AN1024

# PKE System Design Using the PIC16F639


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## INTRODUCTION

Hands-free Passive Keyless Entry (PKE) is quickly becoming mainstream in automotive remote keyless entry applications and is a common option on new automobile models. Instead of pressing a transmitter button to unlock or lock a car door, it is possible to gain vehicle access simply having a valid transponder in your possession.

Hands-free PKE applications require bidirectional communication between the base station and transponder units. The base unit inside the vehicle transmits a Low-Frequency (LF) command that searches for a transponder in the field. Once located, the transponder in the vehicle owner's possession then automatically responds to the base unit. The base unit then unlocks the car doors, if a valid authentication response is received.

In typical PKE applications, the base station unit is designed to output the maximum power that is allowed by electromagnetic field radiation rules that are mandated by government agencies. When it operates with a 9 to 12 VDC of power source, the maximum attainable antenna voltage is about 300 VPP. Because of the non-propagating property of the low-frequency (125 kHz) signal, the signal level becomes only about a few mVPP when it is received by a typical key fob transponder approximately two meters away from the base station unit. Furthermore, due to antenna orientation properties, the input signal level at the transponder becomes considerably weaker if the antenna is not oriented face-to-face with the base station antenna.

The most probable source of PKE operation failure is due to a weak input signal level at the transponder. Therefore, for a reliable hands-free PKE application, it is necessary to make the input signal strong enough (above input sensitivity level) in any condition within the desired communication range.

In order to make the PKE system reliable, the system designer must consider four important parameters:

1. Output power of the base station command,
2. Input sensitivity of the transponder,
3. Antenna directionality, and
4. Battery life of the transponder.

The PIC16F639 is a microcontroller (MCU) with a three-channel analog front-end. The device's analog front-end features are controlled by the MCU firmware. Because of its easy-to-use features, the device can be used for various smart low-frequency sensing and bidirectional communication applications.

This application note provides design circuit examples of the smart PKE transponder using the PIC16F639 MCU. The MCU firmware examples for the circuits shown in this application note are also available. The given circuit and MCU firmware examples can be easily modified for users specific applications.

## PIC16F639 PKE TRANSPONDER

The PIC16F639 has a digital MCU section (PIC16F639 core) and an analog front-end (AFE) section. The device can be used for various low-frequency sensing and bidirectional smart communication applications.

Figure 1 shows an example of a typical PKE system. The base station unit transmits a 125 kHz command to search for a valid transponder in the field. The PKE transponder sends back a response if the received command is valid.

The PIC16F639 device has high analog input sensitivity (up to 1 mVPP) and three antenna connection pins. By connecting three antennas that are positioned to x, y and z directions, the transponder can pick up signals from any direction at any given time. Therefore, it reduces the likelihood of missing signals due to the properties of antenna directionality. The input signal at each antenna pin is detected independently and summed afterwards. Each input channel can be independently enabled or disabled by programming the Configuration register. The device consumes less operating power if fewer channels are enabled.

For hands-free operation, the transponder is continuously waiting and detecting input signals. This presents an issue for the life expectancy of the battery. Therefore, in order to reduce the operating current, the digital MCU section can stay in low-current mode (Sleep), while the Analog Front-End (AFE) is looking for a valid input signal. The digital MCU section is waking up only when the AFE detects a valid input signal. This feature is possible by using an Output Enable Filter (wake-up filter). There are nine Output Enable Filter options available in the PIC16F639. Users can program the filter using the Configuration register. Once the filter is programmed, the device passes detected output to the digital section only if the incoming signal meets the filter requirement.

Figure 2 shows an example of the PKE transponder configuration. The transponder consists of the PIC16F639 device, external LC resonant circuits, push buttons, a UHF transmitter, battery back-up (optional), and a 3V lithium battery.

The digital sections have two I/O ports; PORTA and PORTC. Each of the PORTA pins is individually configurable as an Interrupt-on-change pin. The pins on PORTC have no Interrupt-on-change function.

The AFE section shares three I/O pins in PORTC of the digital section; RC1, RC2 and RC3, which are internally bonded with $\overline{\text{CS}}$, SCLK/$\overline{\text{ALERT}}$ and LFDATA/CCLK/RSSI/SDIO pad of the AFE, respectively. LFDATA/CCLK/RRSI and $\overline{\text{ALERT}}$ are outputs of the AFE. SDIO, SCLK and $\overline{\text{CS}}$ are used to program or read the AFE Configuration registers. Refer to the PIC12F635/PIC16F636/639 Device Data Sheet (DS41232) for more details (see **"References"**).

To save battery power, the digital section is normally in Sleep mode while the AFE section is detecting LF input signals. Although the AFE's output pads are internally bonded to the PORTC pins, the AFE output cannot wake-up the digital section from Sleep by Interrupt-on-change events, because the pins are not Interrupt-on-change pins. Therefore, it is recommended that the LFDATA and $\overline{\text{ALERT}}$ pins of the AFE be connected to the PORTA pins externally, as shown in Figure 2.

The digital section can wake up when one of the following three conditions occur:

1. AFE output at LFDATA pin,
2. AFE output at $\overline{\text{ALERT}}$ pin, or
3. Any event by push button switches on PORTA.

**FIGURE 1: BIDIRECTIONAL PASSIVE KEYLESS ENTRY (PKE) SYSTEM**

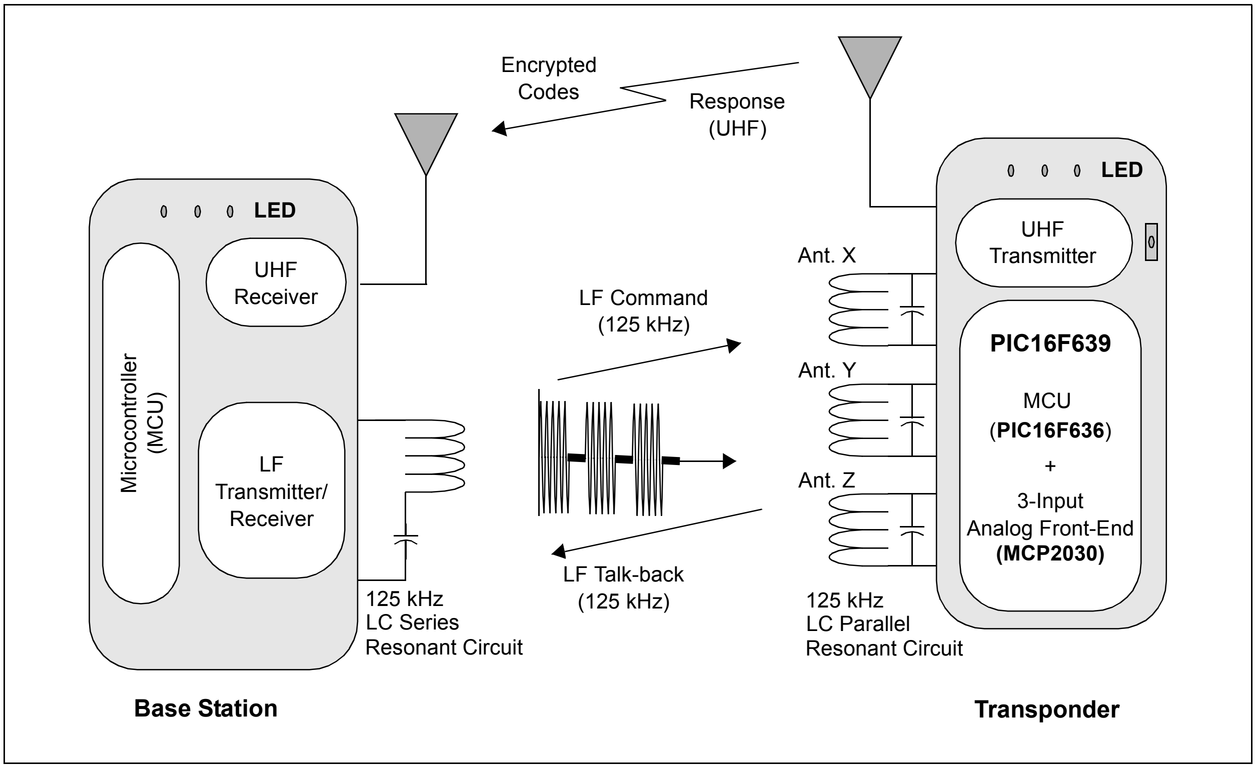
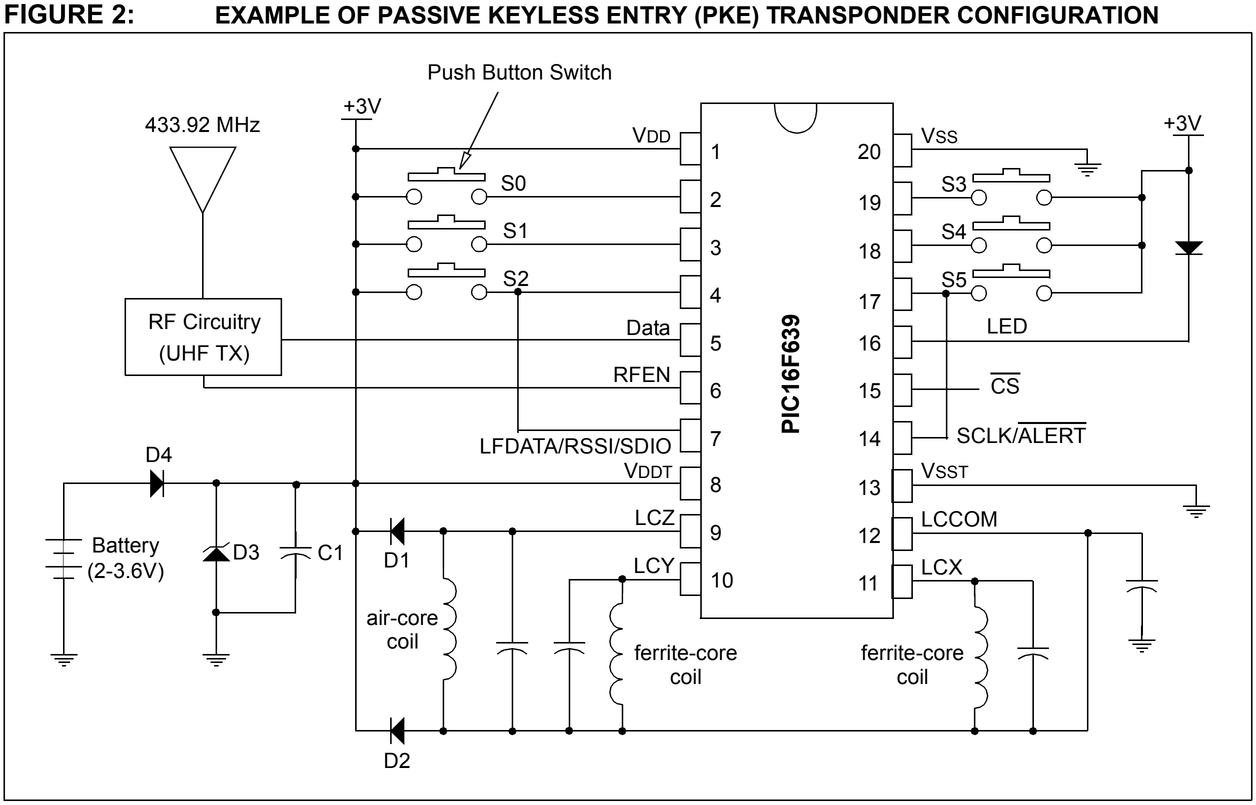



**FIGURE 2: EXAMPLE OF PASSIVE KEYLESS ENTRY (PKE) TRANSPONDER CONFIGURATION**



### Wake-up Filter and Signal Detection

Users can program one of the nine possible Output Enable filters using the Configuration registers. Refer to the PIC12F635/PIC16F636/639 Device Data Sheet (DS41232) for more details (see **"References"**).

