AN1391

Introduction to the BodyCom Technology

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INTRODUCTION

The BodyCom system is a new short-range wireless connectivity technology that uses the capability of the human body to transport a few signals that provide intuitive, simple, and safe communication between two electronically compatible devices. Communication between BodyCom system devices occurs when they are within a few centimeters of the human body: a simple proximity or touch detection can establish a BodyCom system connection.

MICROCHIP SOLUTION

Traditional wireless remote access systems rely on an RF link, with a typical range of 400 to 900 MHz. While providing the convenience of remote control, these systems also require manual activation by the user and an additional level of security to prevent “sniffing” of the security codes during transmits. While these limitations are surmountable, they can be challenging for both the designer and the user, for example, when the user is trying to enter their house during a rain storm while holding a brief case and a bag of groceries.

BodyCom overcomes these limitations by using the user’s body as the medium for data transmission. Data is capacitive coupled between the Base and Mobile Units through the user’s body using a low-frequency Amplitude Shift Key (ASK) format whenever the user and the Base Unit come in contact with each another. The user’s touch also creates a simple capacitive touch detection to initiate the challenge and response sequence between the Base and Mobile Units whenever the user is present.

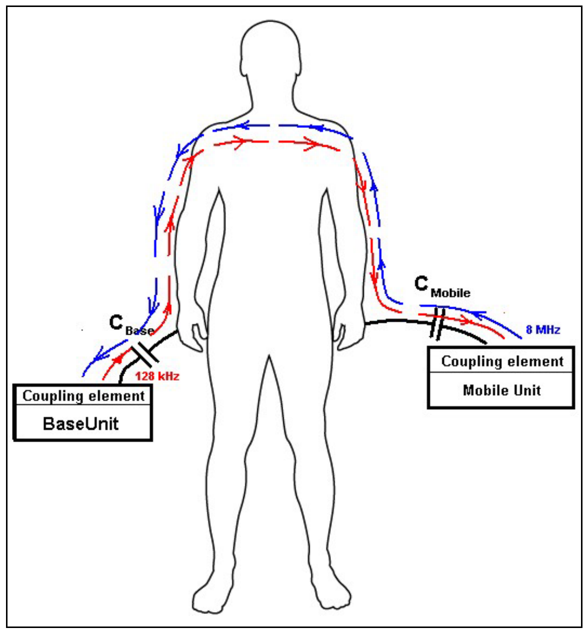
Due to the high permittivity of the human body at low frequencies, transmissions can be achieved with a simple, easily-designed system operating between 60 kHz to 30 MHz. Because the data is coupled through the user, there is no RF transmission creating security issues, and the touch initiation system removes the need for manually triggering the sequence.

The BodyCom system provides an easy-to-use system that is secure to use and easy to design, layout and produce.

The BodyCom system was implemented with the following priorities:

- Very low consumption, especially for the Mobile Unit
- Fast system response
- Stable and Robust communication with Fault detection
- Limited field of action (as little as a few centimeters) to allow an identification when the touch action takes place from whoever wears the Mobile Unit
- Low cost and complexity

FIGURE 1: BODYCOM SYSTEM WORKING PRINCIPLE



The signal transmission uses capacitive coupling between the human body, the Base Unit and the Mobile Unit (Figure 1). Because of this, the signals are more attenuated at low frequencies than at high frequencies, requiring the signals that are transmitted to have higher amplitude for lower frequencies. The Mobile Unit is a battery-powered portable device, and power consumption is a priority, while the Base Unit can deliver more power.

Another constraint in frequency choice is the result of the Mobile Unit's power consumption in Receive mode. This is a result of the limited low-power receiver circuits available on the market, which limits the receiving frequency to the 60-400 kHz range. That, in addition to the low-power consumption in Transmission mode demanded by the same unit, it is recommended to use a frequency between 6 and 13 MHz for the transmitting channel (the relation between the power consumption and the performance is optimum within that frequency range).

A frequency of 128 kHz has been chosen for the channel transmitted from the Base Unit and received by the Mobile Unit.

A frequency of 8 MHz has been chosen for the channel transmitted from the Mobile Unit and received by the Base Unit (frequency is available using the on-chip oscillator).

Base-to-Mobile Transmission

In a BodyCom system, the communication is initiated by the Base Unit. In order to start a communication when the system is coupled with the human body only, the PIC® MCU performs touch detection continuously.

When a touch is detected, the microcontroller stops touch detection and initiates a transmission that searches for the Mobile Unit. The generated sequence is applied through a driver to an LC circuit working in Resonant mode. This circuit is connected to a coupling pad that transfers the signal to the human body. In this way, the human body becomes an extension of the coupling element, allowing the transfer of the signal in the proximity of the Mobile Unit.

As previously mentioned, as the Base Unit can deliver more power to the transmitting channel, a low frequency (128 kHz) was chosen for the transmitting channel. This is possible because the Base Unit, being a fixed part of the system, can be powered externally or can have a bigger battery attached.

The signal generated by the Base Unit will be transmitted to the Mobile Unit, which is typically waiting in Signal mode (low-power consumption). The transmitted signal received will cause a wake-up of the Mobile Unit receiver.

Mobile-to-Base Response

After the transmitted signal is received by the Mobile Unit, it decodes the data and, if a response is necessary, will respond.

The Mobile Unit is also capacitively coupled with the human body; the lowest power consumption in Transmission mode and better coupling phenomena at high frequencies, which demand the use of a high frequency for the response channel (8 MHz is available on the board using the PIC MCU internal RC oscillator).

The response is sent by the Mobile Unit using the 8 MHz transmitting channel; the signal is carried by the human body in the vicinity of the Base Unit and is applied through the coupling pad to the Base Unit receiving block. This is a complete receiver solution, including a pre-amplifier, a step-down mixer, filters and a data decoder/demodulator. The output of the receiver is connected to the PIC microcontroller; and will receive the complete sequence and decode the incoming data.

BASE UNIT BLOCK DIAGRAM

The Base Unit should be able to perform the following functions:

- Touch/proximity detection
- Send challenge to the Mobile Units
- Receive and decode incoming data
- Simple communication/control interface for easy integration with other systems

FIGURE 2: BASE UNIT BLOCK DIAGRAM

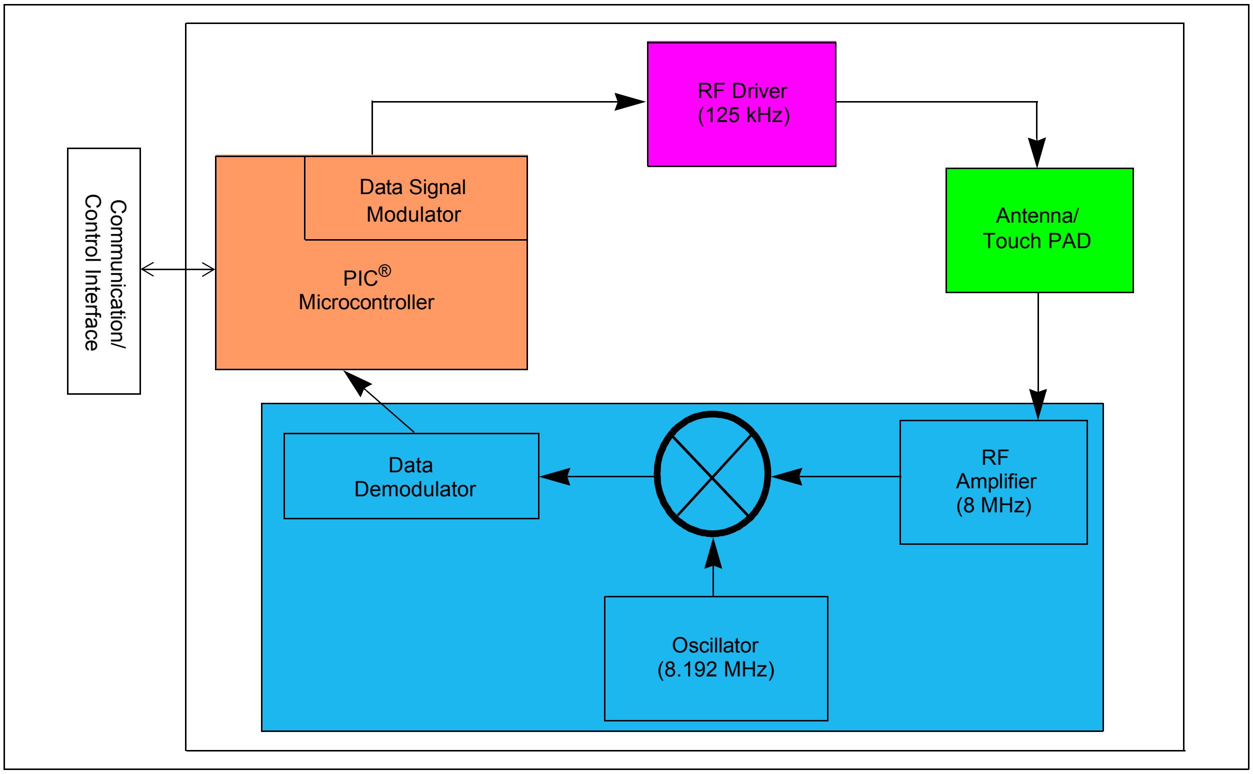


Figure 2 shows a block diagram for the Base Unit. It includes a complete receiver system, the transmission circuitry and a communication interface, all of which are managed by a PIC microcontroller.

The receiver module provides a robust and efficient demodulation/decoding circuitry implementation for compatible transponder signals. The microcontroller manages the complete transmission/receiving process, performing encoding/decoding and error detection. In addition, it supports implementation of a security algorithm for secure communication.

The transmitter module drives a coupling pad designed to support additional touch/proximity detection. A simple serial interface can be directly connected to other systems or microcontrollers to ensure easy integration and design flexibility.

