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Using the PIC16F639 MCU for Smart Wireless Applications

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INTRODUCTION

The PIC16F639 is a suitable microcontroller for bi-directional communications and low-frequency sensing applications. The device includes a PIC16F636 microcontroller and a three channel Low-Frequency (LF) front-end device in a single 20-pin SSOP package. These two devices are internally connected via SPI™ interface pads.

The analog front-end section is optimized to detect 125 kHz low frequency (LF) signal. For the LF signal detection, it needs external LC resonant circuits. The device can detect amplitude-modulated 125 kHz input signals with a typical input sensitivity of 3 mV_{PP}. This high input sensitivity allows for extended low-frequency detection ranges in applications.

The device can transmit data by an internal LF talk-back modulator for a proximity range communication or via an external UHF resonator for a long range communication. The device can transmit and receive secured data based on the built-in KEELOQ® cryptographic hardware peripheral.

A bidirectional communication range of approximately 2 meters can be achieved with an appropriate base station unit.

The device has three low-frequency input channels. Each channel has its own external antenna connection pins. Therefore, three orthogonally positioned antennas can be connected to the device to detect the input signals from x, y and z directions. This will greatly reduce the antenna orientation problems in wireless transponder applications.

Each low-frequency input channel has programmable tuning capacitances up to 63 pF (1 pF per step) for a fine tuning of the external LC antenna circuit.

The functions of the analog front-end section are controlled by the internal configuration registers. The MCU can dynamically reprogram the internal configuration registers based on real-time signal conditions.

The low-frequency, front-end section can output demodulated data, carrier clock or a received signal strength indicator (RSSI current) by controlling the output selection bit of the internal configuration registers.

The analog front-end section also has a dynamically reconfigurable output enable filter that can allow the MCU to wake-up to the wanted input signal only, but ignore all other unwanted signals.

For a low-power battery operation, the device is optimized to consume very low currents during Sleep, Standby, and Active modes. The device can also be operated in battery back-up and batteryless modes using external circuits.

The device is available in a 20-pin SSOP package. Refer to the PIC12F635/PIC16F636 data sheet [1] for more details.

THEORY OF DEVICE OPERATION

The PIC16F639 device is a dual-die packaged device. The microcontroller (PIC16F636) and analog front-end device (MCP2030) are bonded together in a single SSOP package for smart-sensing and bidirectional communication applications. These two devices (sections) communicate via internally connected SPI interface pads.

The device has twelve digital I/O and four analog I/O pins. The digital I/O pins are used the same as the PIC16F636 device. The four analog I/O pins (LCX, LCY, LCZ, LCCOM) are used to detect low-frequency input signals and to transmit data by modulating the input voltage. External LC resonant circuits are connected to the analog I/O pins. The device's analog channels are optimized for 125 kHz input signal with an input sensitivity of about 3 mV_{PP}.

Internal Configuration Registers

The analog front-end section has eight configuration registers. Six of them are used for setting up the device operation; one is for column parity bits and the last one is for device Status indicator bits. Each register has 9 bits, including one row parity bit. The registers are readable and writable except the Status register, which is read-only. The registers are accessible any time during applications via SPI interface commands. The three SPI interface pins (SDIO, $\overline{CS}$, SCLK) are internally bonded with the I/O pins of the digital section.

Low-Frequency (LF) Input Channel

The device detects LF input signals individually using x, y and z channels. The outputs of the individual channels are added for the final detector output. The individual input channels can be enabled or disabled, depending on applications, or to save operating battery power.

External LC Resonant Circuits and Internal Tuning Capacitors

The device needs external LC resonant circuits to receive low-frequency input signals or to transmit data using LF talk-back modulators. Each input channel needs its own external LC resonant circuit. The input voltage that is picked-up by the external LC resonant antenna circuit is maximized when the LC circuit is tuned precisely to the carrier frequency of the incoming signal (carrier frequency of the base station).