Figures 3 and 4 show examples of inputs and demodulated outputs. The input signal is applied to one of the three input pins or on all pins (LCX, LCY, LCZ) at the same time. The outputs are available on the LFDATA pin of the device. The figures show the differences in output pins depending on the setting of the output enable (wake-up) filter option. For the cases shown in Figure 3 and Figure 4, the minimum modulation depth requirement is set to 8% and the Output Enable Filter is set to ($T_{OEH}$: 2 ms, $T_{OEL}$ = 2 ms). The input signal amplitude is 2.7 $mV_{PP}$ with a modulation depth of about 9%. Figure 3 shows the input signal and the demodulated data output after the wake-up filter is matched. The demodulated output of the correct (wanted) input signal wakes up the digital section, and will respond if the command is valid. Figure 4 shows the case when the input does not meet the programmed filter requirement. The demodulated output is not available at the output pin since the input does not meet the programmed filter requirement. This ensures that the digital section will not wake-up due to unwanted input signals.

**FIGURE 3: INPUT SIGNAL AND DEMODULATED OUTPUT WHEN OUTPUT ENABLE FILTER IS ENABLED AND INPUT MEETS THE FILTER TIMING REQUIREMENT**

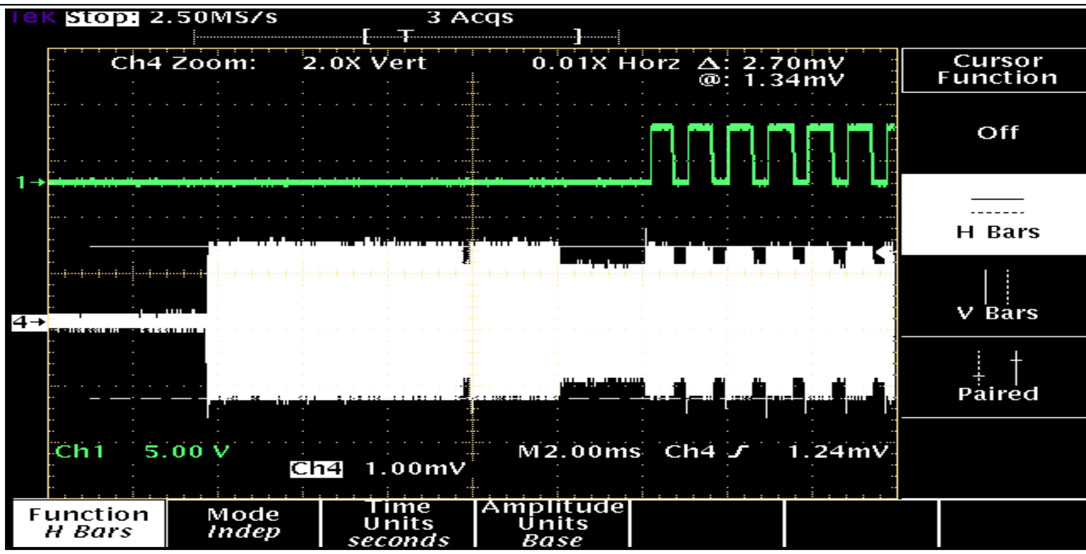
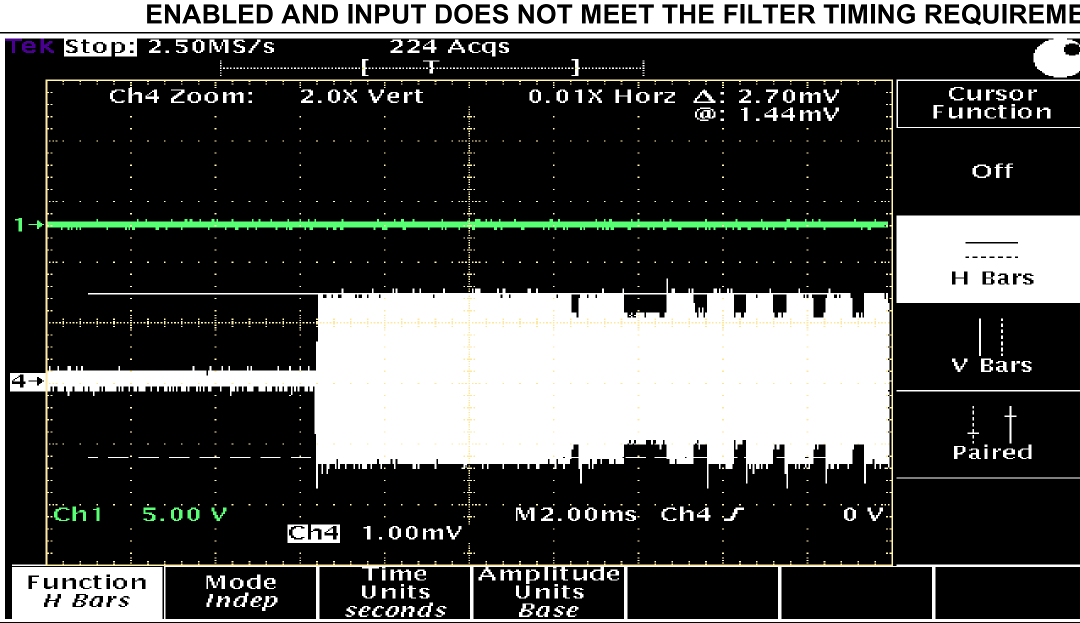



**FIGURE 4: INPUT SIGNAL AND DEMODULATED OUTPUT WHEN OUTPUT ENABLE FILTER IS ENABLED AND INPUT DOES NOT MEET THE FILTER TIMING REQUIREMENT**



## External LC Resonant Antenna

The PIC16F639 device includes three low-frequency input channels. The LCX, LCY and LCZ pins are for external LC resonant antenna circuit connections (for each LF input channel). The external circuits are connected to the antenna input pins and the LCCOM pin. LCCOM is a common pin for all external antenna circuits. A capacitor (1-10 µF) between the LCCOM pin and ground is recommended to provide a stable condition for the internal detection circuit when it detects strong input signals.

Although the PIC16F639 has three LC input pins for the three external antenna attachments, the user can use only one or two antennas, instead of using all three, depending on the application. The operating current consumption is proportional to the number of channels enabled. Fewer channels enabled results in lower current consumption. However, it is highly recommended to use all three antennas for hands-free PKE applications.

### THEORY OF LC RESONANT ANTENNA

To detect a low-frequency magnetic field, a tuned loop antenna is commonly used. In order to maximize the antenna voltage, the loop antenna must be precisely tuned to the frequency of interest. For PKE applications, the antenna should be tuned to the carrier frequency of the base station. The loop antenna is made of a coil (inductor) and capacitors that are forming a parallel LC resonant circuit. The voltage across the antenna is also maximized by increasing the surface area of the loop and quality factor ($Q$) of the circuit.

The resonant frequency of the LC resonant circuit is given by Equation 1:

**EQUATION 1:**

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

where $L$ is the inductance of the loop and $C$ is the capacitance.

For a given LC resonant circuit, the received antenna voltage is approximately given by Equation 2 (refer to application note AN710, "*Antenna Circuit Design for RFID Applications*," (DS00710) for details):

**EQUATION 2:**

$$V_{coil} \approx \frac{f_c}{(1+\Delta f)} NSQB_o \cos\alpha$$

where:

| | | |
|---|---|---|
| $f_c$ | = | Carrier frequency of the base station (Hz) |
| $\Delta f$ | = | $\lvert f_c - f_o \rvert$ |
| $f_o$ | = | Resonant frequency of LC circuit (Hz) |
| $N$ | = | Number of turns of coil in the loop |
| $S$ | = | Surface area of loop in square meters |
| $Q$ | = | Quality factor of LC circuit |
| $B_o$ | = | Magnetic field strength (Weber/m$^2$) |
| $\alpha$ | = | Angle of arrival of signal |

In Equation 2, the quality factor ($Q$) is a measure of the selectivity of the frequency of the interest by the tuned circuit. Assuming that the capacitor is lossless at 125 kHz, $Q$ of the LC circuit is mostly governed by the inductor defined by:

**EQUATION 3:**

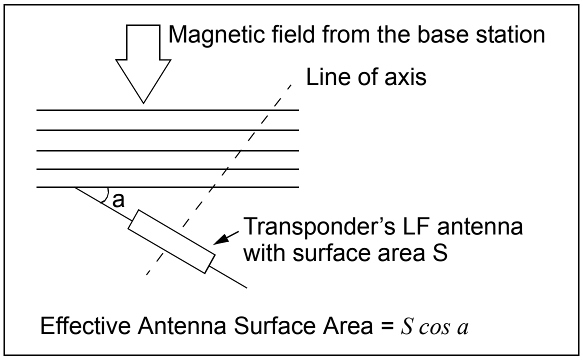
$$Q_L = \frac{2\pi\ f_o\ L}{r}$$

where $f_o$ is the tuned frequency, $L$ is the inductance value and $r$ is the resistance value of the inductor.

In typical transponder applications, the inductance value is in the 1-9 mH range. $Q$ of the LC circuit is greater than 20 for an air-core inductor and about 40 for a ferrite-core inductor.

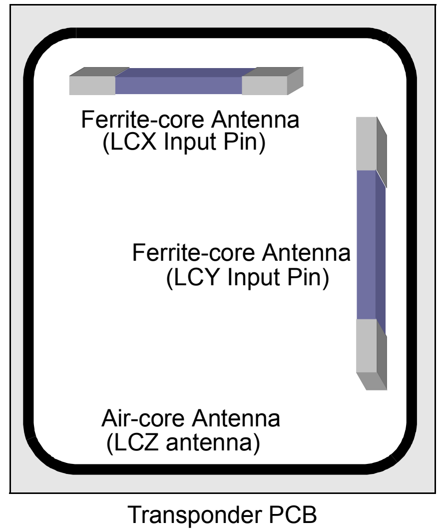
The $S \cos \alpha$ term in Equation 2 represents an effective surface area of the antenna that is defined as an exposed area of the loop to the incoming magnetic field. The effective antenna surface area is maximized when $\cos \alpha$ becomes unity, which occurs when the antennas of the base station and the transponder units are positioned in a face-to-face arrangement. In practical applications, the user might notice the longest detection range when the two antennas are facing each other and the shortest range when they are orthogonally faced. Figure 5 shows a graphical demonstration of the antenna orientation problem in practical applications.