Touch Detection

In a typical BodyCom system, communication between the Base Unit and the Mobile Unit is started when a touch/proximity event is detected. The Base Unit waits for this event and initiates the communication only when the user touches the pad or is in proximity of the coupling element (coupling/attenuation of the low frequency signal through the human body limits the range of the Base Unit to less than 1 cm).

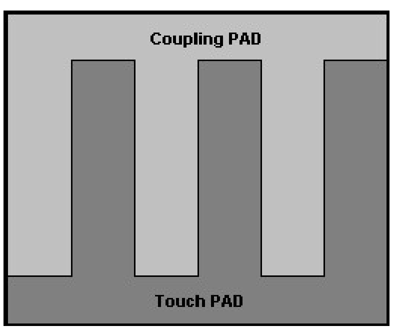
In our example, touch detection is achieved through the PIC microcontroller input using the CVD technique. The user may choose another method to do touch/ proximity detection for better performance of a custom design.

In a standard application, the coupling element and the touch pads are in close proximity. During the transmission, a high voltage is applied to the coupling element and affects touch detection. Because of this, touch detection should be stopped during this period.

The following configurations were used for the coupling element and the touch pad design:

1. **Coupling Element and Touch PAD – Finger Style**

FIGURE 3: COUPLING ELEMENT AND TOUCH PAD – FINGER STYLE

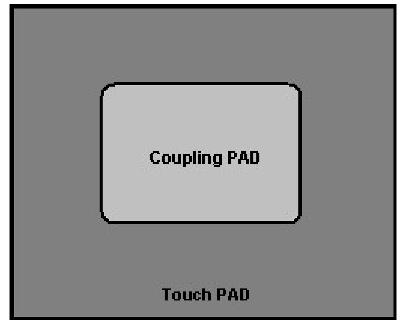


- The coupling capacitance between the coupling element and the touch pad is high, especially when the user touches the pad's surface, which will cause a signal attenuation during the reception/transmission.
- The touch/proximity detection is easy and does not depend on the finger position on the pad area.
- The design needs two pads and wire connection between the pad area and the component area.

Note:	This design has good performance for applications where the coupling element/ touch pad need to be isolated (the user does not touch directly on the pad).

2. **Coupling Element in the Center of the Touch/ Proximity Detection Area**

FIGURE 4: COUPLING ELEMENT IN THE CENTER OF THE TOUCHING PAD



- The coupling capacitance between two pads is lower than with the previous solution; the user touches the coupling element directly, without touching the sensing pad. In this way, the attenuation of the incoming signal is minimum.
- The sensitivity of the receiver is increased compared to the previous solution, because the coupling with the touching pad is reduced.
- The design needs two pads and wire connection between the pad area and the component area.

Note:	The design is recommended for applications that require proximity detection.

3. **The Pad Is Shared by the Coupling Element and the Touch Circuitry**

- The same copper pad is shared by the coupling element and the touching circuitry; only one wire is needed between the pad and the component area.
- The touch pad is connected directly to the LC circuit, where high voltage appears during the transmission. To avoid the possibility for high voltage to be applied directly to the microcontroller pins, the touch input should be connected to one of the ends of the LC oscillating circuit.
- The output capacitance of the driver and the input capacitance of the receiver appear directly in parallel with the capacitance of the pad, reducing the sensitivity of the touch sensing circuit (no proximity detection).

Note:	Because of the structure, a significant capacitance appears between the coupling element and the touch pad when this area is touched. To avoid false triggering of the system, it is recommended that the output of the driver be driven low during capacitive touch detection. The user may need to tune the CVD algorithm because of the big capacitance.

Data Packet Structure

The structure of the data packet used for communication should allow a robust communication between units. In Figure 5, the preamble sequence is required by the MCP2030 to activate its circuitry. This sequence is followed by a timing filter (configurable in the software) that minimizes the false wake-up of the PIC microcontroller in order to minimize the power consumption of the entire circuit.

The communication begins with a 1 ms pulse, which is needed by the PIC MCU to wake-up from Sleep. During this time, the internal RC oscillator will stabilize and the PIC MCU performs all initialization of the peripherals needed for the data reception. To minimize power consumption during the data reception period, the PIC MCU will run at 500 kHz and use the hardware UART for data reception. An auto-baud mechanism is used for data reception, which will minimize the communication errors.

FIGURE 5: RECEIVER STATE DIAGRAM FUNCTION BY DATA PACKET

Preamble	Filter	Wake-up Pulse	Auto Baud Byte	SOF	Length	Data[0..n-1]	CRC Byte	EOF
6 ms ON, 0.5 ms OFF	x ms ON, y ms OFF	1 ms ON	0x55	0x7F	1 Byte	n Bytes	1 Byte	5 ms ON

MCP 2030	Wait for sig-nal	Activate amplifier & data demodulator	Check filter time	Decode incoming data
PIC16LF1827	Sleep mode		Wake-up	USART Tx Active

The data packet is composed of two parts: one that is required by the hardware to work properly, and the other is a data sequence.

The part required by the hardware has the following sequence:

- *Preamble time* – used by MCP2030 internal circuitry to configure and activate its internal Automatic Gain Control (AGC) circuit (see MCP2030 Data Sheet (DS21918) for detailed timing requirements)
- *Filter time* – used as preliminary filtering by MCP2030. This sequence minimizes false wake-up of the PIC MCU
- *Wake-up pulse* – used by the PIC MCU to activate UART data reception

The following section is open for users to create a custom data packet. In the demo application, the following format is used for the data packet:

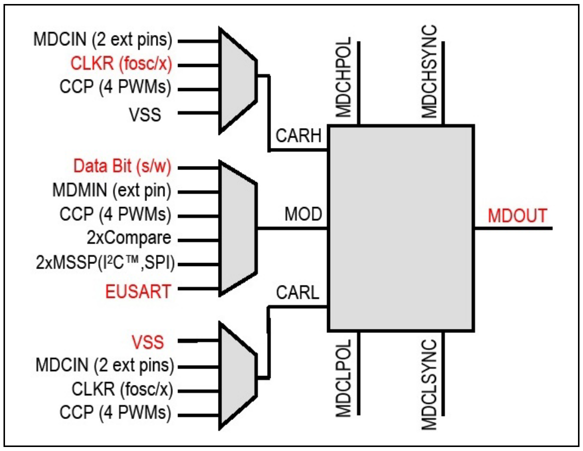
- *Auto Baud byte* – configures baud rate of the PIC MCU UART module for the incoming stream
- *SOF (Start of Frame) byte* – special character used as the start of the data packet indicator
- *Length byte* – contains the length of the data packet
- *Data[0..n-1]* – data packet
- *Checksum byte* – checksum of received bytes
- *End of Frame sequence (EOF)* – continuous signal used by the receiver to evaluate the RSSI value of the incoming signal.

Data Signal Modulator (DSM)

For easy modulation of the data packet, with minimum usage of the PIC MCU processing power, the BodyCom system uses microcontrollers with an on-chip Data Signal Modulator (PIC16F/LF182x family). The Data Signal Modulator (DSM) is a peripheral that allows the user to mix a data stream with a carrier signal to produce a modulated output.

The DSM block diagram is illustrated in Figure 6.

FIGURE 6: DATA SIGNAL MODULATOR



In a BodyCom system, the DSM uses USART as the modulation source for the transmitted signal. For the modulated signal, a 128 kHz frequency for the Base Unit or 8 MHz for the Mobile Unit is generated using the on-chip clock module and applied to the DSM. By using those hardware resources, the PIC MCU processing power is reduced to a minimum.

According to the MCP2030 requirements, the allowed baud rates are between 100 Hz and 10 kHz. A higher possible baud rate in this range is recommended, because it reduces the active time required by the PIC MCU during reception and transmission, reduces power consumption, and increases battery life (especially for the Mobile Unit).

Base Transmitter

On a typical BodyCom system, the Base Unit initiates communication with the Mobile Unit. The microcontroller delivers a square-shaped voltage that is applied to a driver working with a series resonant LC circuit. Due to the full-bridge configuration of the drivers, the peak-to-peak output voltage, V_{pkpk}, is approximately double the power supply, corresponding to an RMS voltage about power supply:

EQUATION 1:

$$V_{PKPK} \sim 2 * V_{DD}$$
$$V_{rms} = V_{LC} = 50\% * V_{PKPK} \sim V_{DD}$$

The current flowing through the coupling pad is sine shaped, and the peak and RMS values are approximately:

EQUATION 2:

$$I_{ant} = \frac{4}{Pi} * \frac{V_{LC}}{R_{LC}}$$

In general, the higher the Q, the higher the power output for a particular LC circuit.

EQUATION 3:

$$P = \frac{V_{rms}^2}{R}$$

Unfortunately, too high a Q may conflict with the band-pass characteristics of the transmitter, and the increased ringing could create problems in the protocol bit timing. Those reasons and the bandwidth required for transmission of the data limit the quality factor of the LC circuit.