The received antenna voltage is approximately given by the following equation [2]:

EQUATION 1:

$$V_{coil} = 2\pi f N S Q B_o \cos\alpha$$

where:

- f = frequency of the arrival signal
- N = number of turns of coil in the loop
- S = area of the loop in square meters (m^2)
- Q = quality factor of the LC circuit
- B_o = magnetic field strength
- α = angle of arrival of the signal

In the above equation, the quality factor Q is a measure of the selectivity of the frequency of the interest that is tuned by the external LC circuit. The Q is defined by:

EQUATION 2:

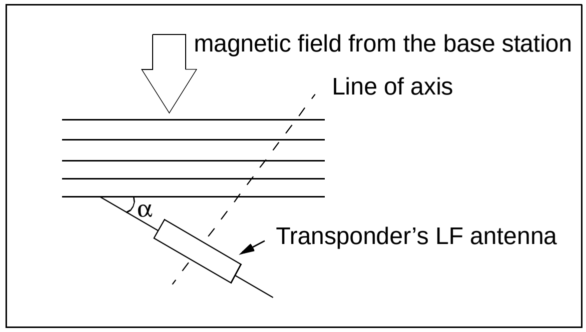
$$Q = \frac{f_o}{B}$$

where f_o is the LC tuning frequency, and B is the 3dB bandwidth of the resonant circuit. The resonant frequency (f_o) of the LC circuit is given by:

EQUATION 3:

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

FIGURE 1: ORIENTATION DEPENDENCY OF ANTENNA VOLTAGE



With a given antenna's physical condition, the induced antenna voltage is a function of the angle of the arrival signal with respect to the LF antenna. The antenna voltage is maximized when the coil antenna is placed in parallel with the incoming signal where $\alpha = 0$, and minimized where $\alpha = 90$ degrees as shown in Equation 1 and Figure 1.

For a reliable operation of the hands-free, passive keyless entry applications, it is recommended to use three orthogonally placed antennas to detect the base station's LF commands from x, y and z directions.

In order to compensate the detuning effects due to the external LC component tolerance or environmental changes, the device has internal tuning capacitors. The internal tuning capacitors are programmed up to 63 pF (1 pF resolution) per channel. The internal tuning capacitor values are programmed by the Configuration register.

Input Signal Dynamic Range

The device can detect LF input signals from 3 mVPP to about 700 VPP of unloaded coil voltage. The device's LF front-end circuit regulates the input coil voltage below about 11 VPP to protect the internal circuits from high input voltage.

Output Enable Filter

The digital section can stay in the Sleep mode for a battery saving purpose or can perform different tasks until an output is available from the analog section. For this purpose, the device has a programmable output enable filter. If the input signal meets the filter requirement, it enables the detected output, otherwise it disables the output. The filter timing criteria consists of high and low pulse durations of the input data header, which are programmed in the configuration register. Figure 2 shows an example of when the output enable filter is enabled and the input meets the filter requirement. The demodulated output is available after the output enable filter waveform. If the demodulator output pin (LFDATA pin) is connected to the interrupt-on-change pin (PORTA), the digital section will wake-up by the interrupt and decode the input data.

Figure 3 shows an example of when the input data does not meet the output enable filter requirement. No output is available at the demodulated data output pin. Therefore, the digital section is not waken-up by any unwanted input signal. If the output filter is disabled, the demodulated output is available immediately after the device's AGC settling time. Figure 4 shows an example of when the output enable filter is disabled.

FIGURE 2: INPUT SIGNAL AND DEMODULATOR OUTPUT WHEN THE OUTPUT ENABLE FILTER IS ENABLED AND INPUT MEETS THE FILTER TIMING REQUIREMENT