**FIGURE 5: ANTENNA ORIENTATION DEPENDENCY**




The antenna orientation problem can be significantly reduced if the three antennas are placed orthogonally on the same PCB board. This increases the probability that at least one of the transponder antennas faces toward the base station antenna at a given incident during application. Figure 6 shows a graphical illustration of placing three antennas on the transponder board. A large air-core coil is used for LCZ and two ferrite-core coils are used for LCX and LCY. There are companies that make the ferrite coils specifically for the 125 kHz RFID and low-frequency sensing applications.

**FIGURE 6: RECOMMENDED ANTENNA PLACEMENT ON TRANSPONDER BOARD**




**Note 1:** Keep the size of the air-core antenna (LCZ) as large as possible, given the PCB space available.

**2:** Keep the separation between the antennas as far apart as possible to reduce a mutual coupling between them.

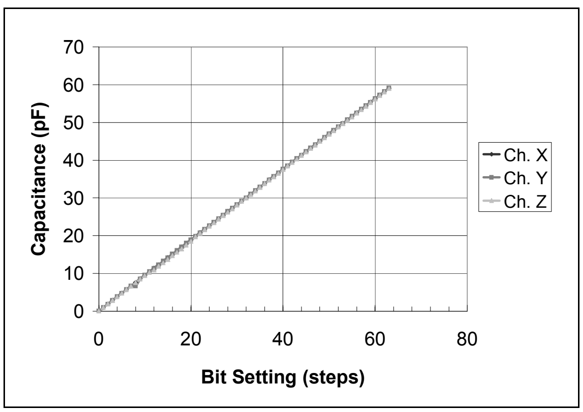
LC ANTENNA TUNING

As shown in Equations 2 and 3, the induced coil voltage is maximized when the LC circuit is tuned precisely to the incoming carrier frequency. In practical applications, however, the LC resonant frequency differs from transponder to transponder due to the tolerance variation of the LC components. To compensate the error due to the component tolerance, the PIC16F639 has an internal resonant capacitor bank per channel. The capacitor value can be programmed up to 63 pF with 1 pF per step. Figure 7 shows an example of the capacitance tuning using the Configuration register bits (6 bits). The capacitance is monotonically increased with the Configuration register bits. Refer to the PIC12F635/PIC16F636/639 Device Data Sheet (DS41232) for more details (see **"References"**).

The capacitance can be effectively tuned by monitoring the RSSI current output. The RSSI output is proportional to the input signal strength. Therefore, the higher RSSI output will be monitored the closer the LC circuit is tuned to the carrier frequency.

The total capacitance adds up as the Configuration register bits step up . The resulting internal capacitance is added to the present capacitor values of the LC circuit. The LC resonant frequency will shift to lower by adding the internal resonant capacitor.

**FIGURE 7: CAPACITANCE TUNING VS. BIT SETTING**




## Battery Back-up and Batteryless Modes

In real-life applications, there is the chance that the battery can be momentarily disconnected from the circuit by accident, for example, if the unit is dropped onto a hard surface. If this should happen, the data stored in the MCU may not be recovered correctly. To protect the battery from accidental misplacement, users may consider using a battery back-up circuit. The battery back-up circuit provides a temporary $V_{DD}$ voltage to the transponder. The circuit is recommended for sophisticated transponders, but may not be a necessary mechanism for all applications. In Figure 2, D4 and C1 form the battery back-up circuit. C1 is fully charged when the battery is connected and provides the $V_{DD}$ when the battery is momentarily disconnected.

The Batteryless mode is the case when the transponder is operating without the battery. In Figure 2, diodes D1, D2, D3 and C1 form a power-up circuit for batteryless operation. When the transponder coil develops voltages, the coil current flows through the diodes, D1 and D2, and charges the capacitor, C1, which can provide the $V_{DD}$ for the transponder. The power-up circuit is useful when the PIC16F639 is used for anti-collision transponder applications, where batteryless operation is preferred. The value of the capacitor, C1, for Batteryless mode is from a few µF to a few Farad (F) depending on the application.

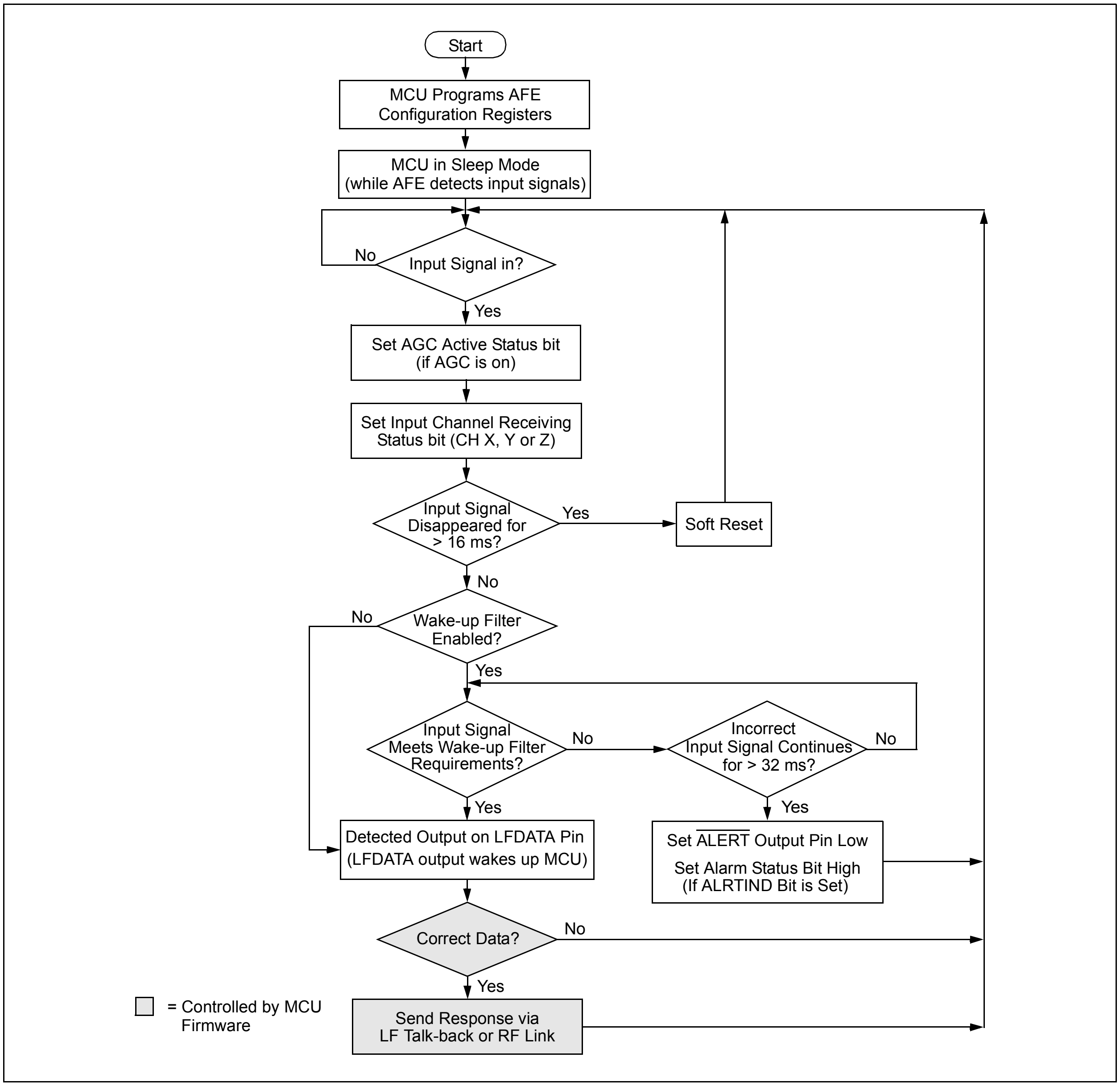
## LOW-FREQUENCY SIGNAL DETECTION ALGORITHM AND DETECTOR OUTPUT

Figure 8 shows the flow chart of the input signal detection with the wake-up filter enabled.

The MCU firmware, *PIC16F639_Basestation.asm*, is available for download from Microchip's web site, www.microchip.com (see **Appendix A: "Source Code"**).

Examples of the schematics for the PKE transponder and the base station are shown in **Appendix B: "Transponder"**, Figure B-1, Figure C-1 and Figure C-2 respectively. These schematics were developed for customer training purposes of the PIC16F639 transponder. Users can use the circuits as references when they develop their own systems. Users can also refer to the PKE reference demonstration kit (P/N: APGRD001), which is available from Microchip.

**FIGURE 8: PIC16F639 SIGNAL DETECTION FLOW CHART**



## TRANSPONDER CIRCUIT

Figure B-1, in **Appendix B: "Transponder"**, shows an example of the PKE transponder circuit which has been used for customer training and device demonstration purposes.

The transponder circuit has three external LC resonant circuits, 5 push button switches, a 433.92 MHz resonator for UHF data transmission and components for Battery Back-up mode.

Each LC resonant circuit is connected to the LC input and LCCOM pins. The air coil antenna is connected to the LCX input and the two ferrite-rod inductors are connected to the LCY and LCZ pins. The LCCOM pin is a common pin for all three antenna connections, which is grounded via C11 and R9. Each resonant antenna must be tuned to the carrier frequency of the base station unit for the best signal reception conditions. The internal capacitor of each channel can be used to tune the antenna for the best performance.

When the device is powered up initially, the digital section programs the Configuration registers of the AFE using the SPI ($\overline{CS}$, SCLK/$\overline{ALERT}$, SDIO).

The AFE is very sensitive to environmental noise due to its high input sensitivity (~3 $mV_{PP}$); therefore, take appropriate care to prevent excess AC noise along the PCB traces. Capacitors C6 and C12 are used for noise filtering for the $V_{DD}$ and $V_{DDT}$ pins, respectively.

Diodes D1 and D2, and capacitor C5 are for the Battery Back-up mode. Diodes D2, D3 and D7 and capacitor C5 are for Batteryless mode. A larger C5 value is needed for stable Batteryless mode operation. Capacitor C5 holds the charges from the battery and from the coil voltage through diodes D3 and D7. The stored charge on C5 can keep the PIC16F639 device powered when the battery is momentarily disconnected. Diodes D3 and D7 are connected across the air coil, which develops the strongest coil voltage among the three external LC resonant antennas.

Once a valid input signal is detected, the digital MCU section is waken up and transmits a response if the command is valid.

