Use three orthogonally placed LF antennas on the transponder board.

Keep the digital section in inactive mode while the analog section is detecting input signals. The digital section wakes up only when the analog section detects a valid base station command.

Table 1. Requirements for a passive keyless entry transponder.

command and sends responses via an external UHF transmitter for a long range, or uses internal talk back over the same 125 kHz for a short-range application. Table 1 summarizes the PKE requirements and its solutions. The transponder may have pushbuttons for optional or back-up operations, but the main operation is accomplished without human interface.

INPUT SENSITIVITY REQUIREMENT

The PKE transponder uses dual frequencies for bidirectional communications: 125 kHz for the base station command and UHF (315/434 MHz) for responses. In low-power transponder applications, the maximum achievable communication distance by using UHF (315/434 MHz) is about 100 meters, but only a few meters by using low-frequency (LF, 125 kHz). Therefore, the communication range of the dual-frequency PKE transponder is limited by the range of the 125 kHz base station command. The reason for using the 125 kHz in the transponder side is to make the transponder chip inexpensive. Implementing the 125 kHz receiving circuit in the transponder

age variations over a distance.

In practical applications, the transponder needs an input sensitivity of about 3 mVpp to detect the low-frequency signals at about two meters away from the base station unit.

Assuming that the smart MCU can detect an input signal greater than 3 mVpp, the next step is designing external antennas to pick up the voltages for the MCU. For the 125 kHz signal, the antenna can be made of an LC parallel resonant circuit. The LC resonant circuit at the transponder develops voltage when the magnetic field transmitted from the base station antenna passes through the transponder coil antenna. The received coil voltage at a given distance is given by [4]:

$$V_{Coil} \approx 2\pi f_0 NSQB_0 \cos\alpha \quad (1)$$

where f_0 is the carrier frequency of the base station unit, N is the number of turns of the coil, S is the cross sectional area of the coil, Q is the quality factor of the LC circuit, B_0 is the magnetic flux density, and $\cos\alpha$ is the directional angle between the incoming magnetic field and the surface area of the receiving antenna coils.

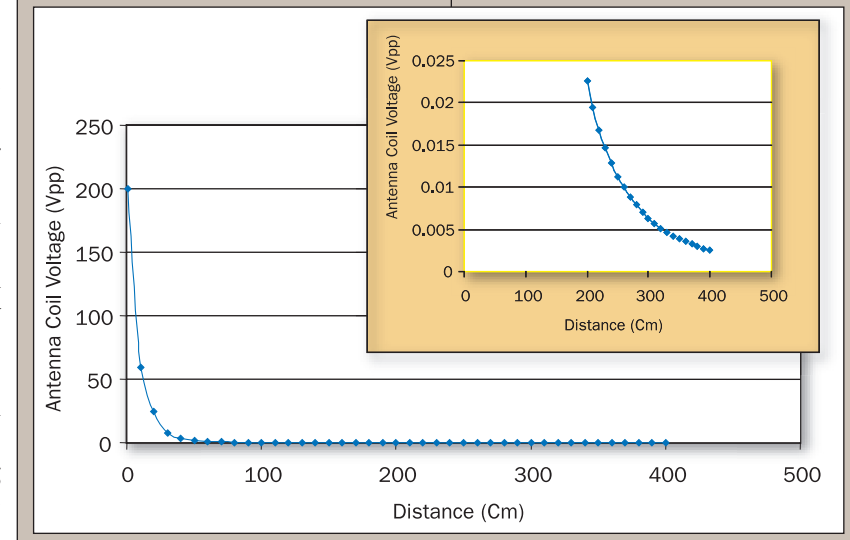


Figure 2. Induced antenna coil voltage over distance: The plot inside the box is a magnified portion at below 25 mVpp.

The antenna tuning frequency f_0 for the LC circuit is

$$f_0 = \frac{1}{2\pi\sqrt{LC}} \quad (2)$$

For the 125 kHz antenna, designers can choose L and C values in the range of a few mH for L and a few hundreds of pF for C. With physical constraints of the LC resonant circuit, the input receiving voltage of the transponder will be maximized when (a) the LC circuit is tuned to the carrier frequency of the base station command (125 kHz) and (b) the surface area of the antenna (inductor, L) is faced to the direction of the incoming magnetic field.