Base Unit LC Driver Guidelines

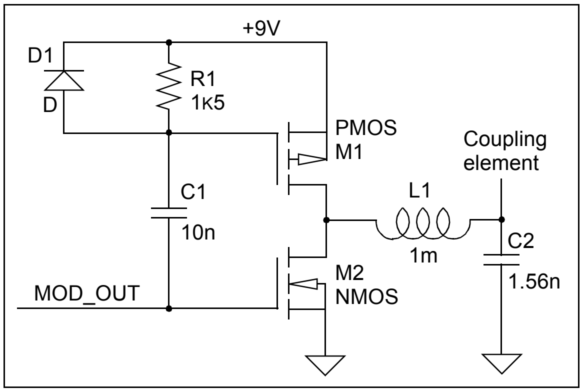
When a specific driver configuration is used for the BodyCom system, the following criteria needs to be considered for this circuit:

- Be able to drive the LC circuit in Resonant mode at 128 kHz, with smooth and fast transitions from on-to-off state
- Have low output resistance in Transmitting mode
- Have high-impedance during reception for the incoming signal (8 MHz)
- Have low-power consumption during reception or Idle state

The following configurations were used for the LC driver:

1. **Half-Bridge MOSFET Driver:**

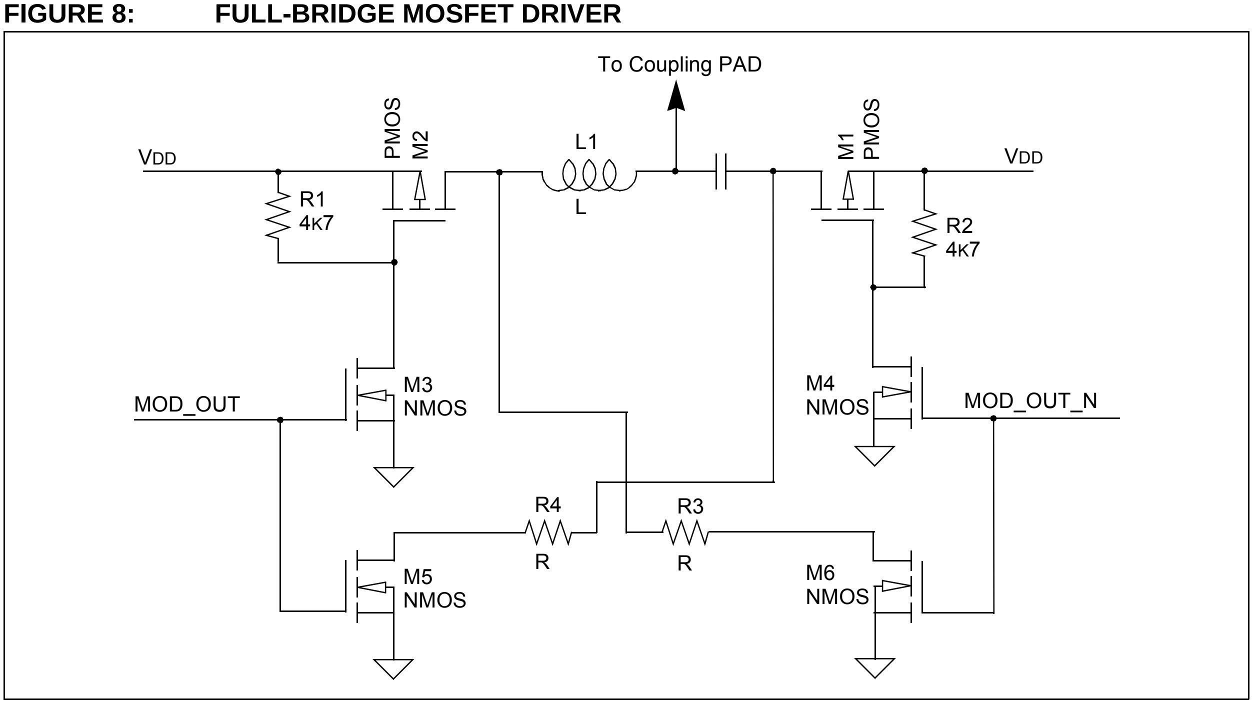
FIGURE 7: HALF-BRIDGE MOSFET DRIVER



- uses only one output pin from the PIC microcontroller – modulation output
- driver tri-state time is high (depends on the R1C1 input constant)
- touch/proximity detection is difficult without additional circuitry when a common pad is used as coupling element and touch detector
- touch detection will not work with the CVD technique (high capacitance); other touch detection techniques should be used
- needs higher voltage than full-bridge configuration for the same performance
- low component count

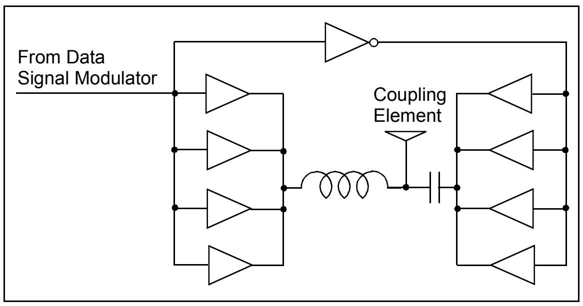
2. **Full-Bridge Bipolar/MOSFET Driver:**
   - the modulation output from the PIC microcontroller needs to be inverted and applied to the driver using the on-chip comparator or an external device (additional resources)
   - has a very low output resistance in Conducting mode
   - the amplitude of the generated signal is easy to configure using the series output resistor
   - works with wide ranges of power supply voltages (3.3 to 12V)
   - touch/proximity can be done when a common pad is used as the coupling element for touch detection as well (the LC circuitry can be isolated from the ground)
   - higher price/component count than the half-bridge solution
   - best performance/configurability

FIGURE 8: FULL-BRIDGE MOSFET DRIVER



3. **Full-Bridge Driver Using Logic Gates:**
   - needs at least two pins for the driver: modulation output and tri-state output
   - many outputs of the logic gates should be connected together in order to minimize the output resistance of the driver
   - no need for additional circuitry/connection to tri-state its outputs when gates with tri-state capabilities are used
   - works only for voltages below 5V
   - low components count
   - easy to be debugged

FIGURE 9: FULL-BRIDGE DRIVER USING LOGIC GATES



4. **Full-Bridge Driver Using MOSFET Drivers with Output Enable Capabilities (MCP14Ex Family)**
   - needs two pins for the driver: modulation output and tri-state output
   - low output resistance
   - tri-state capabilities
   - works only for voltages greater than 4.5V
   - lowest components count
   - easy to be debugged.

Table 1 is a comparison of the driver configuration described previously.

FIGURE 10: FULL-BRIDGE DRIVER USING INTEGRATED MOSFET DRIVERS

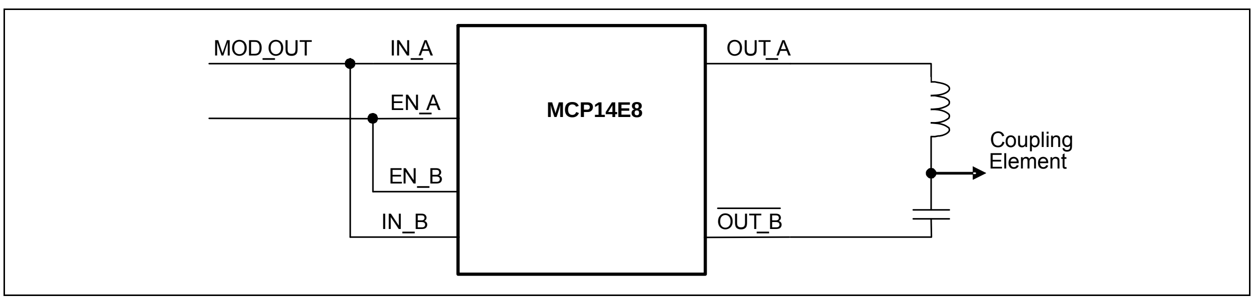


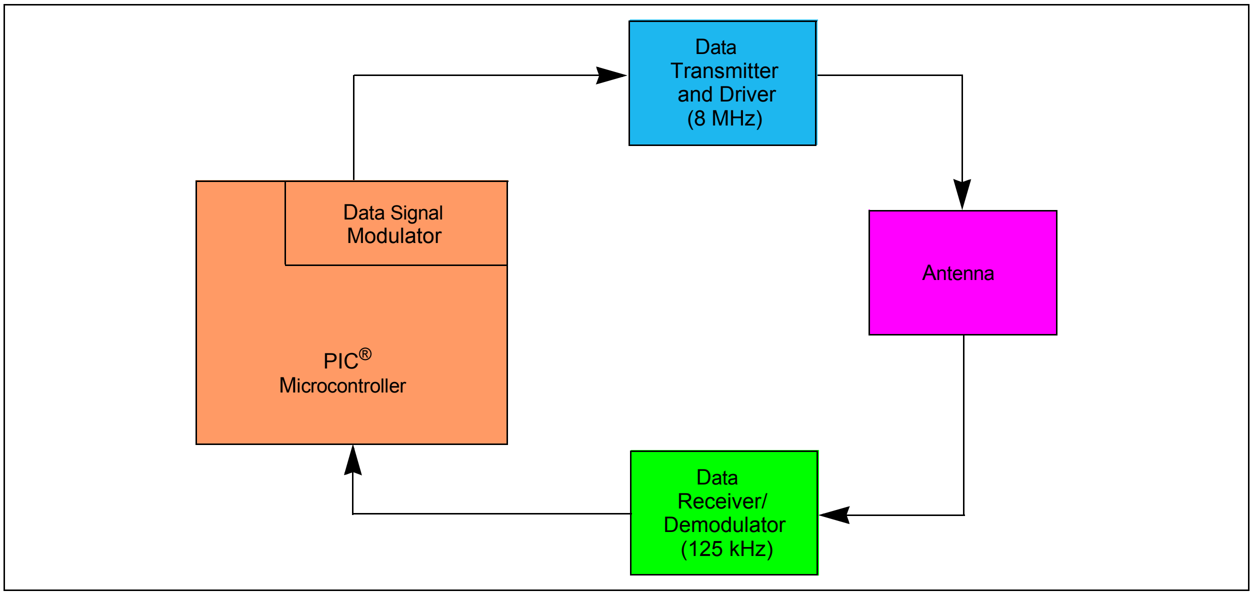
TABLE 1: DRIVER COMPARISON

	Single Ended @9V	Full-Bridge using Logic Gates @ 5V	Full-Bridge MOSFET Transistors @ 5V	Full-Bridge using MOSFET Driver @ 5V	Full-Bridge using MOSFET Driver @ 9V
Driver complexity	Medium	Low	High	Lowest	Lowest
Driver output voltage	+++	+	+++	++	++++
Cost	Low	Low	Medium	High	High

Mobile Unit Block Diagram

In a BodyCom system, the Mobile Unit should be able to receive and process the incoming data, and send back an answer, all performed with very low-power consumption. Figure 11 is a basic diagram of the Mobile Unit.