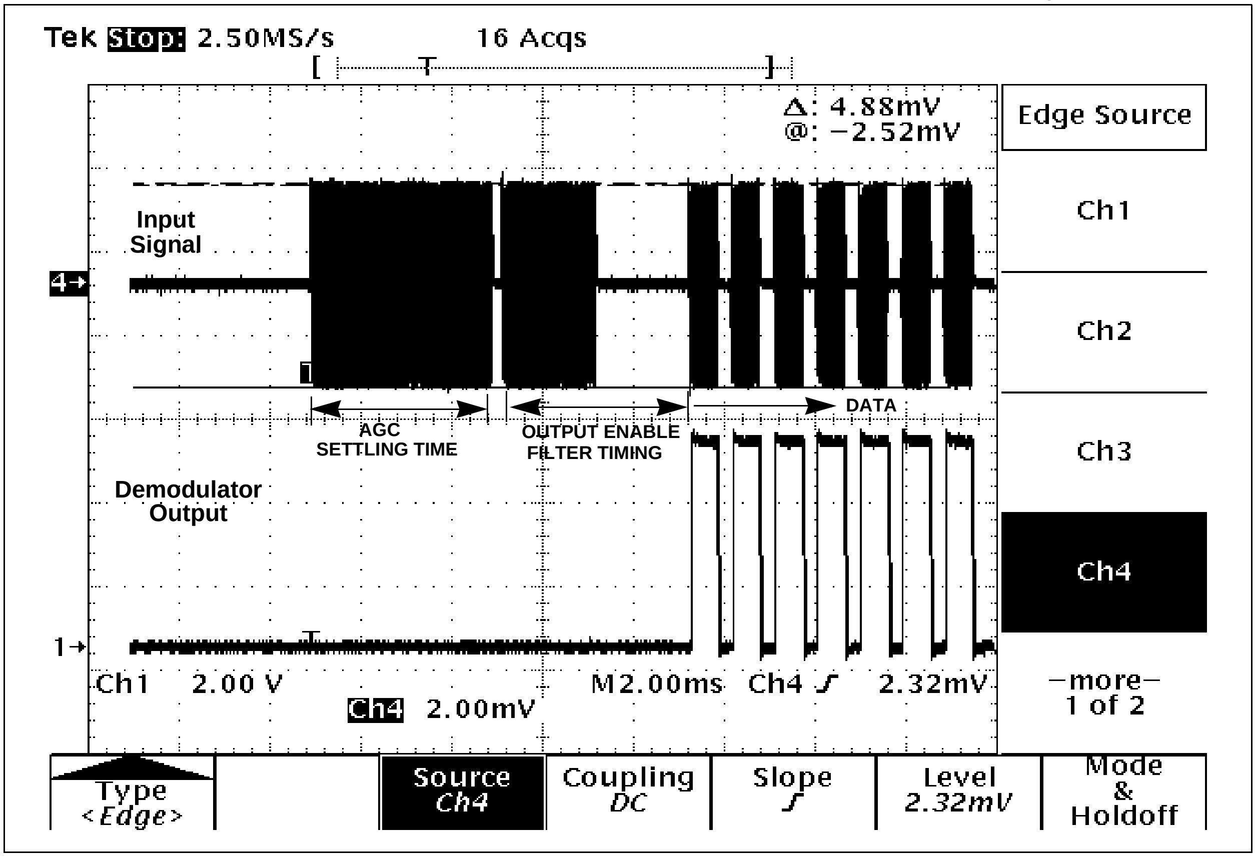


FIGURE 3: INPUT SIGNAL AND DEMODULATOR OUTPUT WHEN THE OUTPUT ENABLE FILTER IS ENABLED AND INPUT DOES NOT MEET THE FILTER TIMING REQUIREMENT