The transponder can send responses using an internal modulator (LF talk-back) or an external UHF transmitter. The analog input channel has an internal modulator (transistor) per channel between the input and the LCCOM pins. The internal modulator is turned on and off if the AFE receives Clamp-On and Clamp-Off commands from the digital MCU section, respectively. The antenna voltage is clamped or unclamped depending upon the Clamp-On or Clamp-Off command, respectively. This is called LF talk-back, which is used for proximity range applications only. The base station can detect the changes in the transponder antenna voltage and reconstruct the modulation data.

See the PIC12F635/PIC16F636/639 Device Data Sheet (DS41232) for more details of the LF talk-back (see **"References"**).

The transponder uses a UHF transmitter for long range applications. An On-Off-Keying UHF transmitter is formed by the UHF (433.92 MHz) resonator U2 and power amplifier Q1. The values of capacitors C2 and C3 are approximately 20 pF range each, but are layout dependent. The L1, which is typically formed by a metal trace on the PCB, is a UHF antenna and its efficiency increases significantly by increasing its loop area.

The UHF transmitter section is turned on when the MCU I/O pin outputs a logic level high; otherwise it is turned off. The output of RC5 is the modulation data of the UHF signal and can be reconstructed by the UHF receiver in the base station.

## BASE STATION CIRCUIT

Figure C-1 and Figure C-2, in **Appendix C: "Base Station"**, show an example circuit of the base station, which has been used for customer training and device demonstration purposes.

The base station unit consists of a microcontroller, 125 kHz transmitter/receiver and an UHF receiver module.

The base station transmits a 125 kHz low-frequency command and receives responses from the transponders in the field via UHF or LF talk-back. After transmitting the LF commands, it checks whether there is any response through LF or UHF link.

The 125 kHz transmitter generates a carrier signal based on the MCU's Pulse-Width Modulator (PWM) output. The power of the125 kHz square pulses from the MCU is boosted by the current driver, U1. The square pulse output from U1 becomes sine waves as it passes through an LC series resonant circuit that is formed by L1, C2, C3 and C4. L1 is an air-core inductor and is used for the 125 kHz LF antenna.

The antenna radiation becomes maximized when the LC series resonant circuit is tuned to the frequency of the PWM signal. At the resonant frequency, the impedance of the LC circuit is minimized. This results in a maximum load current through L1 and therefore produces strong magnetic fields. Users may tune the LC circuit by monitoring the coil voltage across L1.

The components after diode D1 are used to receive the LF talk-back signal from the transponder. When the transponder responds with LF talk-back, there will be changes in the coil voltage (across L1) due to the magnetic fields originated by the voltage on the transponder coil. Since the voltage on the transponder coil is initially caused by the voltage of the base station antenna (L1), the return voltage has 180º phase difference with respect to the originating voltage. Therefore, at a given condition, the voltage across L1 changes with the coil voltage of the transponder coil.

The change in the coil voltage (across L1) can be detected through an envelope detector and low-pass filter formed by D1 and C5. The detected envelope passes through active gain filters, U2A and U2B. The demodulated analog output is fed into the comparator input pin of the MCU for pulse shaping. The output of the comparator is available on TP6 and decoded by the MCU.

U4 is the 433.92 MHz ASK receiver module. This receiver module detects the transponder's UHF responses. The digital output from this module is fed into the MCU for decoding. An antenna (a few inches long) is typically attached to the antenna pad of the module to receive a signal in stable condition. Since the receiver module is next to the LF transmitter section, which produces strong fields, the module typically outputs noise. Therefore, it may require an adequate firmware routine to filter out the noise inputs.

The base station unit displays the data on the LCD or turns on the buzzer each time valid data is received.

## FIRMWARE EXAMPLES

Firmware examples, including HTML documentation for the transponder and the base station units are available in an archived file (see **Appendix A: "Source Code"**).

The main firmware files for the transponder and the base station are *PIC16F639_Transponder.asm* and *PIC16F639_BaseStation.asm*, respectively.

The firmware does not use the KEELOQ® security IC algorithm. Contact Microchip sales for assistance if you want to use KEELOQ security ICs in your design.

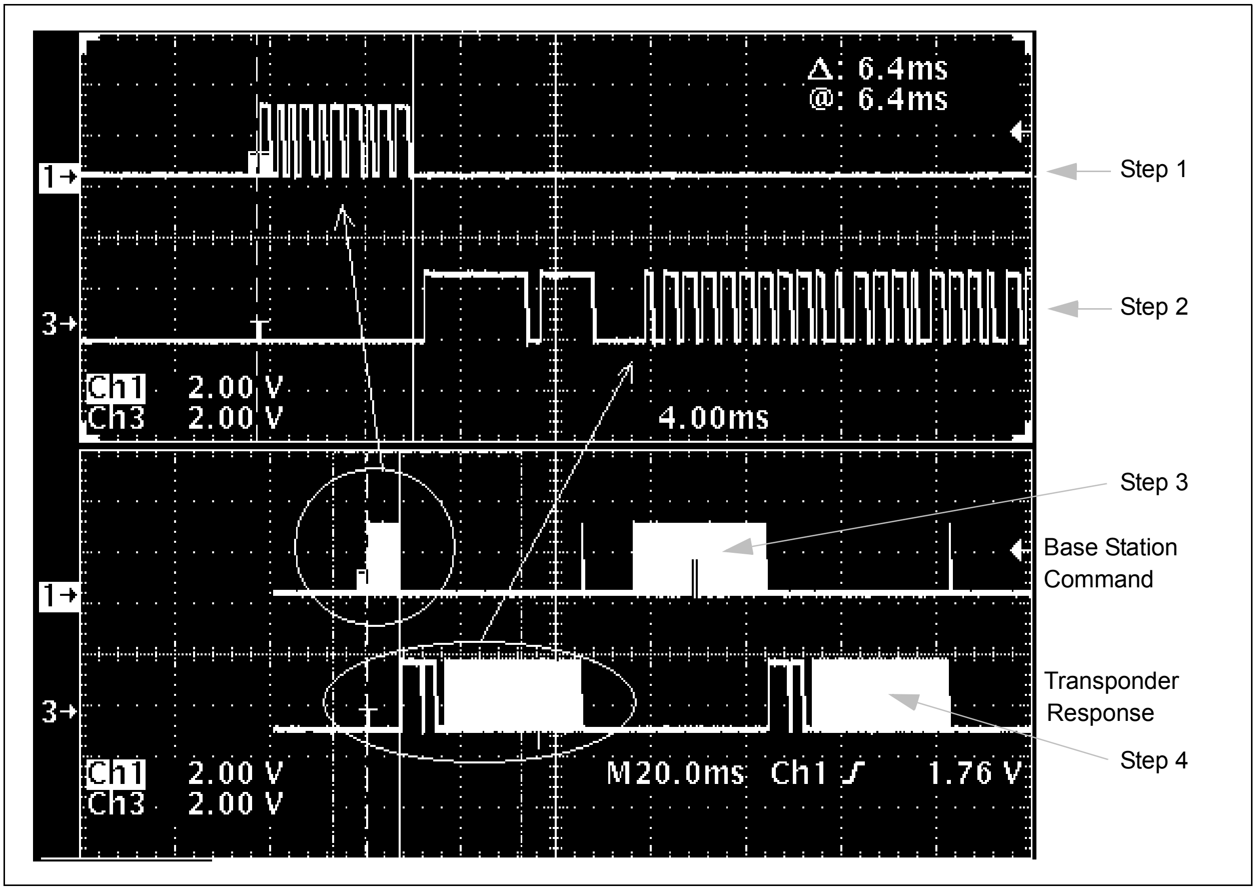
Figure 9 shows an example of the handshake between the base station and the transponder.

Figure 10 shows a communication example between the transponder and base station units by using the firmware.

**FIGURE 9: EXAMPLE OF HANDSHAKE BETWEEN BASE STATION AND TRANSPONDER**

| | |
|---|---|
| Base Station Transmits: (Step 1) | AGC Stabilization Pulse + Wake-up Filter + 10 bits (ID Command + Parity + Stop Bit) |
| Transponder Transmits: (Step 2) | Header + ID (32 bits) + 4 Parity bits |
| Base Station Transmits: (Step 3) | AGC Stabilization Pulse + Wake-up Filter + IFF Command (8 bits) +Challenge (32 bits) + 5 Parity bits + Stop Bit (46 bits) |
| Transponder Transmits: (Step 4) | Header + Response (32 bits) + 4 Parity bits (36 bits) |
| Base Station: | Display message on LCD |

FIGURE 10: COMMUNICATION LINK BETWEEN BASE STATION AND TRANSPONDER




## CONCLUSION

The PIC16F639 device is an easy-to-use, low cost and secure bidirectional communication transponder. This device can be used for various smart hands-free passive keyless entry applications. A basic configuration of the Passive Keyless Entry (PKE) transponder is shown in Figure 2. Example schematics for the transponder and the base station are shown in **Appendix B: "Transponder"** and **Appendix C: "Base Station"**.

The firmware examples for the transponder and the base station are also provided (see **Appendix A: "Source Code"**). Users can modify the provided examples for their application purposes.

## MEMORY USAGE

### Transponder:

- Program Memory – 1131 words
- Data Memory – 65 Bytes

### Base Station:

- Program Memory – 1178 words
- Data Memory – 405 Bytes

## REFERENCES

"*PIC12F635/PIC16F636/639 Data Sheet*," DS41232, Microchip Technology Inc.

AN710, "*Antenna Circuit Design for RFID Applications*," Application Note (DS00710), Microchip Technology Inc.

AN959, "*Using the* PIC16F639 *MCU for Smart Wireless Applications*," Application Note (DS00950), Microchip Technology Inc.

TB088, "PIC16F639 *Microcontroller Overview*," Technical Brief (DS91088) Microchip Technology Inc.

TB090, "*MCP2030 Three - Channel Analog Front-End Device Overview*," Technical Brief (DS91090A) Microchip Technology Inc.

"*MCP2030 Data Sheet*", (DS21981), Microchip Technology Inc.