FIGURE 11: MOBILE UNIT BLOCK DIAGRAM



On the market, there are integrated devices for data reception/demodulation with very low-power consumption, but the working frequency is limited to 60-400 kHz. The frequency should be generated on the Base Unit with minimum PIC microcontroller hardware resources. With this in mind, the receiving frequency of the Mobile Unit is 128 kHz (8.192 MHz divided by 64 using the on-chip reference clock module).

For the data reception/demodulator, the MCP2030 was chosen; it will allow very low power consumption while waiting for challenge. It is a highly integrated, low-frequency receiver used in low-power RFID applications. It performs data filtering/amplification/detection with minimum power consumption, without the need of processing power from the PIC microcontroller.

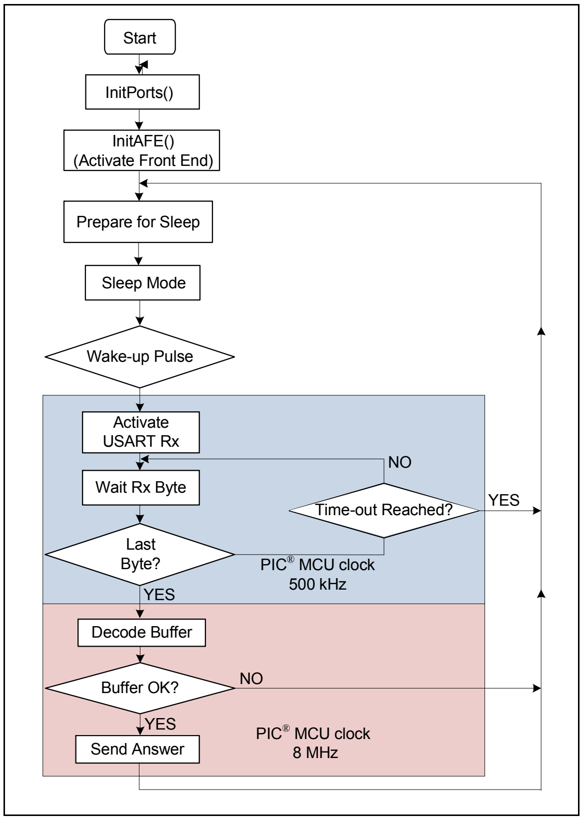
On the microcontroller side, a PIC MCU with low-power capabilities is recommended (XLP series). In addition, this microcontroller should be able to decode all incoming signals with minimum power consumption. If an answer is necessary, the microcontroller should be able to generate an On-Off Key (OOK) modulated signal (with a frequency range between 6 and 13 MHz).

On the current design, PIC16LF1827 was chosen for its multiple resources, which allow users to develop a custom application starting from the current design, without major hardware and firmware changes. PIC16LF1827 is a member of the XLP family, with a power consumption bellow 100 nA in Sleep mode. The frequency of the transmitting channel is generated using the 8 MHz on-chip oscillator.

Mobile Unit – Operating Mode

In normal operation mode, at power-up, the PIC microcontroller performs all initialization of MCP2030 and the internal peripherals, then switches to Sleep mode to lower power consumption. A signal received from the coupled element crosses L1; it has little importance for these frequencies (128 kHz), and is applied to the MCP2030 input through a capacitor. The MCP2030 is programmed to perform a preliminary filtering of the incoming data stream (and minimizes the false wake-up of the PIC microcontroller).

FIGURE 12: MOBILE UNIT STATE DIAGRAM



If the signal meets the filtering timings programmed inside of MCP2030, this chip will start to output the data stream. The stream should start with the 1 ms high pulse needed by the PIC microcontroller to wake-up and to configure its peripherals for data reception. This pulse can also be used as a supplementary filtering in order to minimize power consumption (if the pulse duration does not meet the internal specifications, the microcontroller will go directly to Sleep mode, without waiting to receive any data). In order to minimize power consumption, the microcontroller works at 500 kHz during reception (USART hardware used for data reception). When all data have been received, the PIC microcontroller switches its clocks to 8 MHz and starts processing/decoding the received data. An answer is sent back using an 8 MHz OOK modulated signal.

The output data string is transmitted using the on-chip USART modulated with the internal 8 MHz clock using the DSM. The square-shaped sequence is then applied to a driver working with a series resonant LC circuit.

After the answer sequence is sent, the microcontroller deactivates all internal circuitry and switches back to the Sleep state.

TABLE 2: MOBILE UNIT TYPICAL POWER CONSUMPTION (PRELIMINARY)

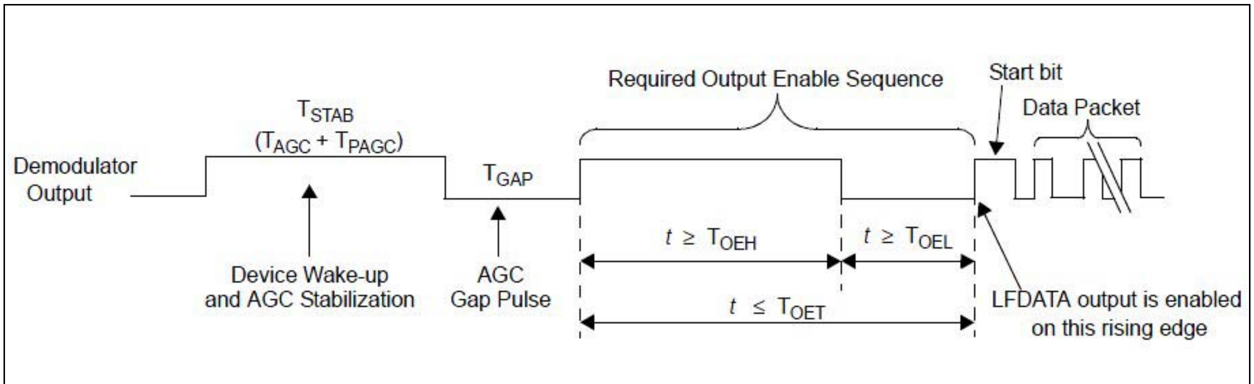
	Wait for Signal	Receive Data	Decode Data	Send Answer
MCP2030	Wait for signal (2 µA)	Decode data (10 µA)	Sleep (0.2 µA)	
PIC18LF1827	Sleep (<1 µA)	PIC® MCU clock: 500 kHz (150 µA)	PIC® MCU clock: 8 MHz (1.3 mA)	
Tx Driver	OFF (0.1 µA)			ON (15 mA)
Time (for 5000 baud rate)	NA	5 ms + (2 ms * Nbytes)	< 1 ms	16 ms + (2 ms * Nbytes)
Power Consumption	3 µA	160 µA	1.3 mA	17 mA

MCP2030 CIRCUIT DESCRIPTION

MCP2030 is a highly integrated configurable device used for low-frequency data demodulation/decoding. The device's high input sensitivity (as low as 1 mV_{pkpk}) and ability to detect weakly modulated input signals (as low as 8%), with its low-power feature set, makes the device suitable for various applications.

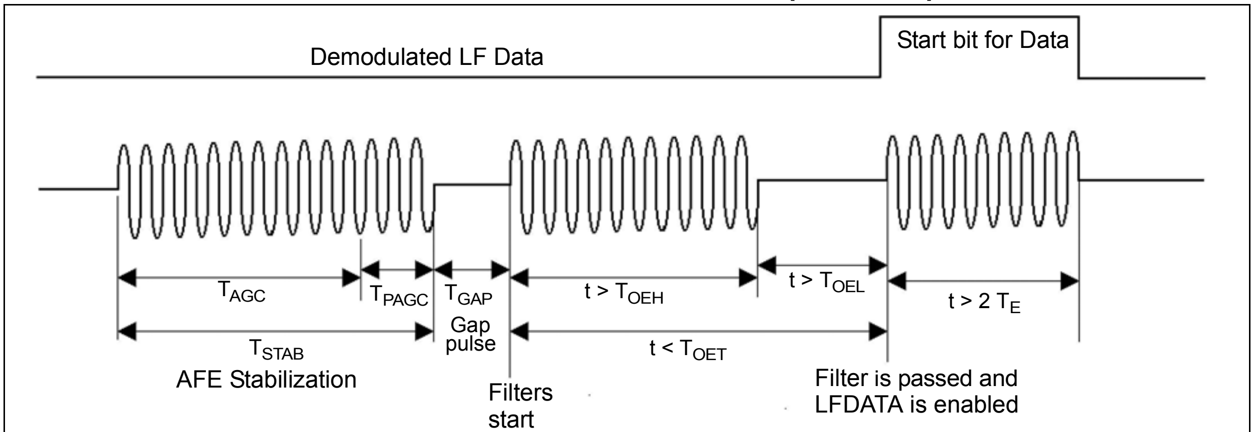
The MCP2030 has an internal configurable, output enable timing filter. The purpose of this filter is to enable the LFDATA output and wake the external microcontroller only after receiving a specific sequence of pulses on the input pins. Therefore, it prevents waking up the external microcontroller due to noise or unwanted input signals. The circuit compares the timing of the demodulated header waveform with a pre-defined value, and enables the demodulated LFDATA output when a match occurs (see Figure 13).

FIGURE 13: OUTPUT ENABLE FILTER TIMING



The output enable filter consists of a high (T_{OEH}) and low (T_{OEL}) duration of a pulse, immediately after the AGC settling gap time. The selection of high and low times further implies a maximum period of time. The output enable high and low times are determined by SPI programming. Figure 13 and Figure 14 show the output enable filter waveforms. There should be no missing cycles during T_{OEH}. Missing cycles may result in failing the output enable condition.