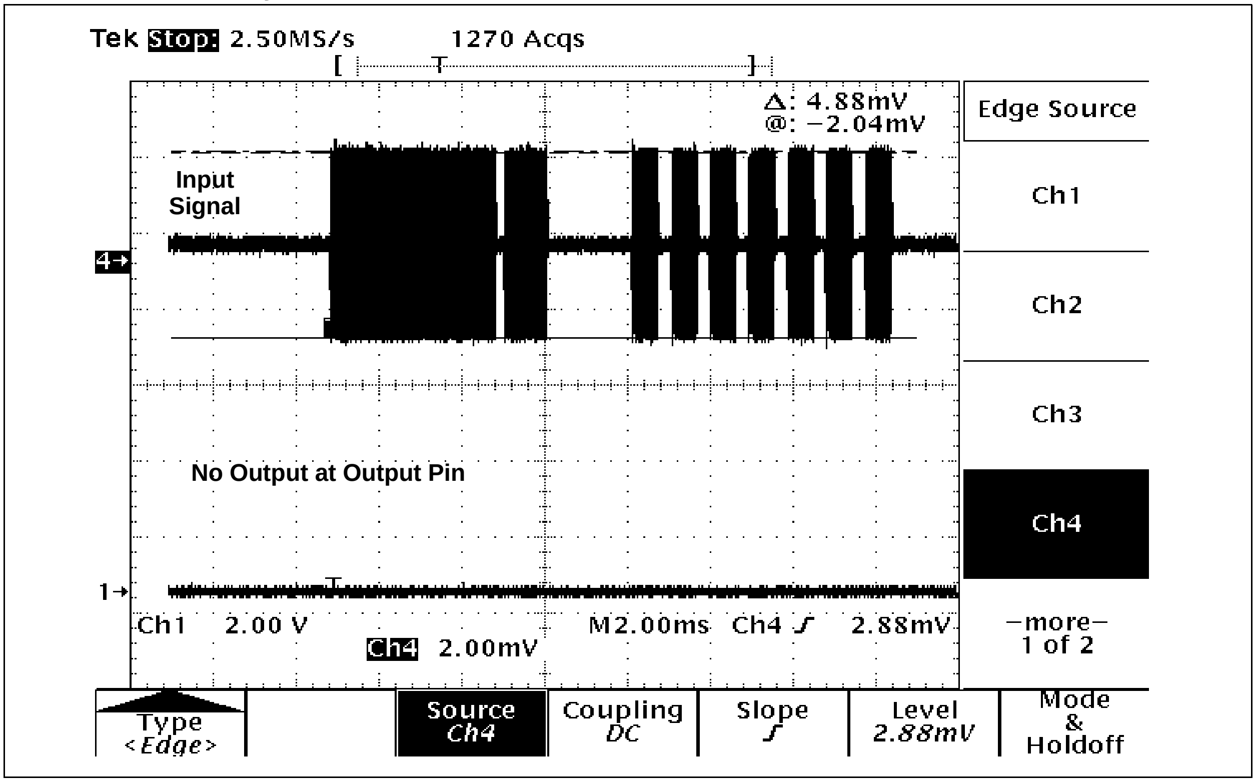
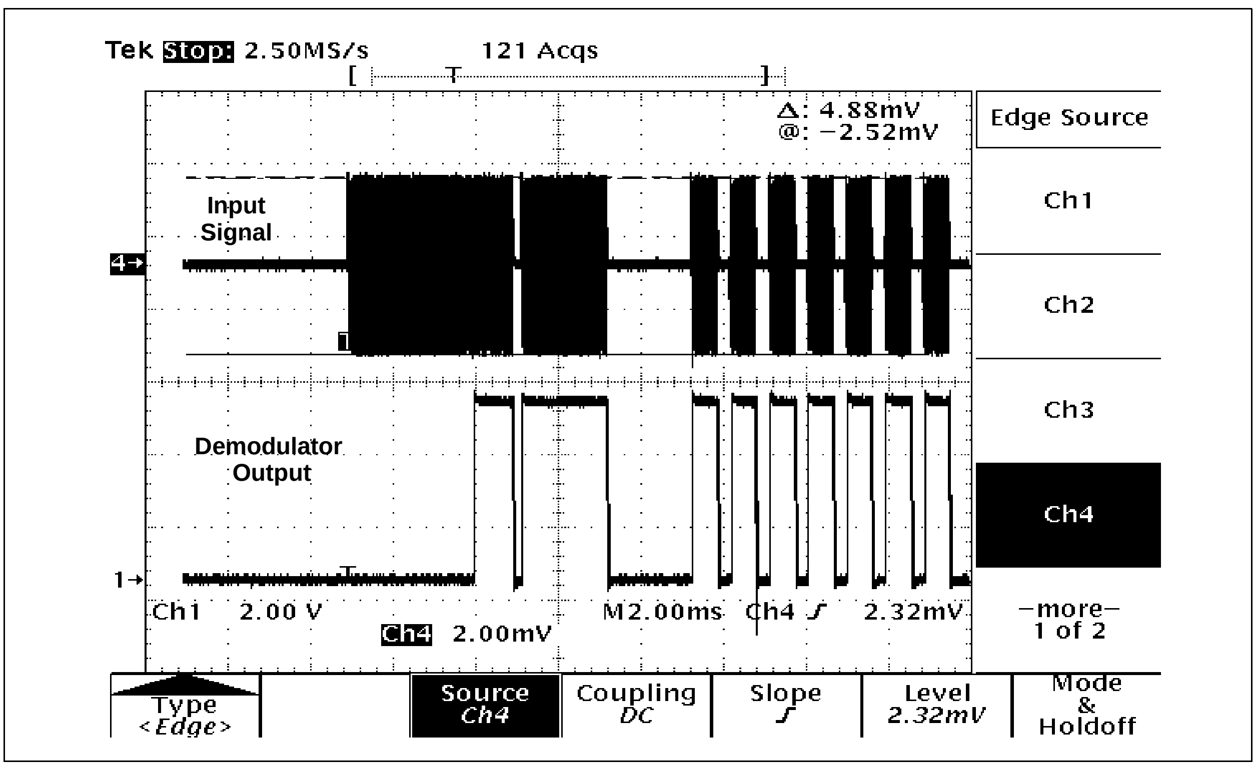


FIGURE 4: INPUT SIGNAL AND DEMODULATOR OUTPUT WHEN THE OUTPUT ENABLE FILTER IS DISABLED



Output Type Selection of LF Signal Detector

The analog front-end section can output demodulated digital data, carrier clocks or received signal strength indicator (RSSI) current that is proportional to the input signal voltage. The selection of the output type is controlled by the Configuration register.

