rfRXD0420 ASK Receiver Reference Design

Author: Steven Bible
Microchip Technology Inc.

INTRODUCTION

This application note describes a low cost, high performance UHF short-range radio ASK receiver design using the Microchip Technology rfRXD0420. The reference design is suitable for:

- Wireless remote command and control
- Remote Keyless Entry (RKE)
- Security systems
- Low power telemetry applications

The specifics of this receiver reference design are:

- Single channel, fixed frequency at 433.92 MHz
- ASK modulation
- Signal rate: 4800 baud

Complete schematics and PCB layout are given in Appendix A. Bill of Materials (BOM) are in Appendix B. Gerber files are available in the companion file AN00860B.ZIP.

ASK RECEIVER REFERENCE DESIGN

Figure 1 is a block diagram of the receiver signal path with external components that apply to ASK operation of the rfRXD0420. In the sections that follow, the purpose of the RF stage, component selection, and performance trade-offs are discussed to assist the designer in understanding, optimizing and/or changing this receiver reference design to suit other applications.

Crystal Oscillator and Crystal Selection

The rfRXD0420 is a single-conversion superheterodyne architecture with a single IF frequency. The receive frequency is set by the crystal frequency (f_{XTAL}) and intermediate frequency (f_{if}).

For this reference design, low-side injection of the Local Oscillator (f_{lo}) frequency was chosen. Calculation of the crystal, LO, and image frequencies are:

Given:

f_{rf} = 433.92 MHz
f_{if} = 10.7 MHz
PLL divide ratio = 16 (fixed)

Crystal frequency (low-side injection):

$f_{XTAL-LOW} = (f_{rf} - f_{if})$ / PLL divide ratio
$f_{XTAL-LOW}$ = (433.92 MHz - 10.7 MHz) / 16
$f_{XTAL-LOW}$ = 26.45125 MHz

Local oscillator frequency (low-side injection):

$f_{lo} = f_{XTAL}$ x PLL divide ratio
f_{lo} = 26.45125 MHz x 16
f_{lo} = 423.22 MHz

Image frequency (low-side injection):

$f_{rf\text{-}image} = f_{rf} - (2 \times f_{if})$
$f_{rf\text{-}image}$ = 433.92 MHz - (2 x 10.7 MHz)
$f_{rf\text{-}image}$ = 412.52 MHz

Frequency planning is illustrated in Figure 2.

FIGURE 1: rfRXD0420 BLOCK DIAGRAM (ASK OPERATION)