SOLUTIONS FOR ANTENNA DIRECTIONALITY PROBLEM

The low-frequency (125 kHz) communication is based on inductive coupling between two antennas. The highest mutual coupling between the base station and transponder antennas takes place when the two antennas are oriented face to face, and is the weakest when they are faced orthogonally. For hands-free PKE applications, the transponder can be placed in any direction inside a person's pocket. To increase the probability of having the best case for the mutual coupling, the transponder needs three antennas. Each antenna

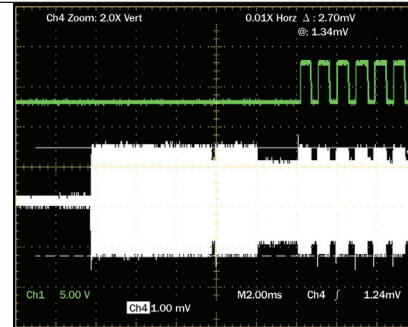


Figure 4. Input signal (Ch. 4) and demodulator output (Ch. 1) when the input meets the wake-up filter timing requirement: The MCU wakes up by the demodulated output and sends responses if the data is valid.

on the transponder is oriented to x, y and z directions. By using the three orthogonally placed antennas, the transponder can pick up the base station signal at any given direction. Figure 3 shows a graphical illustration of the antenna directionality problem. The receiving antenna voltage is maximized when the antenna surface area is placed vertically ($\alpha = 0$) with the direction of the magnetic field.

MINIMIZE POWER CONSUMPTION USING WAKE-UP FILTER

Unlike the remote keyless entry (RKE), the PKE transponder is constantly looking for incoming signals. Saving the operating power is one of the most important considerations. An integrated transponder MCU has digital and analog front-end (AFE)

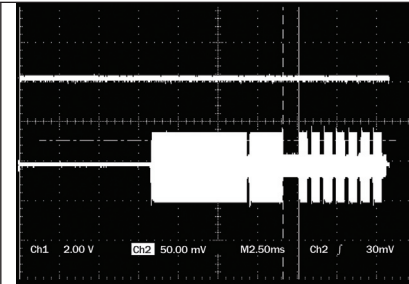


Figure 5. Input signal (Ch. 4) and demodulator output (Ch. 1) when the input does not meet the wake-up filter-timing requirement: No demodulator output is available. The MCU does not wake up and, therefore, stays in a low power mode.

sections. In order to manage power consumption, it is necessary to keep the digital section in a lower-power mode (or inactive mode) while the analog section is looking for a valid input signal. The digital section wakes up only when a valid base-station command is detected. This can be achieved by using a wake-up filter in the analog front-end section. The analog detection circuit is programmed to make its output available only when it detects an input signal with a predefined header.

Figures 4-6 show examples of the input signal waveform and the output of the analog front-end detector. Figure 4 shows the case when the input signal has the same header that is preprogrammed in the analog front-end circuit of a PIC16F639 MCU. The analog front-end circuit outputs the demodulated data. The digital section wakes up by the first rising edge of the output and decodes the detected data. If the data is valid, the transponder sends responses back to the base station by an external UHF transmitter or internal LF talk back modulator.

Figure 5 shows a case when the input signal does not meet the pre-programmed header requirement. In this example, the circuit does not output demodulated data. Therefore, the digital section can remain in the inactive state. The transponder con-

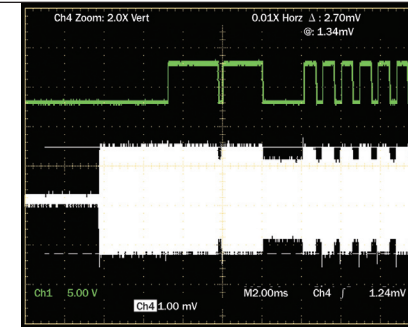


Figure 6. Input signal (Ch. 4) and demodulator output (Ch. 1) when the filter is disabled: The demodulator output is available immediately after AGC settling time.

siders this input as unwanted and ignores it, while remaining in low-power mode. Figure 6 shows the case when the wake-up filter in the analog front-end circuit is disabled. Here, the demodulated output is available as soon as the circuit detects signals. The digital section is designed to wake up in response to any input signals that are detected by the analog front-end circuit. In this scenario, the transponder is drawing unnecessary operating power because the digital section of the MCU is constantly awakened by invalid input signals. Therefore, Figure 6 is not a recommended case for vehicle-access PKE transponder applications.