Data Transmission from Device to Base Station

The device has an internal modulation transistor per each channel, which is placed across each LF antenna and LCCOM pins. Turning on and off the modulation transistors results in clamping and unclamping the coil voltage. This is called an LF talk back. Two SPI commands (Clamping-on and Clamping-off) are used for this purpose. The Clamping-on SPI command shorts the coil voltage and the Clamping-off SPI command releases the shorted coil voltage. The base station can monitor the changes in the transponder coil voltage and reconstruct the modulation data.The LF talk back is used for a proximity range only. The device uses an external UHF transmitter for long range communication.

Bidirectional Communications

A low cost bidirectional communication transponder can be designed by using dual frequencies:

a) Use 125 kHz for receiving the base station command.

b) Use UHF for transmitting data from the transponder to the base station.

Since the device does not include the UHF transmitter internally, an external UHF transmitter is needed. The modulation data is generated by the device and fed into the external UHF transmitter. The modulated UHF signal is transmitted to the base station via a small loop antenna that is formed on the transponder Print Circuit Board (PCB). The typical range of the UHF response is up to 100 meters for unlicensed low-power applications.

Figure 5 shows an example of the passive keyless entry (PKE) system using the bidirectional communications.The PKE communication sequences are as follows:

a) The base station transmits commands using 125 kHz.

b) The device receives the base station command via external 125 kHz LC resonant antennas.

c) The transponder transmits responses (data) via an external UHF transmitter if the command is valid.

d) The base station receives the responses and activates switches if the data is correct.

The communication distance of the dual frequency PKE is limited by the range of the 125 kHz base station command. This is due to the fast fall-off nature of the 125 kHz signal. The transponder's LC resonant antenna can be made to pick up (>3 mV_{PP}) a typical base station signal as far as 2 meters away from the base station unit.

APPLICATIONS

The PIC16F639 is a good fit for smart LF sensor or low-cost bidirectional communication transponder applications. The device can be used for various applications, particularly in the automotive and security industries.

Automotive Industry

- Passive Keyless Entry (PKE) system
- Remote door locks and gate openers
- Engine immobilizer
- LF initiator sensor for tire pressure monitoring systems

Security Industry

- Long range access control
- Parking lot entry
- Hands-free apartment door access
- Asset control and management

Application Examples

Figure 5 shows an example of the Passive Keyless Entry (PKE) system. The base station transmits 125 kHz command. If the command is detected, the PKE transponder responds via an external UHF transmitter or by using internal LF talk back modulators. The three LF antennas are used to pick-up the base station commands from x, y and z directions.

Figure 6 shows an example of the Passive Keyless Entry (PKE) transponder configuration using the device. An air-core coil antenna is connected to the LCX input pin, while the ferrite-core antennas are connected to the LCY and LCZ input pins.

Figure 7 shows an example of the passive keyless entry (PKE) transponder for multi-purpose applications. One transponder can be used for various access control applications.

Figure 8 shows an example when the device is used for tire pressure monitoring sensor applications. The device detects the LF commands from the LF initiator and transmits the tire pressure data to the base station via an external UHF transmitter.