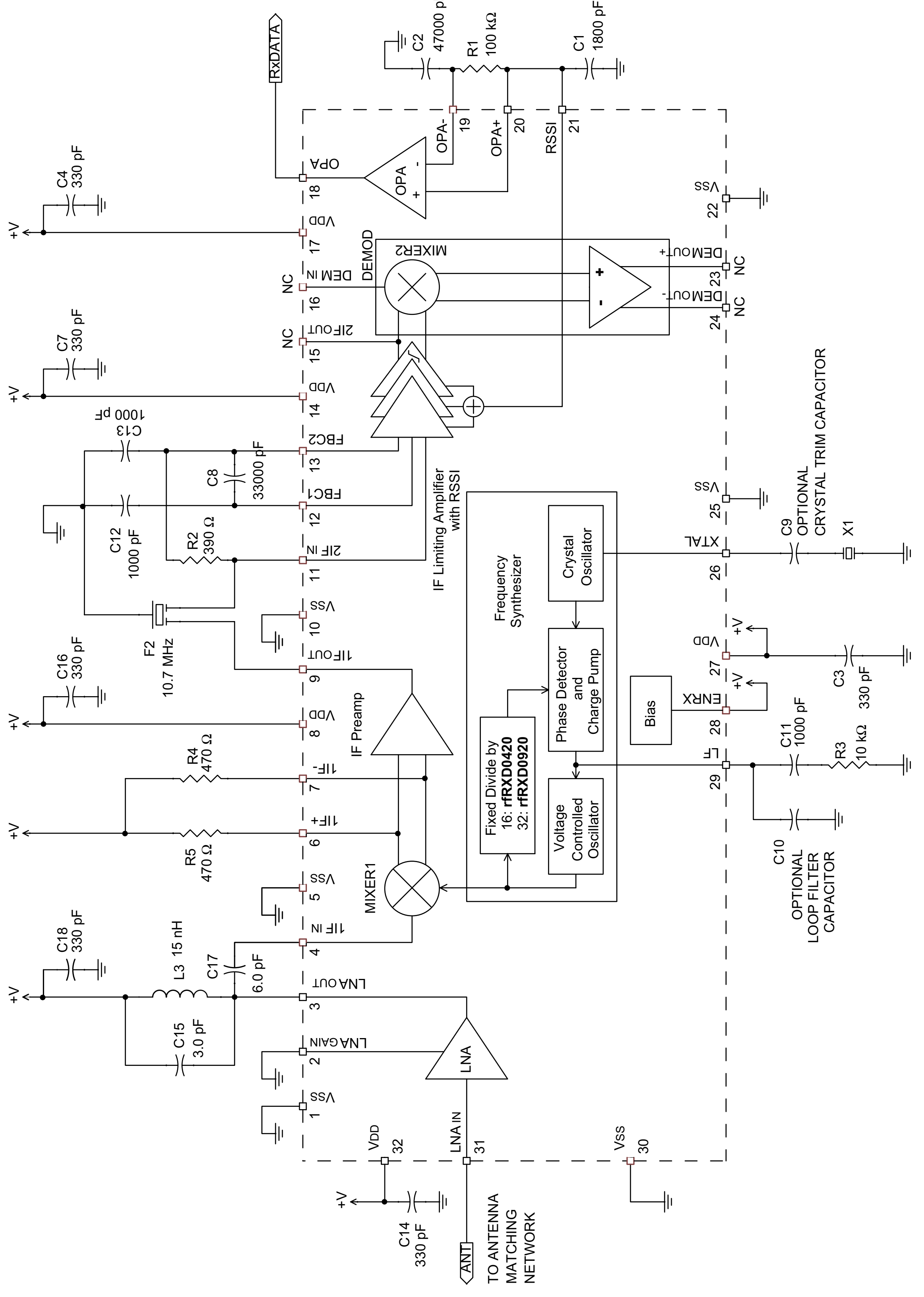
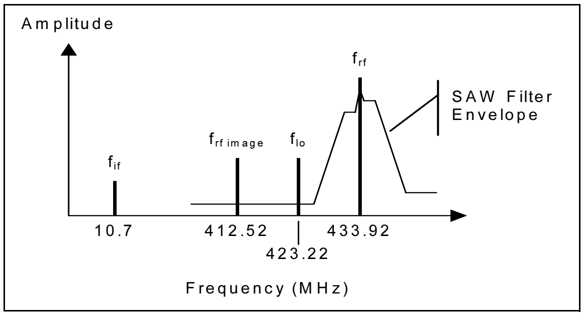


FIGURE 2: FREQUENCY PLANNING



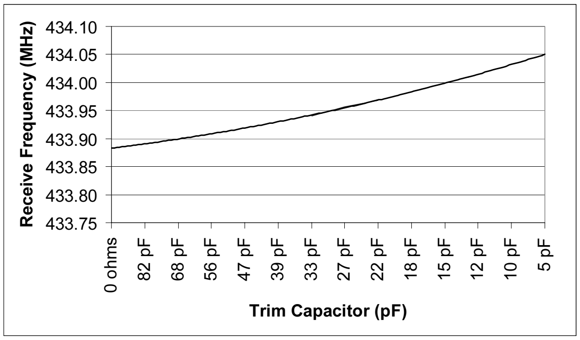
The frequency tolerance of the crystal should be within the communication system's tolerances (transmitter and receiver) and in accordance with local radio regulations. There are three crystal frequency tolerance specifications: 1) frequency tolerance at 25°C (also known as the make tolerance), 2) frequency stability over temperature range, and 3) aging. All three are additive. For example, if the specified crystal frequency tolerances are:

- Frequency Tolerance at 25°C: ±30 ppm maximum
- Frequency Stability over Temperature Range: ±30 ppm maximum
- Aging at 25°C first year: ±5 ppm maximum

The total worst-case frequency error of the crystal can be 30 + 30 + 5 = 65 ppm. In this reference design, the crystal frequency is 26.45125 MHz, multiplied by 65 ppm equals ±1720 Hz error. The total receiver frequency error is found by multiplying the crystal frequency error by the PLL multiplier: ±1720 Hz times 16 equals ±27.5 kHz the intended receive frequency.