*"Coilcraft Data Sheet"*, (P/N 4308 and 5315 Series); http://www.coilcraft.com

## APPENDIX A: SOURCE CODE

The complete source code, including any firmware applications and necessary support files, is available for download as a single archive file from the Microchip corporate web site, at:

**www.microchip.com**

## APPENDIX B: TRANSPONDER

### FIGURE B-1: TRANSPONDER SCHEMATIC SHEET 1 OF 1

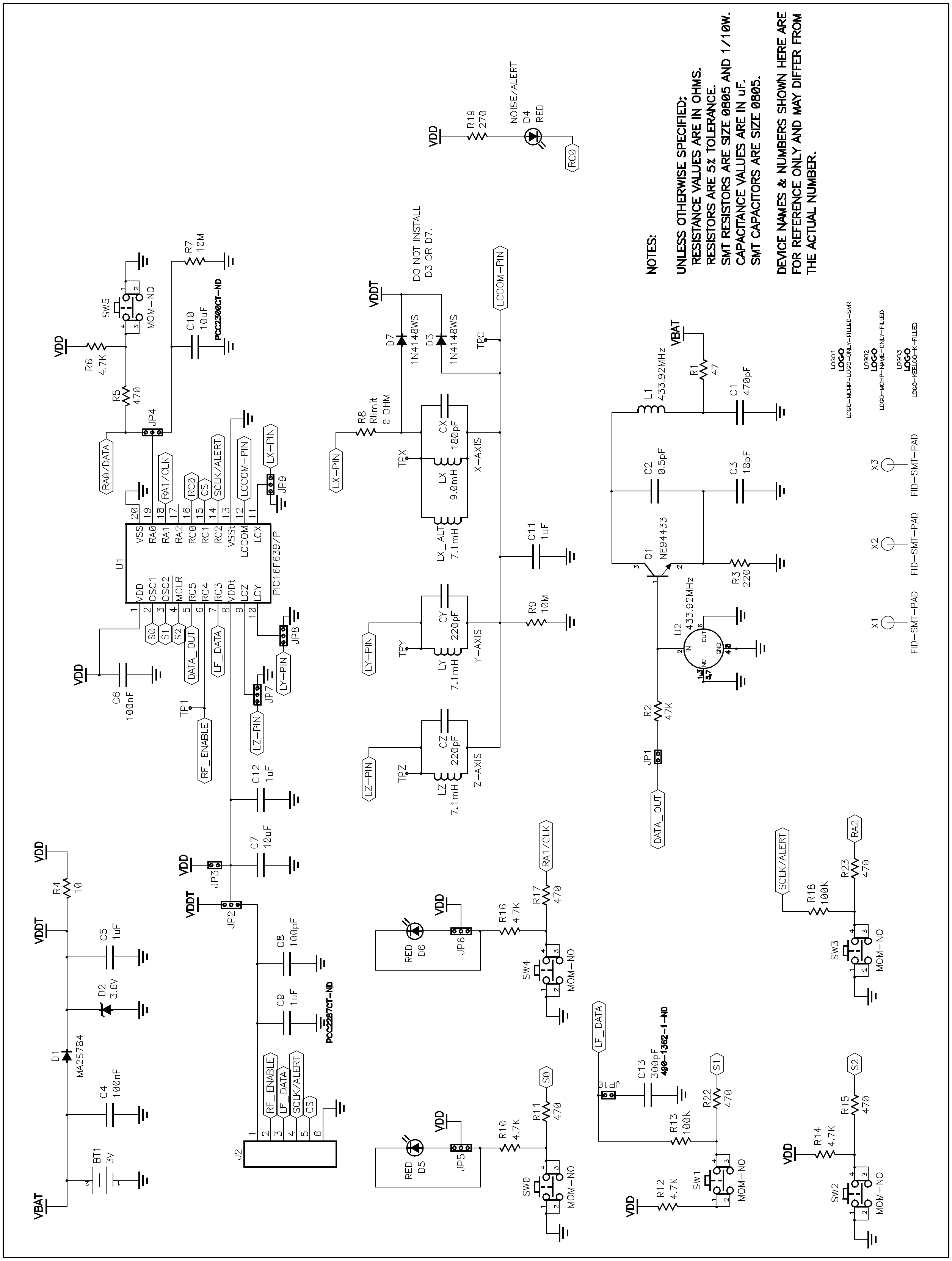


**FIGURE B-2: TOP MASK VIEW OF TRANSPONDER**

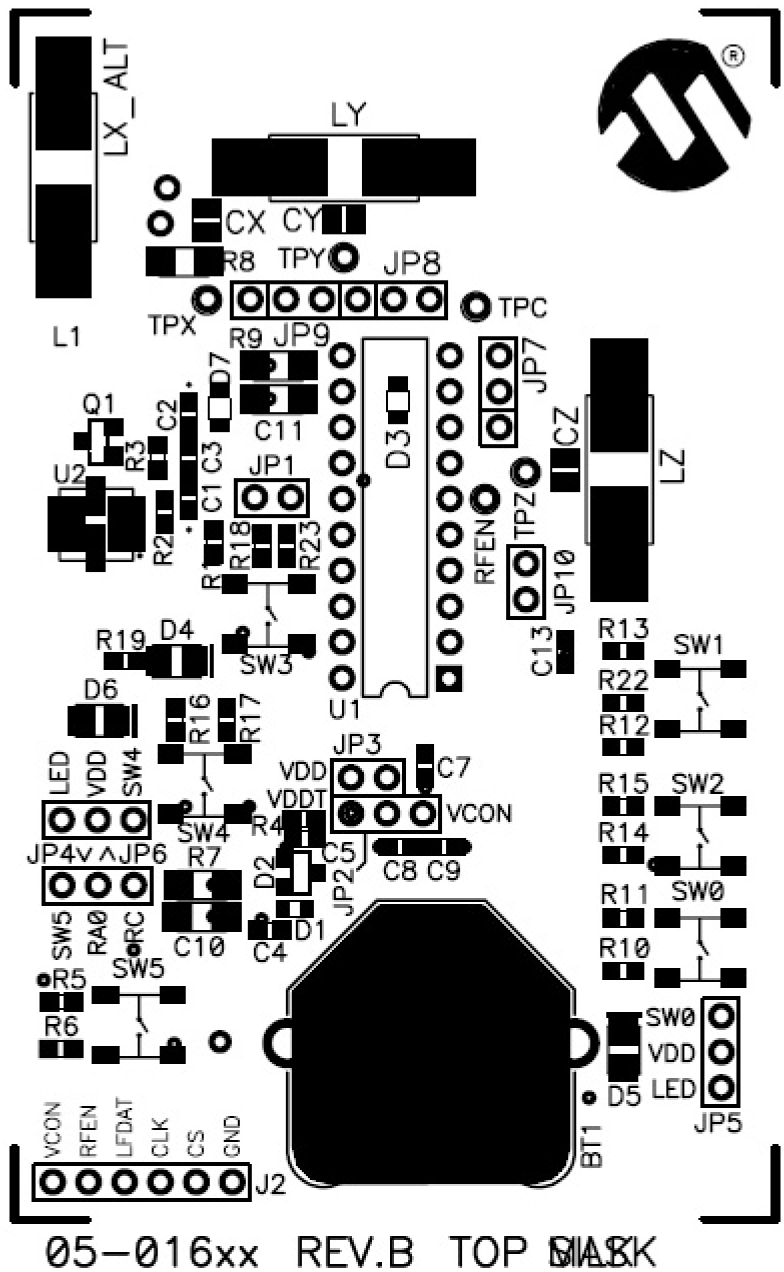
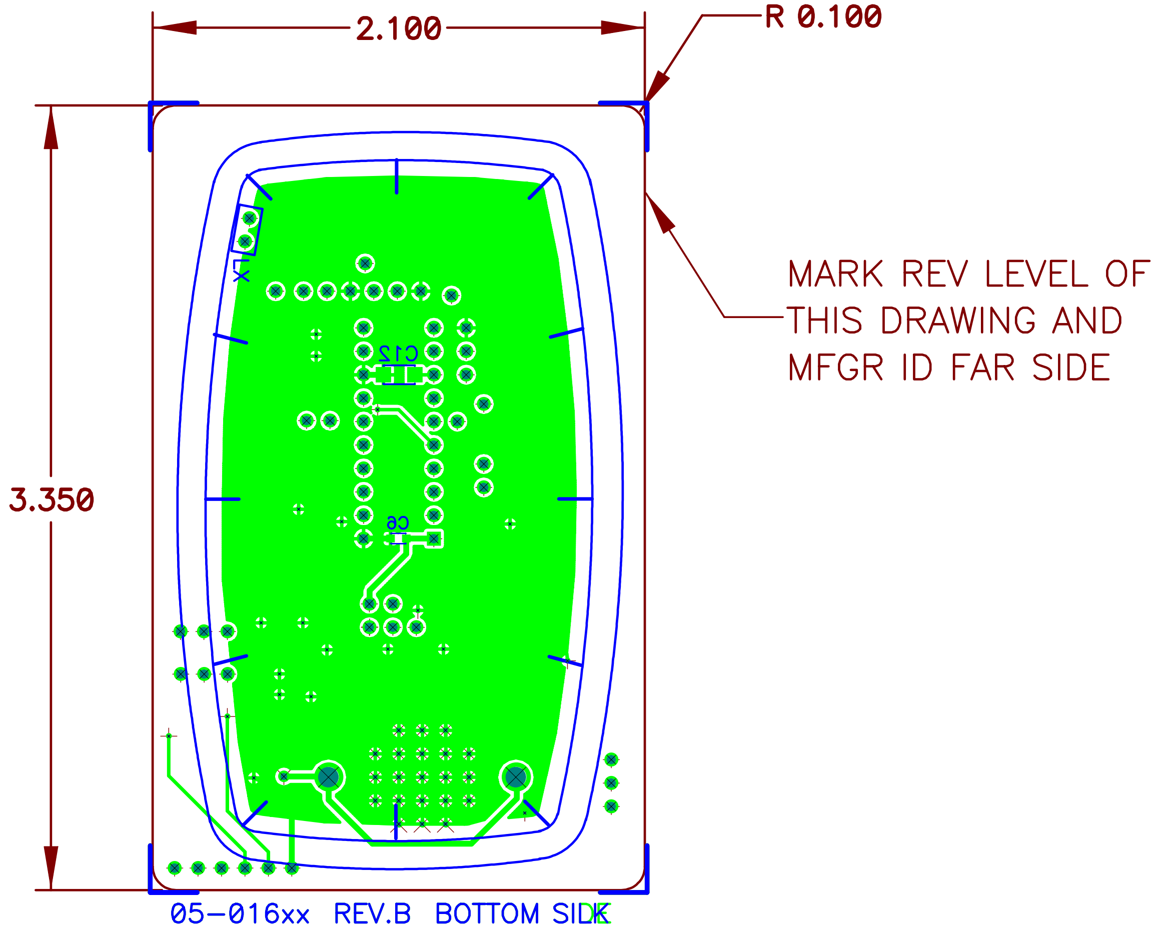