FIGURE 5: BIDIRECTIONAL PASSIVE KEYLESS ENTRY (PKE) SYSTEM

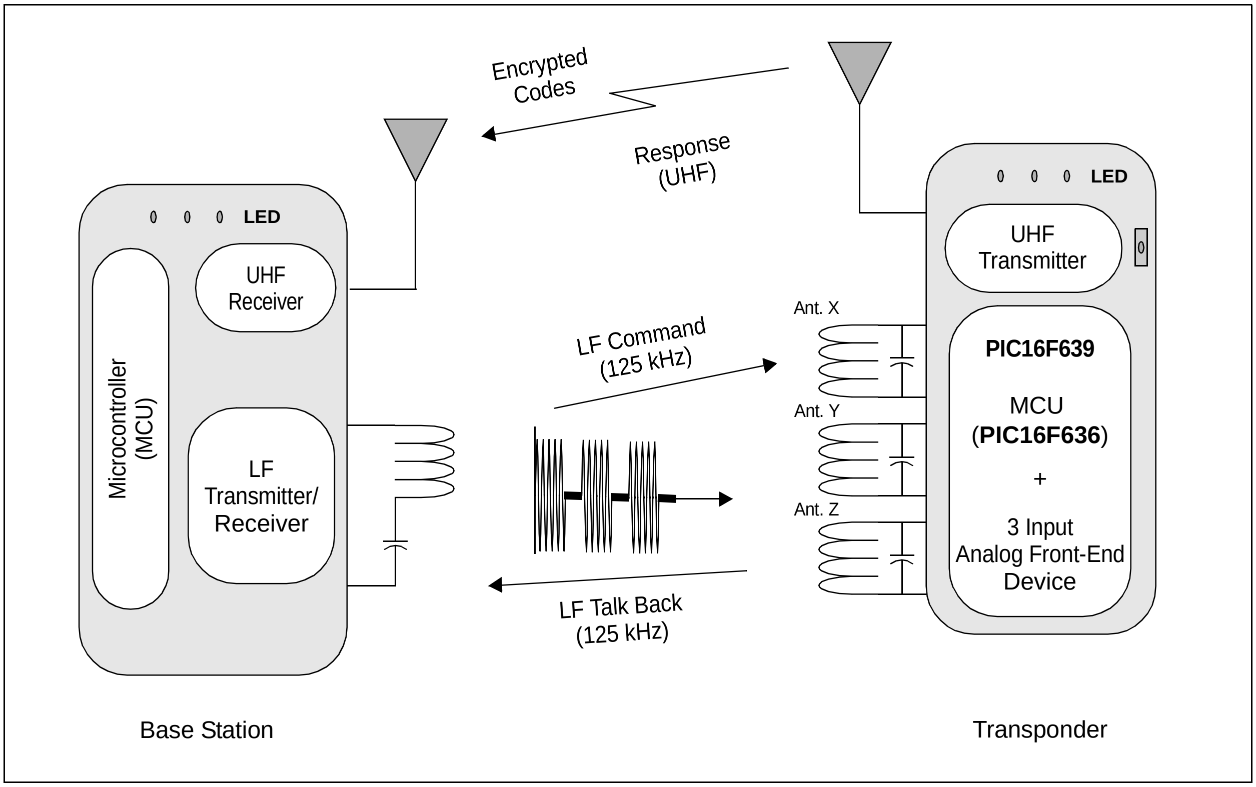


FIGURE 6: PASSIVE KEYLESS ENTRY (PKE) TRANSPONDER CONFIGURATION

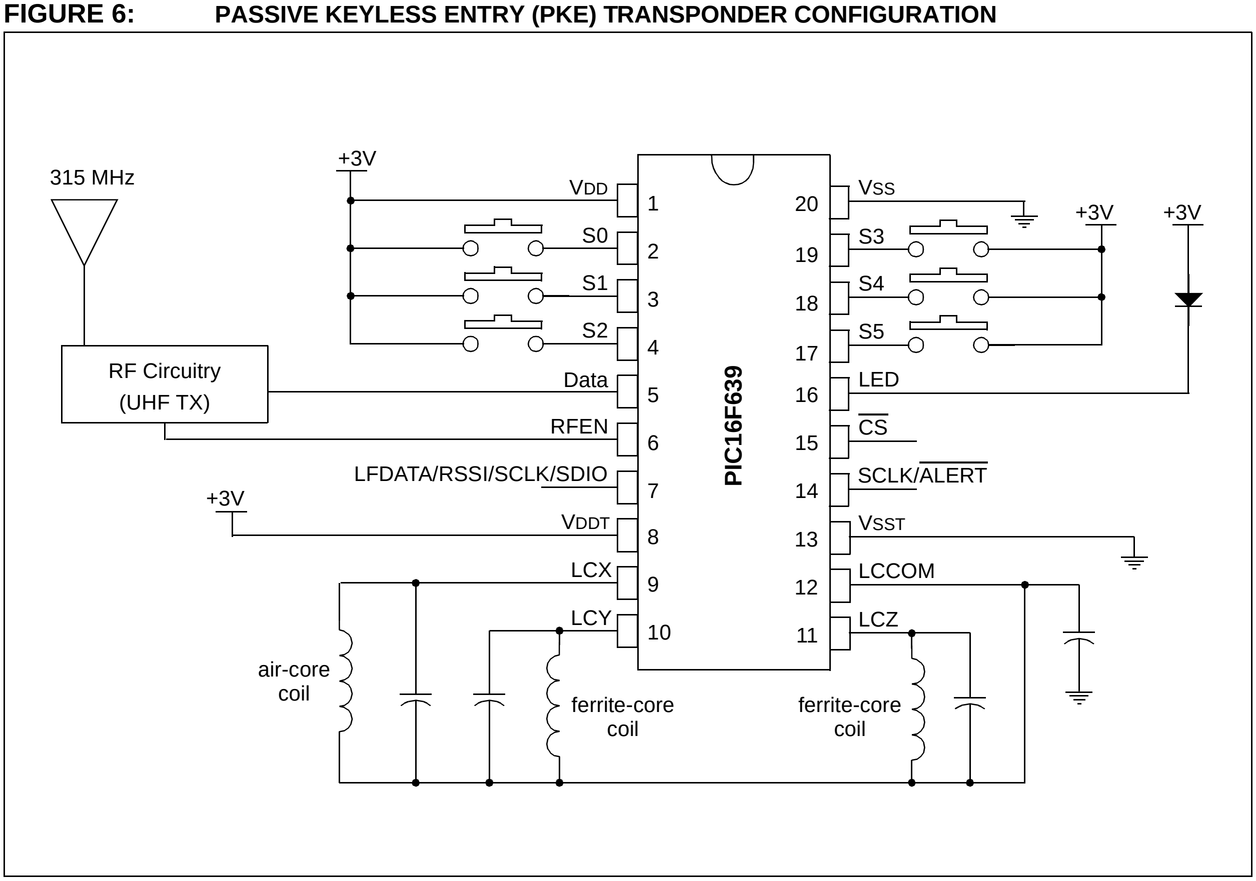


FIGURE 7: PASSIVE KEYLESS ENTRY (PKE) TRANSPONDER FOR MULTI-PURPOSE APPLICATIONS

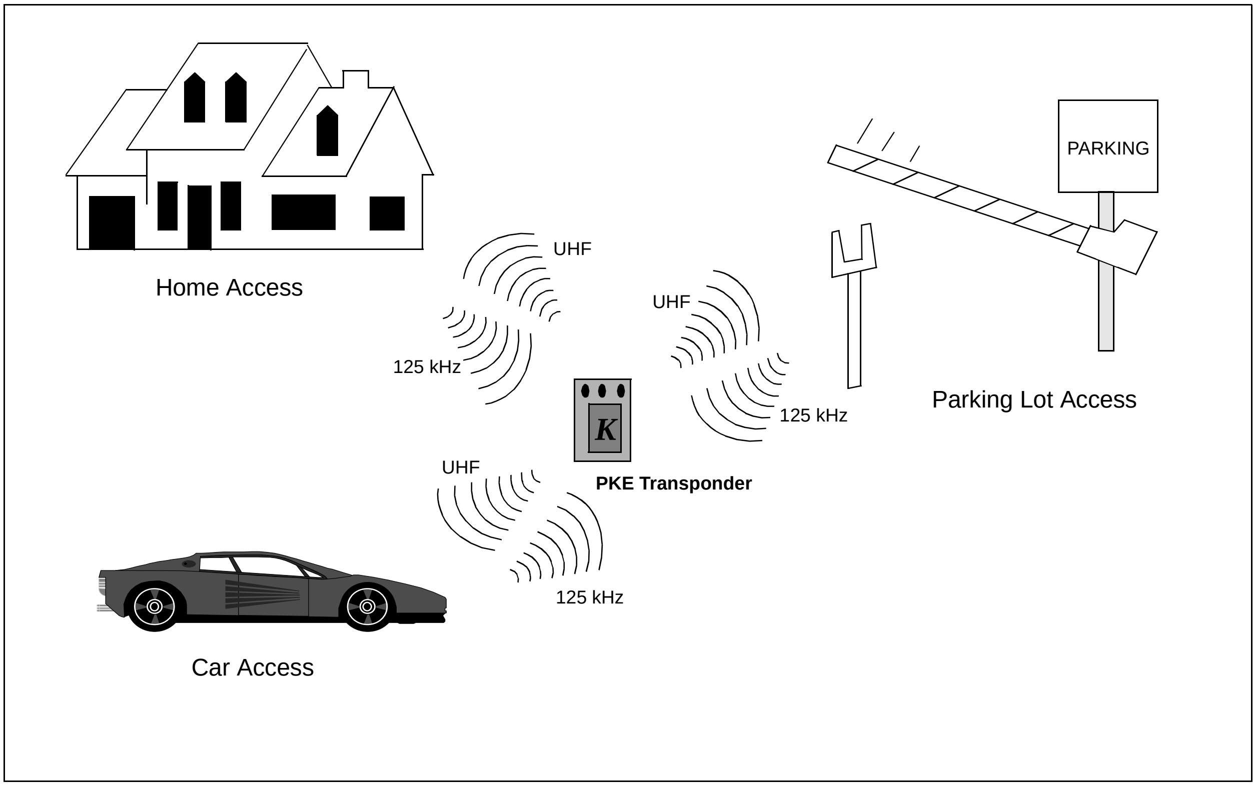
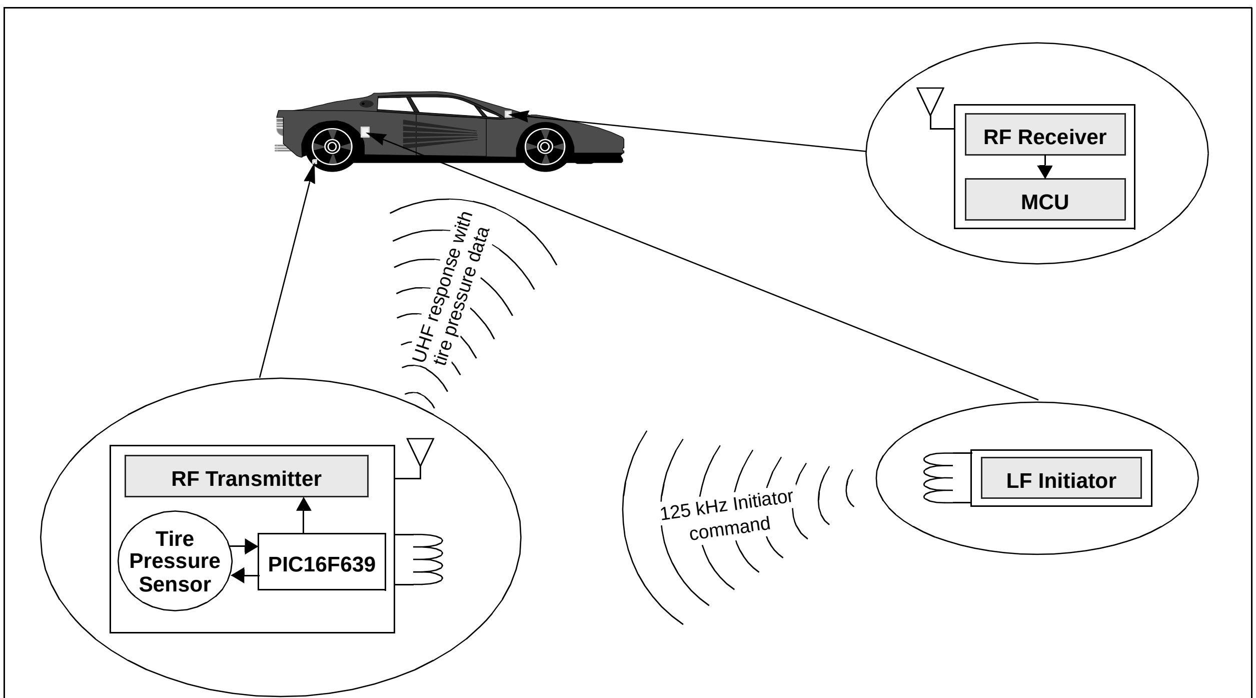


FIGURE 8: TIRE PRESSURE MONITORING SENSOR APPLICATIONS



Note 1: The LF initiator sends LF commands for the tire pressure data.

2: The PIC16F639 picks up the LF commands and transmits the tire pressure data via an external UHF transmitter.

CONCLUSION

The PIC16F639 is an MCU-based, low-frequency detector and transmitter. The device can be used for various intelligent bidirectional communication transponders. By using the device with an external UHF transponder, a low cost Passive Keyless Entry (PKE) transponder can be designed. For secure data communications, the device can transmit and receive encrypted data by using the built-in KEELOQ cryptographic hardware peripheral.

The device's high input sensitivity for low frequency (125 kHz) signal is also appropriate as a magnetic field sensor.

The device can also be operative in batteryless and battery back-up modes with appropriate external voltage charge-up circuits.

MCU Firmware Development Tools

Compatible with the PIC16F636 development tools:

- MPLAB® Integrated Development Environment (IDE)
- MPLAB® ICE 2000 In-Circuit Emulator
- MPLAB® PM3 Universal Device Programmer
- PICSTART® Plus Low-cost Development System
- MPLAB® ICD 2 In-Circuit Debugger
- PICkit™ 1 Flash Starter Kit

REFERENCE

[1] PIC12F635/PIC16F636 data sheet, Microchip Technology Inc.

[2] Antenna circuit design for RFID applications, AN710, Microchip Technology Inc.

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