The crystal load capacitance should be specified to include the internal load capacitance of XTAL (Pin 26) of 15 pF plus PCB stray capacitance (approximately 2 to 3 pF). Capacitor C9 can be used to trim the crystal on frequency within the limitations of the crystal's trim sensitivity and pullability. Figure 3 illustrates the effect the trimmer capacitor has on the receive frequency. Keep in mind that this graph represents one example circuit and the actual frequency pulling effect of C9 depends on the crystal and PCB layout.

FIGURE 3: RECEIVE FREQUENCY VS. TRIM CAPACITANCE



Note that a 0 Ω resistor, in the lower left of the graph, represents an infinite capacitance. This will be the lowest frequency obtainable for the crystal and PCB combination.

For additional information on crystal and crystal oscillator basics, please refer to Microchip Technology application note AN826, Crystal Oscillator Basics and Crystal Selection for rfPIC™ and PICmicro® Devices. It is highly recommended that customers consult with a crystal company to ensure that the selected crystal will operate properly in the specified application.

Loop Filter

Components C10, C11, and R3 comprise a second-order low-pass loop filter for the PLL synthesizer. The components selected have a wide loop bandwidth to suppress noise over a wide frequency range.

Low Noise Amplifier (LNA) Input and Antenna Selection

The rfRXD0420 is a single conversion superheterodyne architecture with only one IF frequency (f_{lo} = 423.22 MHz). Care should be taken to filter the image frequency ($f_{rf\text{-}image}$ = 412.52 MHz).

A SAW filter (Figure 4) can effectively filter the image frequency with a minimum of 40 dB attenuation. The SAW filter has the added benefit of filtering wide-band noise and improving the signal-to-noise ratio (SNR) of the receiver.

SAW filters require impedance matching. Components L1 and C5 match the antenna to the SAW filter's input and components L2 and C6 match the SAW filter's output to LNAIN (Pin 31) input impedance of 26 Ω || 2 pF of the rfRXD0420. Refer to the SAW filter manufacturer's data sheet and application notes for specified impedances and recommended matching circuits.

A SMA connector (J1) was used in this receiver reference design to facilitate lab measurements and connection to an external antenna. The designer may elect to remove the SMA connector and connect a wire antenna. The length of the wire antenna should be one-quarter the wavelength (λ) of the receive frequency. For example, the wavelength of 433.92 MHz is:

$$\lambda = c / f_{rf} \text{ where } c = 3 \times 10^8 \text{ m/s}$$

$$\lambda = 3 \times 10^8 \text{ m/s} / 433.92 \text{ MHz}$$

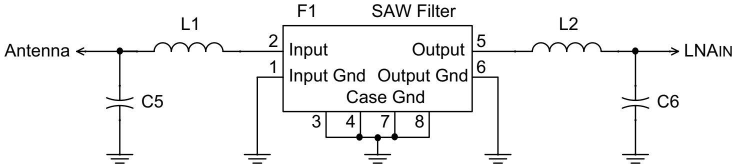
$$\lambda = 0.69 \text{ m}$$

or

$$0.25\lambda = 17.3 \text{ cm or } 6.8 \text{ inches}$$

The designer should then match the input impedance of the SAW filter to the wire antenna impedance of 36 Ω.

FIGURE 4: SAW FILTER FRONT END



Note: Refer to SAW filter manufacturer’s data sheet for pinouts and values for impedance matching components.

Low Noise Amplifier (LNA) Output and MIXER1 Input

Components C15, L3, and C17 provide collector current via a pull-up, impedance matching between the LNA and 1IF stages, and decoupling (C17). To a lesser extent, they provide band-pass filtering at the receive frequency (f_{rf}). Component values depend on the selected receive frequency. The challenge is to design the filter with the fewest components and setting Q as high as possible as limited by component tolerances.

The LNAOUT (Pin 3) is an open-collector output. It is connected to a parallel resonant LC circuit (C15, L3) pulled up to the supply voltage +V. It is also connected to 1IFIN (Pin 4) via a series matching capacitor (C17). 1IFIN has an input impedance of approximately 33 Ω || 1.5 pF.