FIGURE 14: OUTPUT ENABLE FILTER TIMING EXAMPLE (DETAILED)



Legend:

T_{AGC}	AGC initialization time
T_{PAGC}	High time after T_{AGC}
T_{STAB}	AGC stabilization time
T_{GAP}	AGC stabilization gap
T_{OEH}	Minimum output enable filter high time
T_{OEL}	Minimum output enable filter low time
T_{OET}	Maximum output enable filter period
T_E	Time element for pulse

Disabling the output enable filter disables the TOEH and TOEL requirement and the device passes all detected data. Table 3 shows the supported combinations for TOEH and TOEL.

TABLE 3: OUTPUT ENABLE FILTER TIMING

OEH <1:0>	OEL <1:0>	TOEH (ms)	TOEL (ms)	TOET (ms)
01	00	1	1	3
01	01	1	1	3
01	10	1	2	4
01	11	1	4	6
10	00	2	1	4
10	01	2	1	4
10	10	2	2	5
10	11	2	4	8
11	00	4	1	6
11	01	4	1	6
11	10	4	2	8
11	11	4	4	0
00	xx	Filter Disabled		

Mobile-to-Base Transmission

With the BodyCom system, the coupling element is shared by the receiver and the transmitter. Because of the different working frequencies for the receiver and the transmitter, the circuitry used for the transmitter should not affect the sensitivity of the receiver at the working frequency.

For transmission, an 8 MHz OOK modulated signal with an amplitude of about 25V peak-to-peak should be generated on the coupling element. A square wave OOK modulated signal is generated using the on-chip DSM and is applied to a driver that works with an LC circuit in Resonant mode. The resonant frequency of the LC circuit can be calculated:

EQUATION 4:

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

Reactive components such as capacitors and inductors are often described as quality factor Q. While it can be defined in many ways, its most fundamental description is a measure of the ratio of stored vs. lost energy per unit time:

EQUATION 5:

$$Q = P_{LC} / P_{AVG}$$

Generally, an ideal active element (L or C) stores the energy:

EQUATION 6:

$$P_{LC} = \frac{1}{2} * \omega_0 * L * I_{pk}^2 = \frac{1}{2} * \omega_0 * C * V_{pk}^2$$

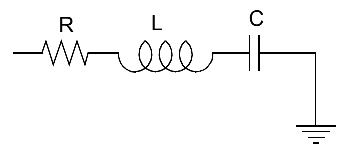
and is lost due to the resistive component of the same components:

EQUATION 7:

$$P_{AVG} = \frac{1}{2} * R * I_{pkpk}^2 = \frac{1}{2} * 1/R * V_{pkpk}^2$$

If we consider an example of a series resonant circuit:

FIGURE 15: RLC SERIES CIRCUIT



At resonance, the reactances cancel out, leaving just a peak voltage, V_{pkpk}, across the loss resistance, R. Thus, $I_{pkpk} = V_{pkpk}/R$ is the maximum current which passes through all elements.

In terms of the series equivalent network for a capacitor shown above, its Q is given by:

EQUATION 8:

$$Q = \frac{1}{\omega_0 * R * C}$$

Since this Q refers only to the capacitor itself, in isolation from the rest of the circuit, it is called unloaded Q or QU. The higher the unloaded Q, the lower the loss. Notice that the Q decreases with frequency.

MOBILE UNIT LC DRIVER REQUIREMENTS

This application note will not describe how to design an LC driver in Resonant mode, but will cover different driver typologies that can be used on the board, with some advantages and disadvantages for each typology used in the past; the user should choose the best version for a specific design.

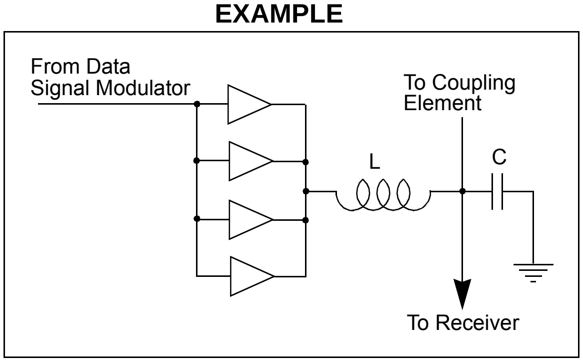
The following are recommended when a new driver is used:

- should have a low complexity and cost
- should work at low voltage (minimum 2.2V)
- should have minimum power consumption in Sleep/waiting for Signal mode
- the output impedance should be very low in Transmission mode and High-Z in Receiving mode
- should be able to drive the LC circuit at 8 MHz in Resonant mode
- the transition from on-to-off state of the modulated signal should be smooth

The following two designs were used:

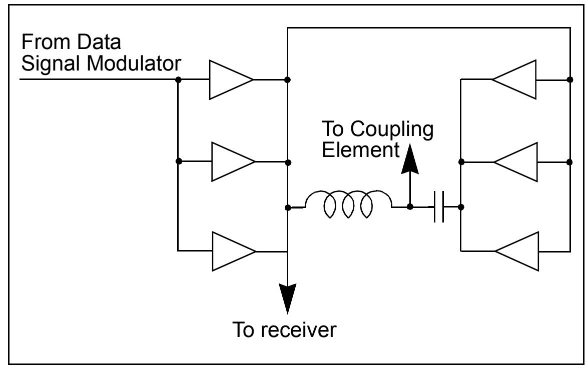
1. **Single ended driver** has the lowest output impedance. The main disadvantage of this configuration is the capacitor connected between the coupling pad and the ground; this capacitor acts like a short during the reception for low frequency and decreases the sensitivity of the Mobile Unit.

FIGURE 16: MOBILE UNIT – SINGLE ENDED LC DRIVER EXAMPLE



2. **Full-bridge driver** also has a low output impedance. Because of this configuration, the decrease in sensitivity caused by the capacitor situated between the coupling element and the ground is eliminated. By using this configuration, the amplitude of the square wave signal to the LC ends will be double than when a single ended driver is used.

FIGURE 17: MOBILE UNIT – FULL-BRIDGE LC DRIVER EXAMPLE



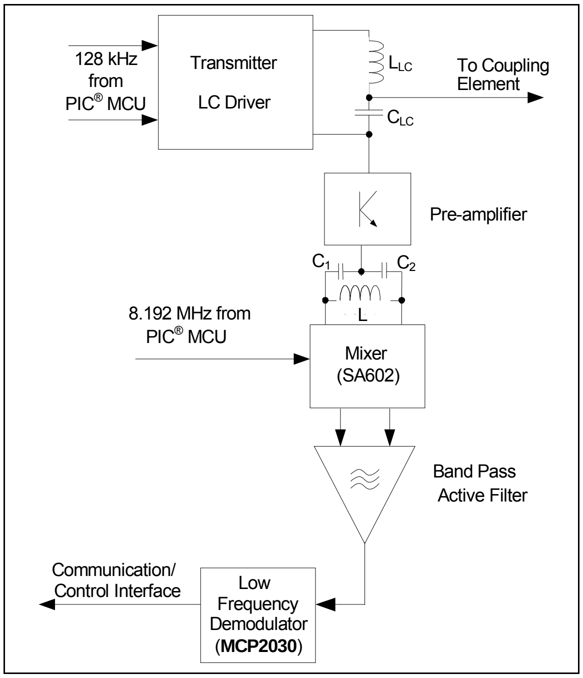
To minimize the power consumption during reception and in Sleep mode, the driver needs to be tri-stated by cutting off its power supply using a power switch. This method can be used because small signals are applied during the reception and those signals will not affect/ damage the unpowered device.

> **Note:** The power switch used should have very low output impedance for all working voltages (2.2 to 3 Volts). The user should use an active element (MOSFET in this design) that has ensured operation for all voltage range.

BASE UNIT RECEIVER OVERVIEW

The receiving block is a complete receiver solution, including a pre-amplifier, step-down mixer, filters and a data demodulator.

FIGURE 18: RECEIVER SCHEMATIC

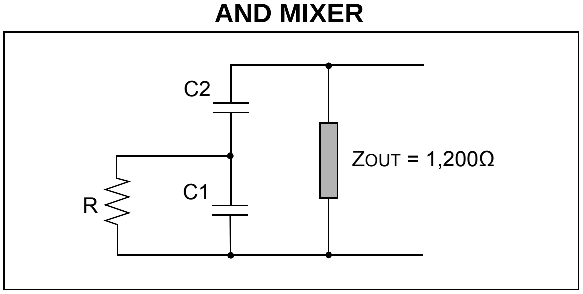


The signal sequence generated by the Mobile Unit is capacitively coupled with the Base Unit receiver through a coupling element. The incoming data crosses capacitor CLC and is applied to a pre-amplifier circuit (bipolar transistor in amplifier configuration, Q1).

This circuit is followed by a mixer that performs the down conversion of the incoming data. The chosen mixer circuit (SA602) has excellent gain, intercept and sensitivity. It also needs low count external parts.

On the mixer input, an unbalanced capacitor matching circuit is used. This matching network is composed of two capacitors and one inductor. The circuit optimizes the signal transfer from the pre-amplifier to the mixer and also acts as a band-pass filter:

FIGURE 19: MATCHING NETWORK BETWEEN PRE-AMPLIFIER AND MIXER



The matching circuit can be calculated using the following formula:

EQUATION 9:

$$L = \frac{1}{(2\pi f_0)^2 * \frac{C_1 C_2}{C_1 + C_2}}$$

where f_0 = 8 MHz is the working frequency.