**FIGURE B-3: BOTTOM MASK VIEW OF TRANSPONDER**



## APPENDIX C: BASE STATION

**FIGURE C-1: BASE STATION SCHEMATIC SHEET 1 OF 2**

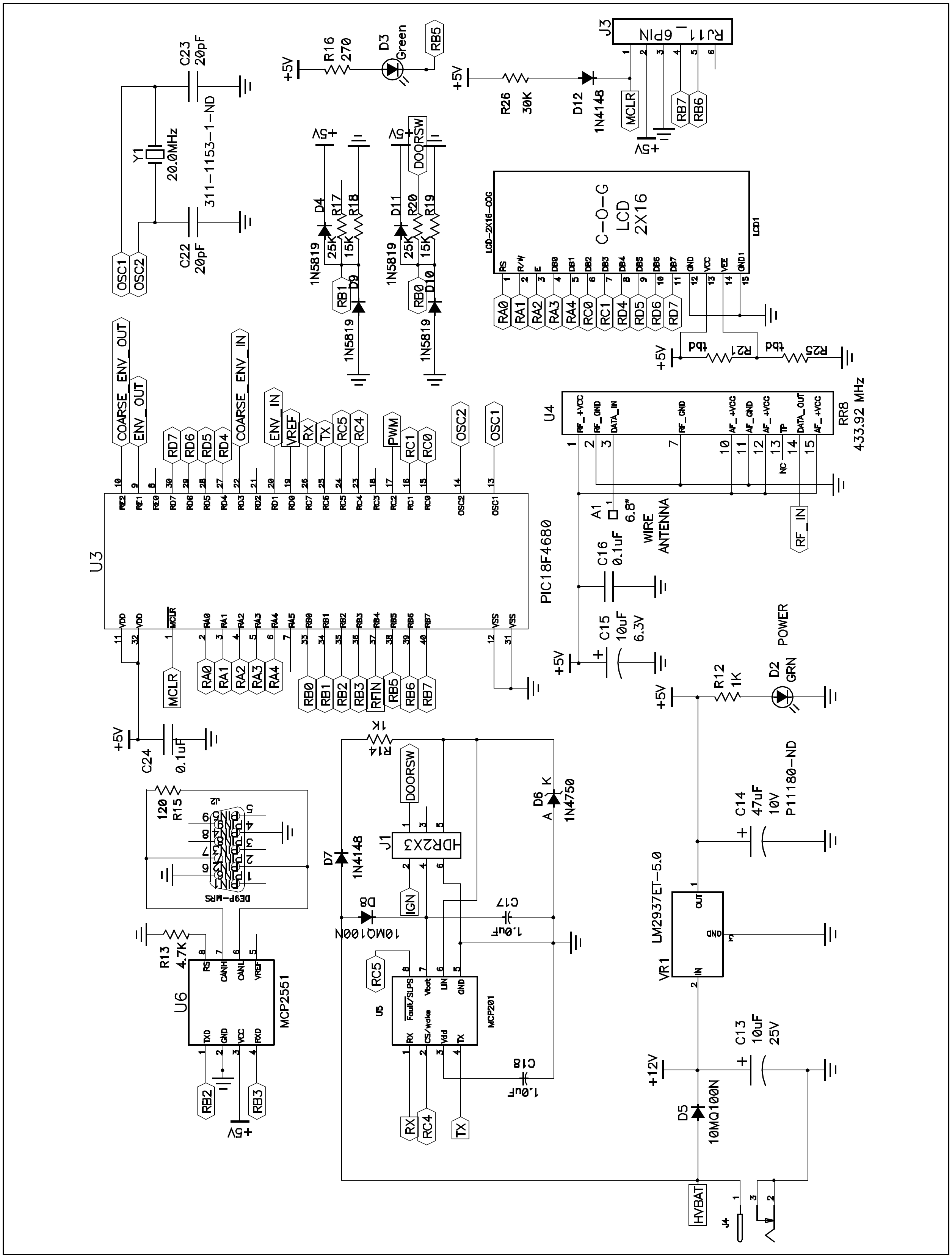


**FIGURE C-2: BASE STATION SCHEMATIC SHEET 2 OF 2**

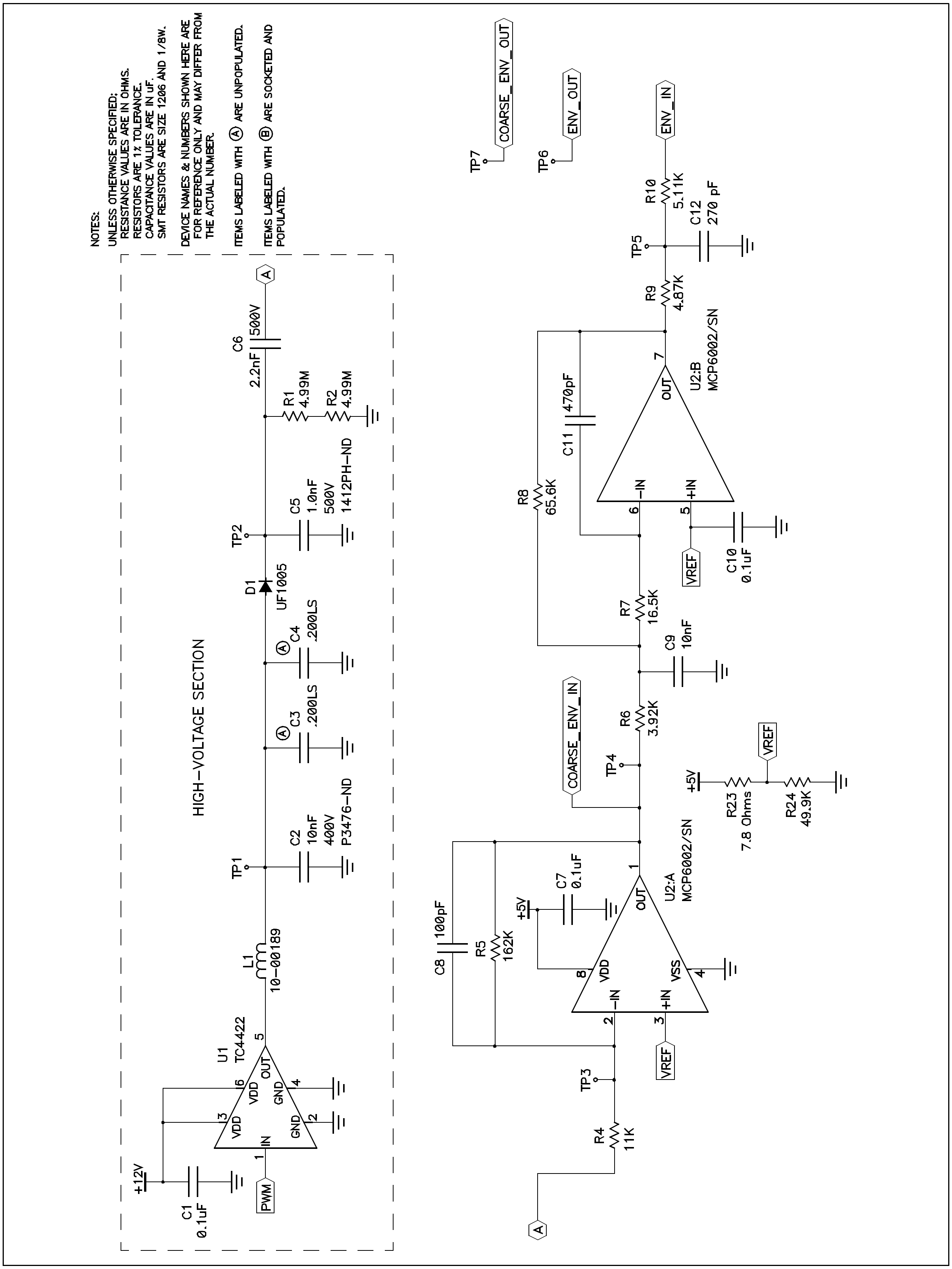


**FIGURE C-3: TOP MASK VIEW OF BASE STATION**

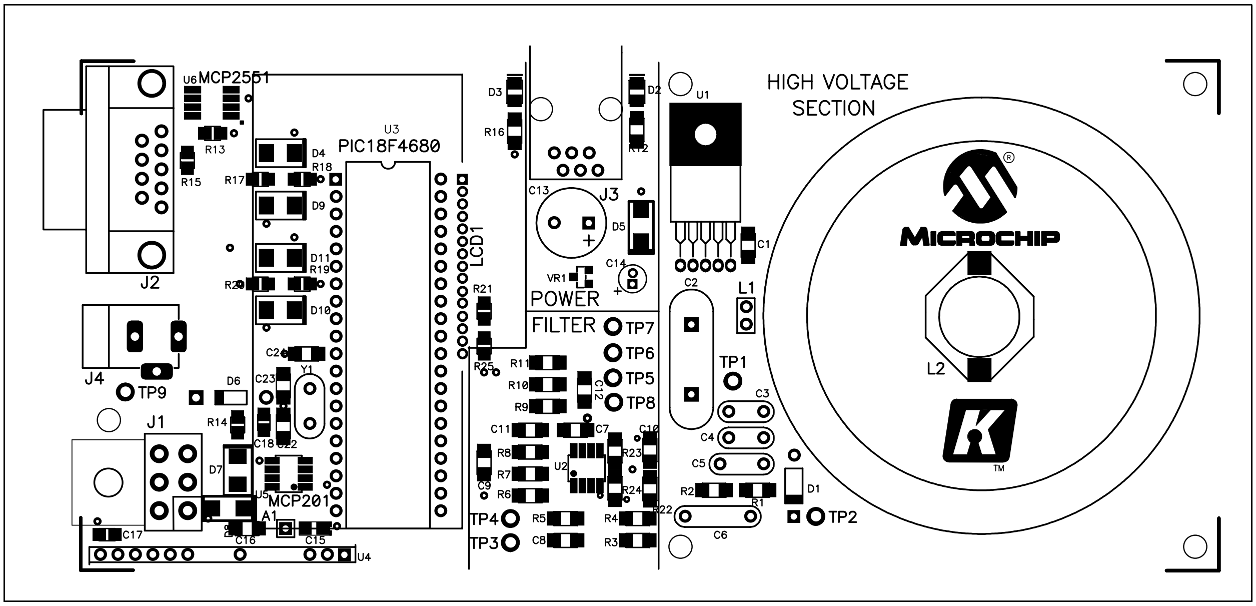
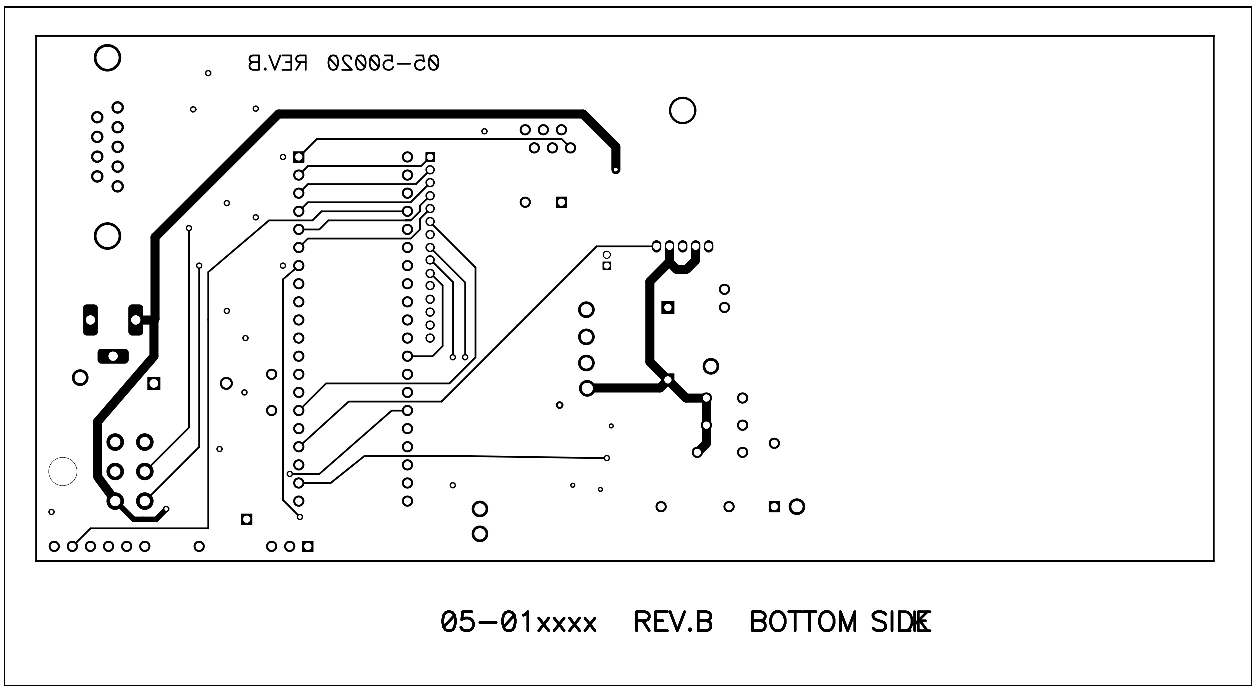