In the PIC16F639 MCU example, the wake-up filter of the PKE transponder can be programmed by pulse widths and total period of the two first pulses. Various settings of the wake-up filter can be made by selecting different timing of the pulse widths.

In PKE applications, the vehicle has a microtouch switch at the door handle. This switch, once touched, turns the base-station unit on. The transponder in the vehicle owner's pocket then responds to the base station command, and the base station unit unlocks the door if the response is valid. The total time requirement for the bidirectional communication is about 100 milliseconds. Therefore, the door is unlocked without any

noticed delay time. Since the base station unit is not transmitting any command signals, unless the door handle is touched, any other PKE transponders that might have the same wake-up filter for the base station unit will not wake up by just

passing near the car. Using an identification number of the transponder for the wake-filter is also available. In this case, the system designer must consider the total bidirectional communication time. A shorter time for the wake-up filter is desired for a short

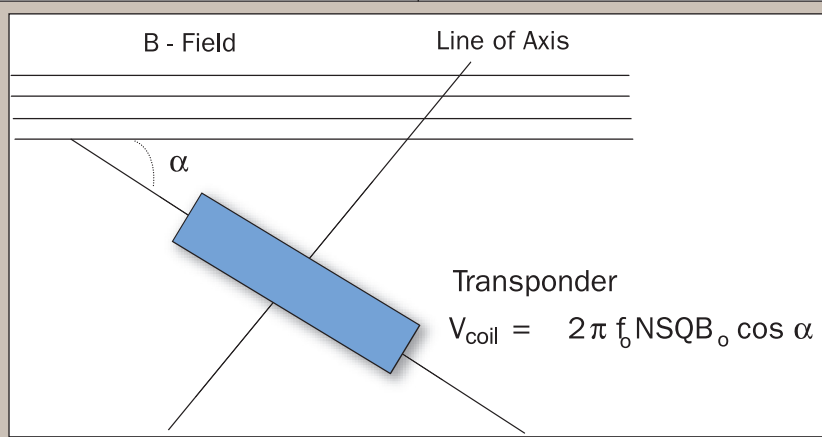


Figure 3. Illustration of transponder antenna directionality problem.

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bidirectional communication time.

The current draw of the analog-front-end circuit varies depending on how many channels are enabled or being active. The transponder consumes more currents if more input channels are enabled or active.

CONCLUSION

The key element of the hands-free vehicle access PKE transponder is reliably detecting input signals with the least amount of operating power. To achieve this goal, the transponder needs to have a high input

sensitivity, ability to detect input signals with low modulation depth, multiple input channels to detect signals from different directions, ability to enable or disable input channels depending on input signal and application conditions, and programmable wake-up filter to operate the transponder in a low-power mode until it receives valid input signals. These feature sets need to be controlled dynamically by the MCU firmware. A low-cost smart microcontroller that is able to support these intelligence functions is needed to foster rapid customer acceptance in passive vehicle-access-control applications. ■

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ABOUT THE AUTHOR

Youbok Lee is a technical staff engineer for Microchip Technology Inc.'s Security, Microcontroller and Technology Development Division. Lee holds a BS from the Yeungnam University in Korea, an MS from the University of Pennsylvania in Philadelphia, PA, and a Ph.D. from the Marquette University in Milwaukee, WI.

James B. Nolan is a senior technical staff engineer for Analog and Interface Products Division at Microchip Technology Inc. Nolan holds a BS from the University of Nebraska, and a MS from the University of Texas in Austin, Texas.

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