At the working frequency (f_0), the network should transform the output impedance of the pre-amplifier to the input impedance of the mixer (1200 Ohm). The impedance conversion is figured using the following equation:

EQUATION 10:

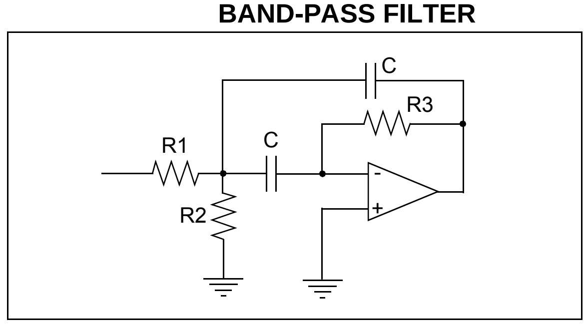
$$Z_{out}(jf_0) \cong \left(1 + \frac{C_1}{C_2}\right)^2 * R_c = 1,200\Omega$$

The working frequency (8 MHz) is step down converted by a mixer circuit to an intermediate frequency of about 192 kHz using an 8.192 MHz frequency for the mixer. This frequency is generated by the PIC microcontroller using an external crystal, and is applied to the mixer through a coupling capacitor.

> **Note:** The coupling element will also capture the noise of the system (the PIC microcontroller oscillator is a potential source of noise); so, it is recommended to use the same clock frequency for the PIC MCU oscillator and the mixer circuit. When clock frequencies are the same, the noise generated by the PIC microcontroller is moved outside of the working bandwidth of the system and the signal to noise ratio is improved significantly, without using any other filter techniques.

The mixer circuit is followed by an active band-pass filter:

FIGURE 20: ACTIVE SECOND ORDER BAND-PASS FILTER

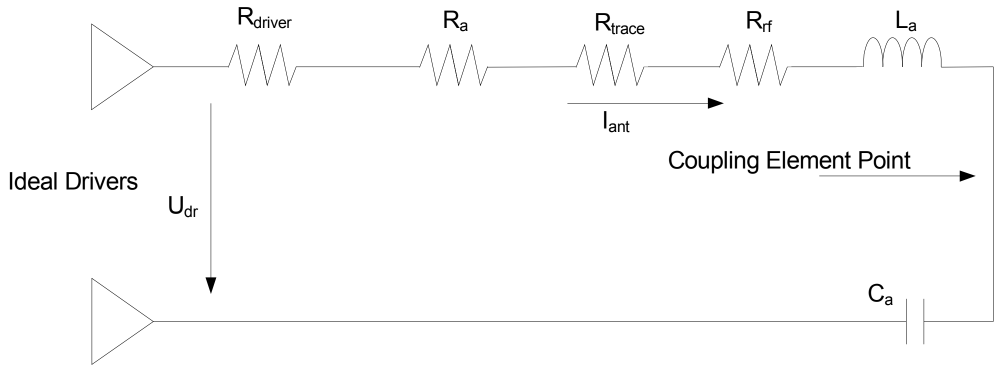


The resulted signal is applied to MCP2030, which performs additional filtering and decodes the incoming data. The data stream is then received by the PIC MCU via the USART interface. If the received stream is decoded correctly, and the answer is according to the sent challenge, the PIC MCU will perform a specific action (e.g., displays a message on the LCD).

In order to have a robust communication, a retransmission mechanism is implemented when the received data has errors or no data is received. Additionally, on the Base Unit, a USB-to-UART bridge for PC interfacing is built. The PC application allows control, configuration and testing of the board.

The driver and LC circuit driving coupling element can be transformed using ideal components into the following equivalent circuit:

FIGURE 21: TRANSMITTER EQUIVALENT CIRCUIT



where:

R_{driver} = driver resistance and

Ra = current adapting resistor

R_{trace} = resistance of connections leads on PCB

R_{rf} = winding resistance of inductor

Because R_{trace} is very low compared to other elements, it can be ignored.

The maximum current flows when in optimally tuned conditions. It equals:

EQUATION 11:

$$\widehat{I}_{ant_{max}} = \frac{\widehat{U}_{driver}}{R_{LC}} = \frac{4}{\pi} * \frac{V_{DD}}{R_{LC}}$$

The term 4/π transforms the amplitude of the rectangular driver voltage to the equivalent sine voltage, which is the fundamental of the rectangular signal.

Starting from the previous equation, the maximum allowed resistance can be calculated for a specific current.

Example:

Base Unit: V_{DD} = 5V and Iantmax = 50 mA → R_{LC} = 127.5Ω

Mobile Unit: V_{DD} = 2.2V and Iantmax = 25 mA → R_{LC} = 112Ω

Choosing the inductance is not critical. However, the quality factor is determined by the inductance and resistance by:

EQUATION 12:

$$Q = \frac{\omega_0 * L}{R_{LC}}$$

While Q increases, the data transfer bandwidth reduces creating an upper limit for the LC quality factor. For the BodyCom system, an upper limit of 20 is recommended for quality factor. From the formula given above, the maximum inductance can be calculated from RLC and Q.

Example:

Base Unit: RLC = 127.5Ω and Q = 20 → ≤3.17mH

Mobile Unit: RLC = 112Ω and Q = 20 → ≤11.2µH

The capacitance of the tuned LC circuit can be calculated using this formula:

EQUATION 13:

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

Example:

Base Unit: L=1mH, f_0 = 128 kHz → C= 1.547 nF

Mobile Unit: L=4.7µH, f_0 = 8.00 MHz → C= 84.3 pF

> **Note:** The Mobile Unit parasitic capacitance of the coupling pad (20-30 pF) appears in parallel with physical capacitance of the LC circuit. So, the assembled value for the LC circuit should be the difference between the resulted capacitance (84.3 pF, in this example) and the parasitic capacitance. The parasitic capacitance can be evaluated by measuring the capacitance between the coupling pad and ground, when the Mobile Unit is not powered.

The maximum voltage on the coupling element point can be calculated with the formula in Equation 14:

EQUATION 14:

$$\widehat{U}_{LCpkpk} = 2 * \widehat{U}_{LC_{max}} = 2 * \omega_0 * L * \widehat{I}_{ant_{max}}$$

$$\widehat{U}_{LCpkpk} = 2\omega_0 L\frac{4}{\pi} * \frac{VDD}{RLC}$$

Example:

Base Unit: L=1mH, f_0 = 128 kHz → $\widehat{U}_{LCpkpk} \cong 80V$

Mobile Unit: L=4.7µH, f_0 = 8.00 MHz → $\widehat{U}_{LCpkpk} \cong 12V$

For a custom design, the current can be adapted to the desired value by changing the current adapting resistor from the output of the driver (*Ra*).

FIRMWARE (API FUNCTIONS)

The BodyCom Evaluation board can be interfaced with a PC using the on-board USB-to-USART bridge. The firmware stack allows an easy implementation of the custom design using the following high level API commands:

1. **BC_InitHW()** – init function that configures hardware peripherals needed by the BodyCom software stack. This function does not provide public arguments or a returned value; the user must make changes via the "*Body_Com_config.h*" file.
2. **BC_Send_Pckt** (cmd, *tx_data, lngth) – transmit function that formats a data packet and sends it via the BodyCom interface. The user should provide the following parameters for a proper transmission:
   - cmd – command byte that asks the Mobile Unit for a specific action. The next commands are supported:
     - PING – asks for the presence/get ID (the Mobile Unit returns an internal ID)
     - LOOPBACK – loopbacks the received data (the Mobile Unit loopbacks the received data packet)
     - GET_PARAM – gets Mobile Unit parameters (the Mobile Unit returns internal or debug parameters: battery voltage, number of data packets received from power-on)
     - SET_ID – sets Mobile Unit ID (the Mobile Unit changes its ID)
   - *tx_data – this field is a pointer to a valid data string
   - lngth – contains the length of the data packet in bytes (maximum length is 16 bytes). It can be zero for PING or GET_PARAM commands
3. **BC_Recv_Pckt** (cmd, *data, *lngth) – receive function that returns an unsigned char containing a status code. The following status code are allowed:
   - NO_DATA No new data has been received (no data field in the packet)
   - VALID DATA Valid packet received and checksum verifies
   - TIMEOUT No activity on the receiver before time-out
   - INVALID Receiver activity, but packet incomplete or fails checksum verify

   The following parameters are passed through the function:
   - cmd – this byte contains the command byte received with the previous packet (the received command byte is loopbacked – see transmit command codes for allowed values)
   - *data – pointer to the received data string
   - *lngth – pointer to the length of the received packet
4. **bodycom_ISR()** – this function is a state machine that handles transmit and receive functions. The function does not provide public arguments or returned values; the user should use the transmit and receive functions described before and this state machine function will update the following status flags:
   - BC_sys_flags.TX_busy

     If set, the base is sending a packet.
   - BC_sys_flags.RX_busy

     If set, the base is receiving a packet.
   - BC_isbusy

     If set, the transmitter/receiver is busy.

A person who uses the BodyCom software stack to develop a custom application should call the **BC_InitHW()** function before using the transmit and receive functions. After that, the user needs to call **BC_Send_Pckt()** to transmit a data packet. The function prepares the data packet and communicates to the state machine (**bodycom_ISR()**) to start the transmission. During the transmission and receiving process, the internal status flags are active.

After the **BC_Send_Pckt()** call, the user should wait for the status flags to be cleared. After that, the receiving routine (**BC_Recv_Pckt()**) should be called. The user application should perform specific action functions according to the returned status code:

- VALID DATA – the packet data was sent and the answer is correct
- TIMEOUT or INVALID: no answer received in a specific time or the data is received with errors. In this case, the user application could implement a retransmission algorithm for a robust communication.