**FIGURE C-4: BOTTOM MASK VIEW OF BASE STATION**



# APPENDIX D: BILL OF MATERIALS

## FIGURE D-1: TRANSPONDER BOM

| Qty | Component Name | RefDes | Value | Description | Mfr. | Mfr. P/N | Notes |
|---|---|---|---|---|---|---|---|
| 1 | BTH-20MM-PTH-MTL | BT1 | 3V/6V | 20MM THRU HOLE MT COIN HOLDER | Keystone® Electronics | 3003 | |
| 1 | CAP-0603-DOUBLE | CX | 180pF | CAP,180PF,50V,CERAMIC,0603,SMD | Panasonic® | ECJ-1VC1H181J | |
| 2 | CAP-0603-DOUBLE | CY<br>CZ | 220pF | CAP,220PF,50V,CERAMIC,0603,SMD | Panasonic | ECJ-1VC1H221J | |
| 2 | CAP-CRCW0603 | C5<br>C9 | 1uF | CAP 1UF 16V CERAMIC F 0603 | Panasonic | ECJ-1VF1C105Z | |
| 1 | CAP-CRCW0603 | C2 | 0.5pF | CAP,0.5PF,50V,CERAMIC,0603,SMD | Panasonic | ECJ-1VC1H0R5C | |
| 1 | CAP-CRCW0603 | C3 | 18pF | CAP,18PF,50V,CERAMIC,0603,SMD | Panasonic | ECJ-1VC1H180J | |
| 2 | CAP-CRCW0603 | C7a<br>C7b | 10uF | CAP CER 10UF 10V 10% X5R 0805 | Murata® Electronics | GRM21BR61A106KE19L | |
| 2 | CAP-CRCW0603 | C4<br>C6 | 100nF | CAP CER 0.10UF 50V X7R 10% 0603 | TDK | C1608X7R1H104K | |
| 1 | CAP-CRCW0603 | C8 | 100pF | CAP CERAMIC 100PF 50V NP0 0603 | BC Components | VJ0603A101JXACW1BC | |
| 1 | CAP-CRCW0603 | C13 | 300pF | CAP CERM 300PF 5% 50V C0G 0603 | Rohm® | MCH185A301JK | |
| 1 | CAP-CRCW0603 | C1 | 470pF | CAP,470PF,50V,CERAMIC,0603,SMD | Panasonic | ECU-V1H471KBV | |
| 2 | CAP-CRCW1206 | C11<br>C12 | 1uF | CAP 1UF 25V CERAMIC X7R 1206 | Panasonic | ECJ-3YB1E105K | |
| 1 | CAP-CRCW1206 | C10 | 10uF | CAP 10UF 16V CERAMIC F 1206 | Panasonic | ECJ-3YF1C106Z | |
| 2 | DIO-1N4148WS-SOD-323 | D3<br>D7 | 1N4148WS | DIODE SWITCH 75V 200MW SOD-323 | Diodes Inc. | 1N4148WS-7 | |
| 1 | DIO-MA2S784-SS-MINI | D1 | MA2S784 | DIODE SCHOTTKY 30V 100MA SS-MINI | Panasonic | MA2S784-(TX) | |
| 1 | DIO-ZENER-BZX84-SOT23 | D2 | 5.1V | DIODE ZENER 5.1V 0.35W SOT-23 | Fairchild® Technologies | BZX84C5V1 | |
| 1 | HDR-1X6 | J2 | 1X6 | CONN HEADER 1X6 .100" PITCH | Samtec® | TSW-106-07-S-S | |
| 1 | ICP-PIC16F639/P-20PIN-PDIP | U1 | PIC16F639/P | PIC, MICROCHIP, 16F639, 20-PIN, PDIP | Microchip | PIC16F639/P | |
| 1 | IND-AIR-9MH-PINS-INSIDE | LX | 9.0mH | COIL, AIR, CREDIT CARD, 40AWG | Amatech | 10-00269 | |
| 3 | IND-PROTO2<br>IND-PROTO2<br>IND-PROTO2 | LX_ALT<br>LY<br>LZ | 7.1mH<br>7.1mH<br>7.1mH | INDUCTOR,RFID,TRANSPONDER | Coilcraft, Inc | 4308RV-715XJBD | DO NOT STUFF LX_ALT |
| 3 | JMP-2PIN-VIAS | JP1<br>JP3<br>JP10 | 1X2 | CONN HEADER 1X2 .100" PITCH | Samtec | TSW-102-07-S-S | |
| 7 | JMP-3PIN-VIAS | JP2<br>JP4<br>JP5<br>JP6<br>JP7<br>JP8<br>JP9 | 1X3 | CONN HEADER 1X3 .100" PITCH | Samtec | TSW-103-07-S-S | |

**FIGURE D-1: TRANSPONDER BOM (CONTINUED)**

| Qty | Component Name | RefDes | Value | Description | Mfr. | Mfr. P/N | Notes |
|---|---|---|---|---|---|---|---|
| 3 | LED-SML-LX231C-TR-RED-2X3MM-SM | D4<br>D5<br>D6 | RED | LED 2X3MM 635NM RED WTR CLR SMD | Lumex® | SML-LX23IC-TR | |
| 5 | RES-CRCW0603 | R6<br>R10<br>R12<br>R14<br>R16 | 4.7K | RES 4.75K OHM 1/10W 1% 0603 SMD | Yageo® | 9C06031A4751FKHFT | |
| 1 | RES-CRCW0603 | R4 | 10 | RES 10.0 OHM 1/10W 1% 0603 SMD | Yageo | 9C06031A10R0FKHFT | |
| 1 | RES-CRCW0603 | R1 | 47 | RES 47.0 OHM 1/16W 1% 0603 SMD | Yageo | 9C06031A47R0FKHFT | |
| 1 | CRCW0603 | R2 | 47K | RES 47.0K OHM 1/16W 1% 0603 SMD | Yageo | 9C06031A4702FKHFT | |
| 2 | CRCW0603 | R13<br>R18 | 100K | RES 100K OHM 1/10W 1% 0603 SMD | Yageo | 9C06031A1003FKHFT | |
| 1 | CRCW0603 | R3 | 220 | RES 220 OHM 1/16W 1% 0603 SMD | Yageo | 9C06031A2200FKHFT | |
| 1 | CRCW0603 | R19 | 270 | RES 270 OHM 1/16W 1% 0603 SMD | Yageo | 9C06031A2700FKHFT | |
| 6 | CRCW0603 | R5<br>R11<br>R15<br>R17<br>R22<br>R23 | 475 | RES 475 OHM 1/16W 1% 0603 SMD | Yageo | 9C06031A4750FKHFT | |
| 2 | CRCW1206 | R7<br>R9 | 10M | RES 10.0M OHM 1/10W 1% 0603 SMD | Yageo | 9C12063A1005FKHFT | |
| 1 | CRCW1206 | R8 | Rlimit 1.7 | RES 1.00 OHM 1/4W 1% 1206 SMD | Yageo | 9C12063A1R00FGHFT | |
| 1 | CRCW0603 | U2 | 433.92MHz | RESONATOR SAW 433.92MHZ 1 PORT | ECS Electronics | ECS-SDR1-4339-TR | |
| 6 | SWT-EVQ-PLMA15 | SW0<br>SW1<br>SW2<br>SW3<br>SW4<br>SW5 | MOM-NO | LIGHT TOUCH SWITCH SMD 260GF 5MM | Panasonic | EVQ-PLMA15 | |
| 1 | TRS-NE94433-SOT23-3 | Q1 | NE-94433 | TRANS NPN OSC FT=2GHZ SOT-23 | NEC® Electronics | NE94433-T1B | |
| 5 | TSP-P60R38 | TP1<br>TPC<br>TPX<br>TPY<br>TPZ | RFPEN | TEST POINT PC MINI .040"D WHITE | Keystone Electronics | 5002 | |
| 1 | CR2032 3V BATTERY | ST1 | Lithium Cell | BATTERY 20MM LITHIUM COIN | Panasonic-BSG | CR2032 | |
| 10 | SHORTING SHUNT | J1-J10 | Shunt | CONN JUMPER SHORTING SHUNT TIN | Sullins® | STC02SYAN | |
| 1 | SOCKET 20-PIN | SU1 | Socket | PCB TRANSPONDER CC W/GND | Mill-Max® | 110-99-320-41-001000 | |
| 1 | PCB | PCB1 | PCB | PLANE | Microchip | 05-50011_RevB.pcb | |