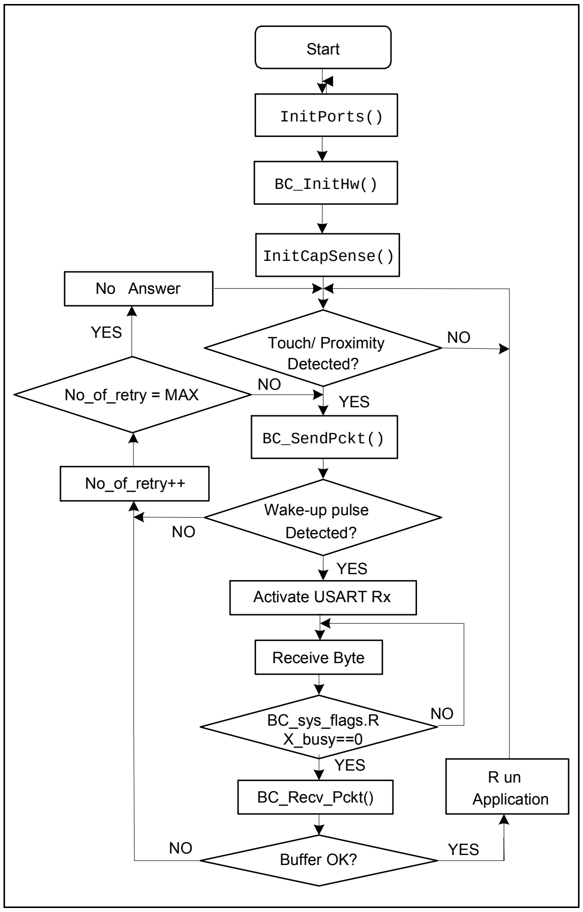
Other Design Requirements:

To optimize the performance of the system and minimize the signal-to-noise ratio, the following rules are recommended:

- separate ground planes for the digital and analog sections
- use bypass capacitors for the amplifier, mixer and band pass filter
- working frequency of the PIC microcontroller and the mixer frequency should not produce harmonics in the working bandwidth of the system

Note:	The intermediate frequency value (192 kHz, in this example) is not very critical; it is the result of the mixing frequencies for the existing crystals on the market. The user can change the working frequency by using different crystals for the Mobile Unit and the Mixer circuit (or the PIC microcontroller). The only constraint is to be in the range of the working frequency of MCP2030 (between 60 and 250 kHz).

FIGURE 22: BASE UNIT STATE DIAGRAM



Q&A FOR BODYCOM

Q1: I cannot detect a touch

- Check the touch sensor for shorts
- Check that the ADC input is configured as an input
- Check the threshold level
- Check that the ISR is being called

Q2: I cannot transmit from the Base or Mobile (no MDOUT)

- Check the oscillator frequency
- Check the configuration of the DSM peripheral
- Check the configuration of the EUSART
- Check the filter pulse setting
- Check that the APFCON register is set correctly

Q3: I have low output voltage on the Base or Mobile

- Check the signals to the driver
- Check the supply voltage on the driver
- Check for a short on the coupler
- Check that both the normal and inverted signals are at the driver

Q4: I have low output voltage on the Base Unit and the power supply dips during transmit

- Check the polarity of the comparator generating the inverted drive signal

Q5: I have good output voltage on the Base or Mobile, but no modulation

- Check the configuration of the EUSART
- Check that the low carrier frequency of the Data Signal Modulator is set to ground

Q6: I cannot configure the MCP2030 in the Base or Mobile

- Check that the MSSP is configured correctly
- Check that the APFCON register is set correctly
- Check that the SDI pin is not configured as an analog input in the ANSEL register
- Check that the parity bits are correct in the configuration commands

Q7: My received signal is the right amplitude, but noisy

- Check that the microcontroller oscillator is set for external crystal oscillator

Q8: The signal is getting to the remote, but it does not respond

- Check the checksum calculation
- Check the filter pulse settings
- Check that the interrupt-on-change interrupt is configured and enabled

Q9: The remote is responding, but the Base Unit does not see it

- Check that the mixer (SA602) is getting power
- Check the oscillator frequency of the Mobile Unit
- Check the checksum calculations

Q10: The Mobile stops working if I close my hand around it

- The Mobile Unit will lose the signal if the user's hand encloses the unit

Q11: I get a good signal from the Mobile when it starts transmitting, but it fades out

- Check the power supply of the Mobile Unit; it may not have enough current for transmit. If battery-powered, the battery may be dying.

REFERENCES:

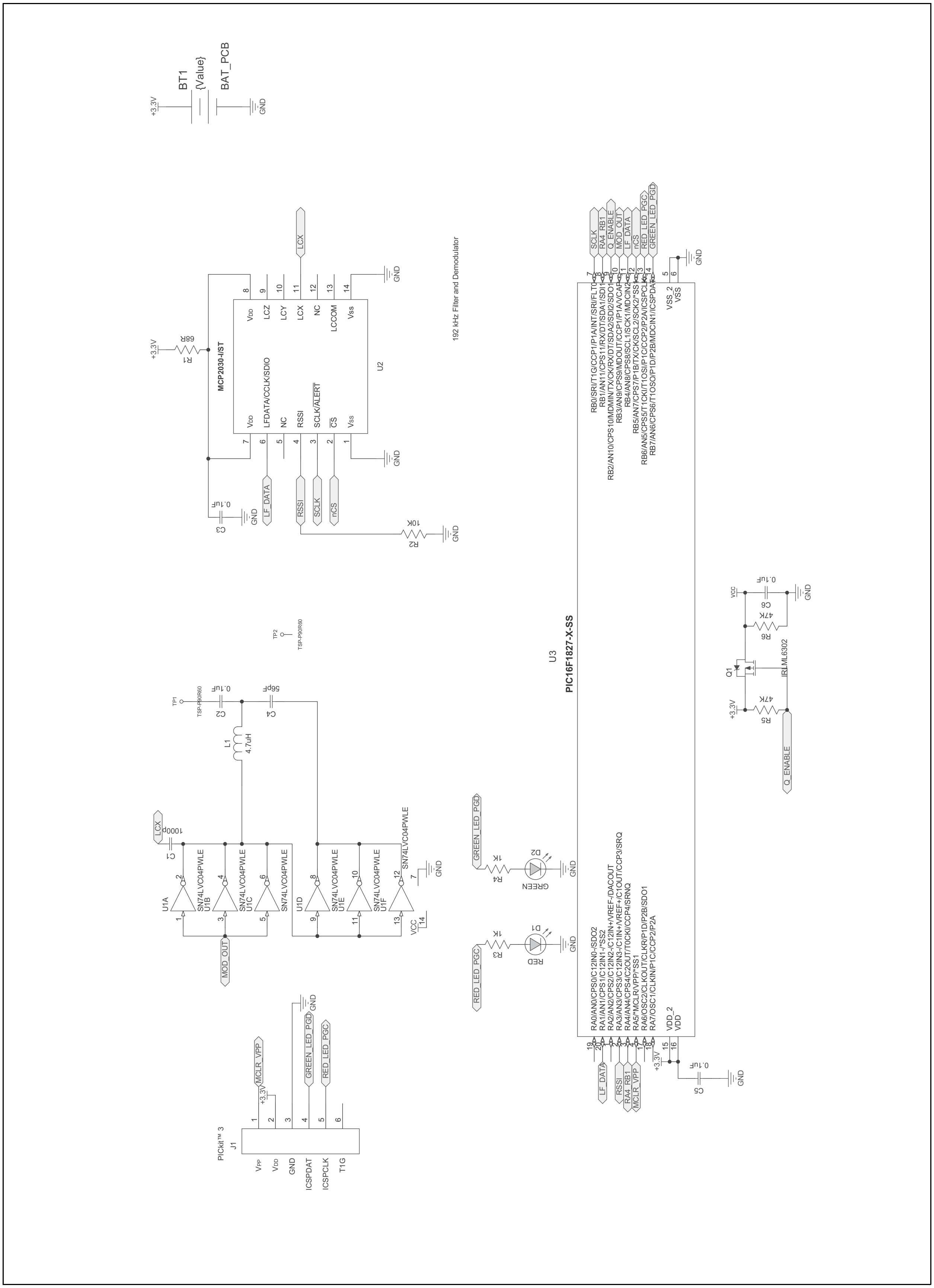
MCP2030 Data Sheet (DS21981)

PIC12F1822/16F182X Family Data Sheet (DS41406)

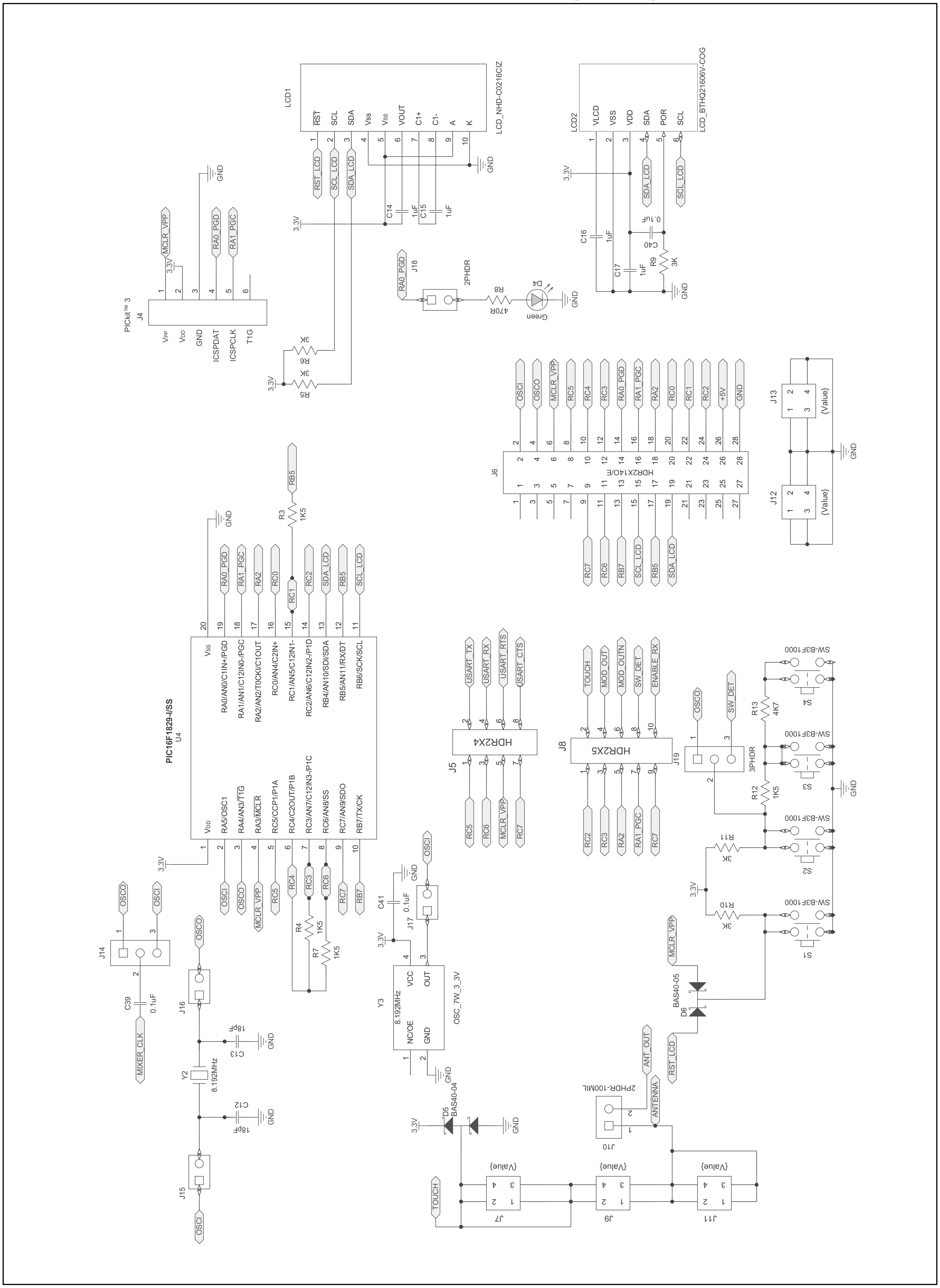
AN1298 - Capacitive Touch Using Only an ADC (CVD)

SA602 Data Sheet (http://www.nxp.com/documents/data_sheet/SA602A.pdf)

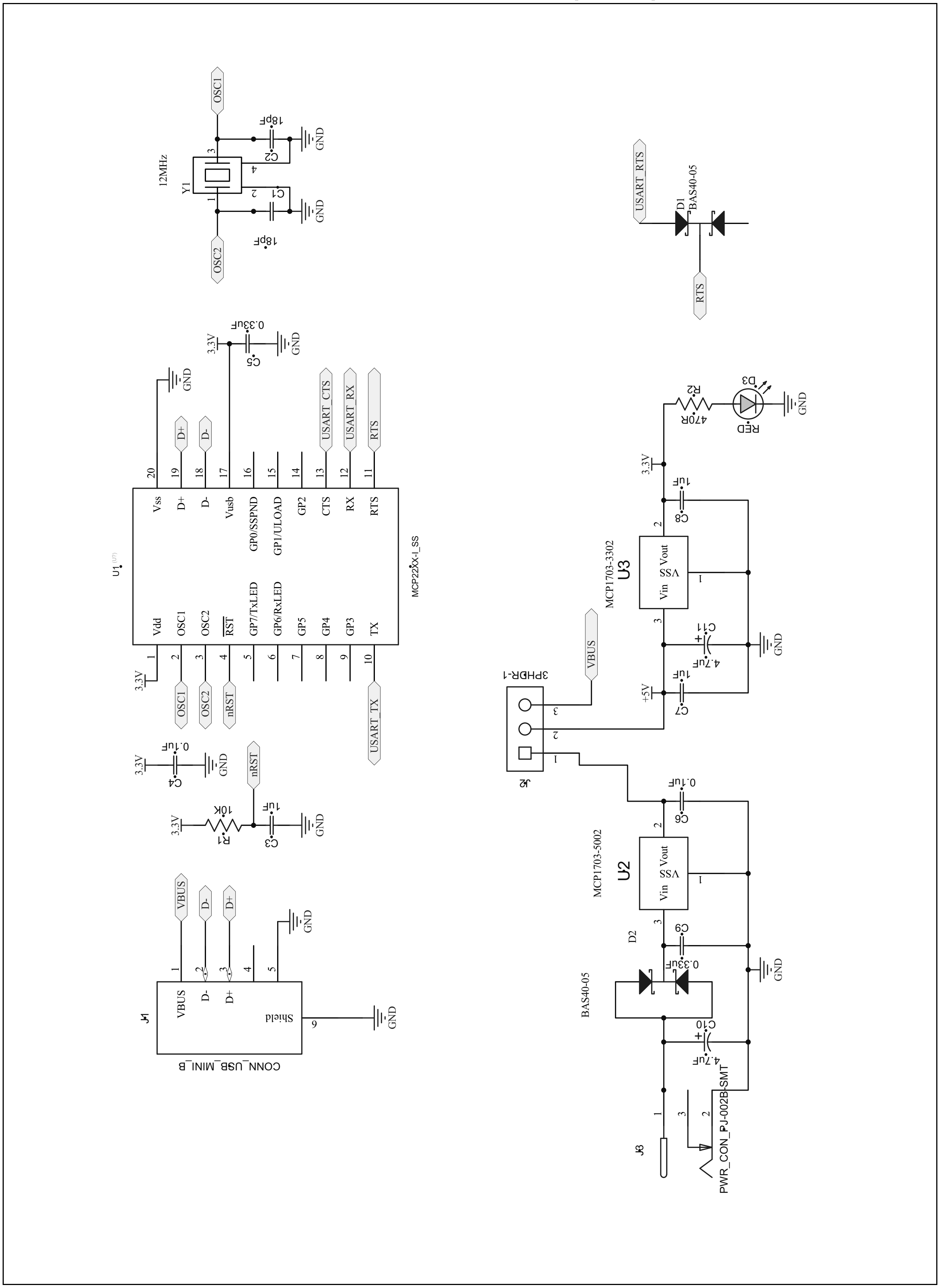
APPENDIX 1: MOBILE UNIT DETAILED SCHEMATIC



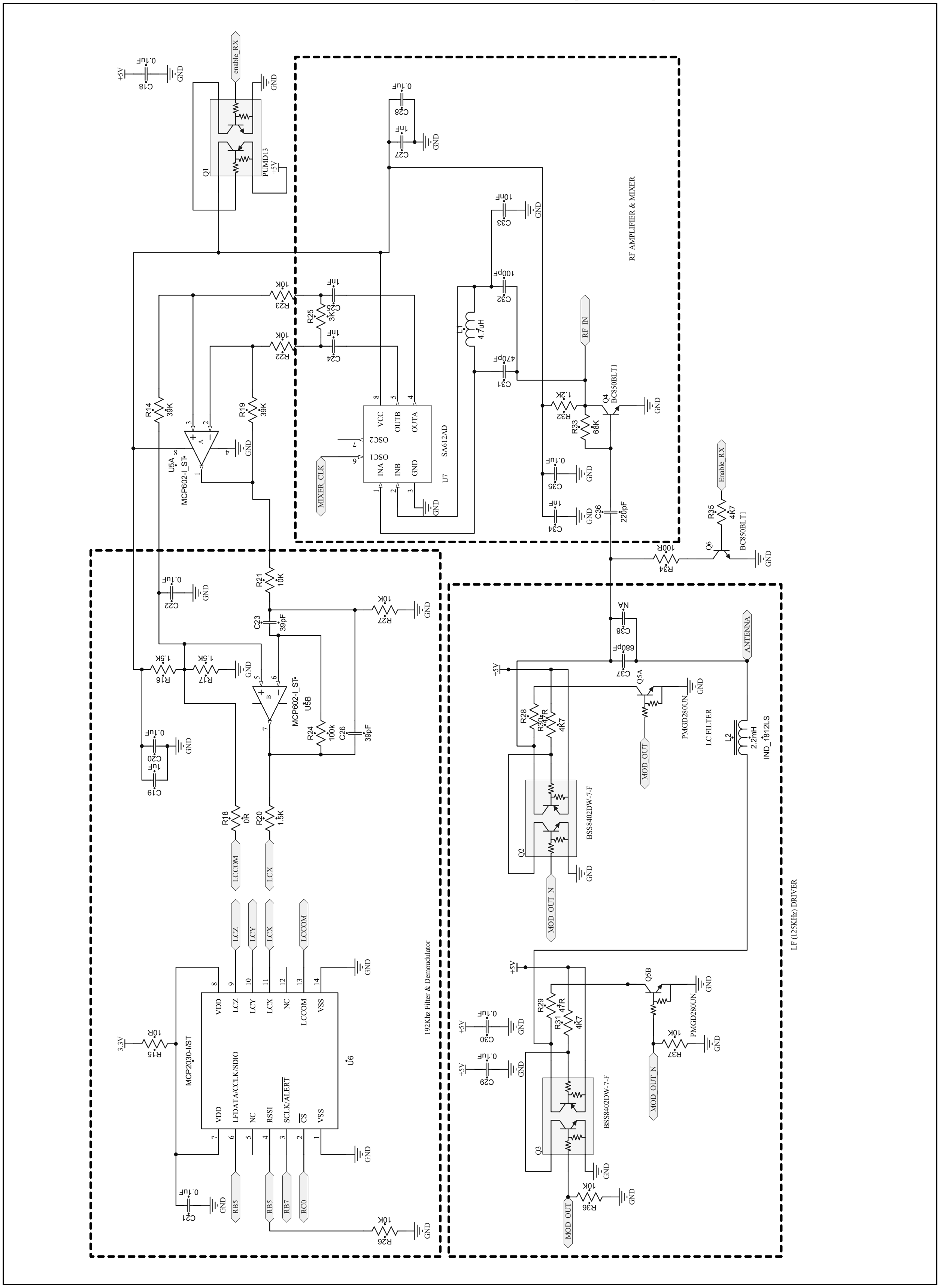
APPENDIX 2: BASE UNIT DETAILED SCHEMATIC (1 OF 3)



APPENDIX 2: BASE UNIT DETAILED SCHEMATIC (2 OF 3)



APPENDIX 2: BASE UNIT DETAILED SCHEMATIC (3 OF 3)



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