## FIGURE D-2: BASE STATION BOM

| Qty | Component Name | RefDes | Value | Description | Mfr. | Mfr. P/N | Notes |
|---|---|---|---|---|---|---|---|
| 1 | ANTENNA-LEAD | A1 | 6.8" | 20MM THRU HOLE MT COIN HOLDER | Keystone® Electronics | 3003 | |
| 2 | CAP-200LS-NONPOLAR<br>CAP-200LS-NONPOLAR | C3<br>C4 | 0.200LS | CAP,180PF,50V,CERAMIC,0603,SMD | Panasonic® | ECJ-1VC1H181J | |
| 1 | CAP-250LS-NONPOLAR | C5 | 1.0nF | CAP,220PF,50V,CERAMIC,0603,SMD | Panasonic | ECJ-1VC1H221J | |
| 1 | CAP-375LS-NONPOLAR | C6 | 2.2nF | CAP 1UF 16V CERAMIC F 0603 | Panasonic | ECJ-1VF1C105Z | |
| 5 | CAP-CRCW1206<br>CAP-CRCW1206<br>CAP-CRCW1206<br>CAP-CRCW1206<br>CAP-CRCW1206 | C1<br>C7<br>C10<br>C16<br>C24 | 0.1uF | CAP,0.5PF,50V,CERAMIC,0603,SMD | Panasonic | ECJ-1VC1H0R5C | |
| 2 | CAP-CRCW1206<br>CAP-CRCW1206 | C9<br>C12 | 10nF | CAP,18PF,50V,CERAMIC,0603,SMD | Panasonic | ECJ-1VC1H180J | |
| 2 | CAP-CRCW1206<br>CAP-CRCW1206 | C22<br>C23 | 20pF | CAP CER 10UF 10V 10% X5R 0805 | Murata® Electronics | GRM21BR61A106KE19L | |
| 1 | CAP-CRCW1206 | C8 | 100pF | CAP CER 0.10UF 50V X7R 10% 0603 | TDK | C1608X7R1H104K | |
| 1 | CAP-CRCW1206 | C11 | 150pF | CAP CERAMIC 100PF 50V NP0 0603 | | VJ0603A101JXACW1BC | |
| 1 | CAP-ECQ-P4103JU | C2 | 10nF | CAP CERM 300PF 5% 50V C0G 0603 | Rohm® | MCH185A301JK | |
| 1 | CAP-EIA3216-A | C15 | 10uF | CAP,470PF,50V,CERAMIC,0603,SMD | Panasonic | ECU-V1H471KBV | |
| 2 | CAP-CRCW0805<br>CAP-CRCW0805 | C17<br>C18 | 1uF | CAP 1UF 25V CERAMIC X7R 1206 | Panasonic | ECJ-3YB1E105K | |
| 1 | CAP-RAD-160D060S | C14 | 47uF | CAP 10UF 16V CERAMIC F 1206 | Panasonic | ECJ-3YF1C106Z | |
| 1 | CAP-RAD-400D200S | C13 | 100uF | DIODE SWITCH 75V 200MW SOD-323 | Diodes Inc. | 1N4148WS-7 | |
| 1 | CNN-DB9-MALE-RA-PTH | J2 | DE-9P (Male) | DIODE SCHOTTKY 30V 100MA SS-MINI | Panasonic | MA2S784-(TX) | |
| 1 | CNN-POWER-IN-MOD-2.5MM | J4 | 2.5mm | DIODE ZENER 5.1V 0.35W SOT-23 | Fairchild® Technologies | BZX84C5V1 | |
| 1 | RJ11_6PIN | J3 | ICD | CONN HEADER 1X6 .100" PITCH | Samtec® | TSW-106-07-S-S | |
| 1 | AMP770969 | J1 | | PIC, MICROCHIP, 16F639, 20-PIN, PDIP | Microchip | PIC16F639/P | |
| 2 | DIO-10MQ100N-SMA-SMT<br>DIO-10MQ100N-SMA-SMT | D5<br>D8 | 10MQ100N | COIL, AIR, CREDIT CARD, 40AWG | Amatech | 10-00269 | |
| 1 | DIO-UF1005-PTH-DO-41 | D1 | UF1005 | INDUCTOR,RFID,TRANSPONDER | Coilcraft, Inc | 4308RV-715XJBD | |
| 1 | DIODE-DO214AA | D7 | 1N4148 | DIODE SWITCH 75V 500MW MINIMELF | Diodes Inc. | LL4148-13 | |
| 4 | DIODE-DO214AA<br>DIODE-DO214AA<br>DIODE-DO214AA<br>DIODE-DO214AA | D4<br>D9<br>D10<br>D11 | 1N5819 | RECT SCHOTTKY 1A 40V DO-214AA | Micro Comm. | SMB5819 | |
| 1 | DIODE-DO-41 | D6 | 1N4750 | DIODE ZENER 27V 1W 5% DO-41 | Diodes Inc. | 1N4750A-T | |
| 1 | ICA-MCP6022/SN-SOIC-8PIN | U2 | MCP6022 | | Microchip | MCP6022-I/SN | |
| 1 | MCP201-SO8-150 | U5 | MCP201 | | Microchip | MCP201-I/SN | |
| 1 | ICA-TC4422CAT-TO220-5LEAD | U1 | TC4422CAT | | Microchip | TC4422CAT | |
| 1 | ICP-PIC18F4680/P-40PDIP | U3 | PIC18F458/P | | Microchip | PIC18F458-I/P | |
| 1 | MCP2551-SO8 | U6 | MCP2551 | | Microchip | MCP2551-I/SN | |

**FIGURE D-2: BASE STATION BOM (CONTINUED)**

| Qty | Component Name | RefDes | Value | Description | Mfr. | Mfr. P/N | Notes |
|---|---|---|---|---|---|---|---|
| 1 | IND-AIR-10-00189-500V-PTH | L1 | 160uH | IND 160UH 500V AIR | WireBenders® | 10-00189 | |
| 1 | IND-DO5022P-SMT | L2 | DO5022P | IND | Coilcraft, Inc. | | **Do Not Populate** |
| 1 | LCD_2X16_COG | LCD1 | {Value} | LCD | United Radiant | UMSH-3112JNV-1G | |
| 2 | LED-SML-LX231C-TR-RED-2X3MM-SM | D2<br>D3 | GRN | LED 2X3MM 565NM GRN WTR CLR SMD | Lumex | SML-LX23GC-TR | |
| 1 | RES0805 | R14 | 1K | RES 1.00K OHM 1/8W 1% 0805 SMD | Yageo | 9C08052A1001FKHFT | |
| 1 | RES0805 | R13 | 4.7K | RES 4.75K OHM 1/8W 1% 0805 SMD | Yageo | 9C08052A4751FKHFT | |
| 2 | RES0805<br>RES0805 | R18<br>R19 | 15K | RES 15.0K OHM 1/8W 1% 0805 SMD | Yageo | 9C08052A1502FKHFT | |
| 2 | RES0805<br>RES0805 | R17<br>R20 | 25K | RES 24.9K OHM 1/8W 1% 0805 SMD | Yageo | 9C08052A12492FKHFT | |
| 1 | RES0805 | R15 | 120 | RES 121 OHM 1/8W 1% 0805 SMD | Yageo | 9C08052A1210FKHFT | **Do Not Populate** |
| 1 | RES0805 | R21 | Do Not Pop. | RES 121 OHM 1/8W 1% 0805 SMD | Yageo | | |
| 1 | RES0805 | R25 | 0 | RES 0.0 OHM 1/8W 5% 0805 SMD | Yageo | 9C08052A0R00JLHFT | |
| 1 | RES-CRCW1206 | R12 | 1K | RES 1.00K OHM 1/4W 1% 1206 SMD | Yageo | 9C12063A1001FKHFT | |
| 1 | RES-CRCW1206 | R6 | 3.92K | RES 3.92K OHM 1/4W 1% 1206 SMD | Yageo | 9C12063A3921FKHFT | |
| 1 | RES-CRCW1206 | R9 | 4.87K | RES 4.87K OHM 1/4W 1% 1206 SMD | Yageo | 9C12063A4871FKHFT | |
| 1 | RES-CRCW1206 | R3 | 4.99K | RES 4.99K OHM 1/4W 1% 1206 SMD | Yageo | 9C12063A4991FKHFT | |
| 4 | RES-CRCW1206 | R1<br>R2<br>R11<br>R22 | 4.99M | RES 4.99M OHM 1/4W 1% 1206 SMD | Yageo | 9C12063A4994FKHFT | |
| 1 | RES-CRCW1206 | R10 | 5.11K | RES 5.11K OHM 1/4W 1% 1206 SMD | Yageo | 9C12063A5111FKHFT | |
| 1 | RES-CRCW1206 | R7 | 16.5K | RES 16.5K OHM 1/4W 1% 1206 SMD | Yageo | 9C12063A1652FKHFT | |
| 2 | RES-CRCW1206<br>RES-CRCW1206 | R23<br>R24 | 49.9K | RES 49.9K OHM 1/4W 1% 1206 SMD | Yageo | 9C12063A4992FKHFT | |
| 1 | RES-CRCW1206 | R8 | 78.7K | RES 78.7K OHM 1/4W 1% 1206 SMD | Yageo | 9C12063A7872FKHFT | |
| 1 | RES-CRCW1206 | R4 | 80.6K | RES 80.6K OHM 1/4W 1% 1206 SMD | Yageo | 9C12063A8062FKHFT | |
| 1 | RES-CRCW1206 | R5 | 162K | RES 162K OHM 1/4W 1% 1206 SMD | Yageo | 9C12063A1623FKHFT | |
| 1 | RES-CRCW1206 | R16 | 270 | RES 270 OHM 1/4W 1% 1206 SMD | Yageo | 9C12063A2700FKHFT | |
| 1 | RF-MODULE-RR8 | U4 | 433.92MHz | RR8 433.92MHZ ASK RF RECEIVER | Tellicontrolli | AMHRR3-433 | |
| 7 | TSP-P90R60 | TP1<br>TP2<br>TP3<br>TP4<br>TP5<br>TP6<br>TP7 | WHI | TEST POINT PC MULTI PURPOSE WHI | Keystone Electronics | 5012 | |
| 2 | TSP-P90R60 | TP8<br>TP9 | BLK | TEST POINT PC MULTI PURPOSE BLK | Keystone Electronics | 5011 | |

**FIGURE D-2: BASE STATION BOM (CONTINUED)**

| Qty | Component Name | RefDes | Value | Description | Mfr. | Mfr. P/N | Notes |
|---|---|---|---|---|---|---|---|
| 1 | VRG-5.0V-ZMR500F-SOT23 (223) | VR1 | LM3480IM3-5.0 | IC 5.0 100MA LDO VREG SOT23 | National Semiconductor | LM3480IM3-5.0 | |
| 1 | XTL-200LS-PTH-CAN | Y1 | 20.0MHz | CRYSTAL 20.000MHZ 20PF HC-49/US | ECS Inc. | ECS-200-20-4 | |
| 1 | SOC-SOCKET-MACH.PINS-40-PIN | SU3 | 40-PIN | IC SOCKET 40PIN MS TIN/TIN .600 | Mill-Max Corp. | 110-93-640-41-001000 | |
| 1 | PCB-BLANK | PCB1 | | | Microchip | 05-50020_RevB | |
| 1 | BUZZER | BZ1 | | AUD SIG DEVICE 3-20VDC PCB | Mallory Sonalert | MSR320 | |
| 1 | NO PATTERN - MODIFICATION | Rmod1* | 11.0K | RES 11.0K OHM 1/4W 1% METAL FILM | Yageo | MFR-25FBF-11K0 | |
| 1 | NO PATTERN - MODIFICATION | Dmod1* | 1N41418 | RECTIFIER SILICON .15A 75V DO-35 | Micro Commercial | 1N4148 | |

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