MIXER1 Bias Connections

Pins 1IF+ (Pin 6) and 1IF- (Pin 7) are open-collector outputs that are connected to external pull-up resistors (R5, R4 respectively).

IF Filter

A ceramic IF filter (F2) is placed between 1IFOUT (Pin 9) and 2IFIN (Pin 11) to filter the 10.7 MHz IF signal. Selection of the ceramic filter bandwidth depends on the signal rate of the incoming digital data signal.

For example, this reference design is optimized for a signal rate of 4800 baud. The required bandwidth for ASK modulation is twice the signal bandwidth, or 9600 Hz. Typical ceramic bandwidths are 110, 150, 180, 230, and 280 kHz. These bandwidths are much larger than the signal bandwidth. Therefore, a compromise must be made by adding additional low-pass filtering to the data slicer circuitry, which will be discussed later. For this reference design, a 280 kHz ceramic filter was chosen for price versus performance considerations.

The output impedance of 1IFOUT (pin 9) is approximately 330 Ω. This matches with the input impedance of the ceramic filter. However, the output impedance of the ceramic filter (also 330 Ω) and the input impedance of 2IFIN (pin 11) requires impedance matching. Resistor R2 (390 Ω) is connected to the output of the ceramic filter (2IFIN) and FPC2 (pin 13), which is parallel to an internal 2.2 kΩ, to perform this match.

RSSI Filtering and Comparator

The Received Signal Strength Indicator, RSSI (pin 21), is the final signal in the receiver chain. This baseband signal is proportional to the log of the RF input signal at 2IFIN (pin 11). The RSSI signal is first low-passed filtered and then compared to a dynamic reference voltage (created by RC low-pass filter R1 and C2) to determine if the received signal represents a binary one or zero. The internal operational amplifier (OPA+, OPA-, and OPA) is configured as a comparator. The comparator circuitry is also known as a data slicer.

RSSI FILTERING

First the RSSI signal is low-pass filtered to remove high frequency and pulse noise to aid the decision making process of the comparator and increase the sensitivity of the receiver. The RSSI signal low-pass filter is a RC filter created by the RSSI output impedance of 36 kΩ and capacitor C1. Setting the time constant (RC = τ) of the RC filter depends on the signal period and when the signal decision will be made by the PICmicro® microcontroller unit (MCU) or KEELOQ® decoder.

Signal Period - Optimum sensitivity of the receiver with reasonable pulse distortion occurs when the RC filter time constant is between 1 and 2 times the signal period. If the time constant of the RC filter is set too short, there is little noise filtering benefit. However, if the time constant of the RC filter is set too long, the data pulses will become elongated causing inter-symbol interference.

Signal Decision - If the bit decision occurs in the center of the signal period (such as KEELOQ decoders), then one or two times the RC filter time constant should be set at less than or equal to half the signal period. Figure 5 illustrates this concept. The top trace represents the received on-off keying (OOK) signal. The bottom trace shows the RSSI signal after the RC low-pass filter.

If the bit decision occurs near the end of the signal period, then the time constant should be set at less than or equal to the signal period. Figure 6 illustrates this concept.

FIGURE 5: CENTER SIGNAL PERIOD DECISION RSSI LOW-PASS FILTERING

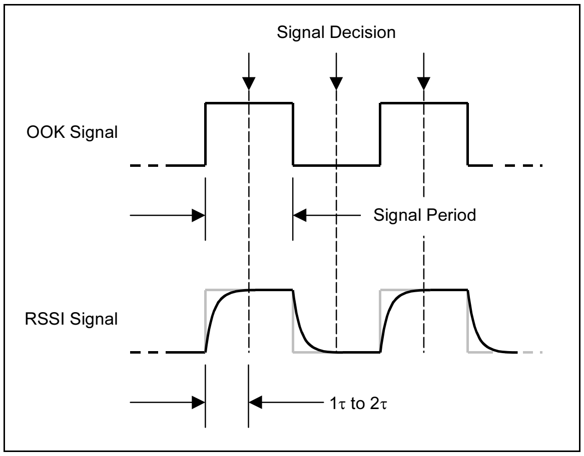
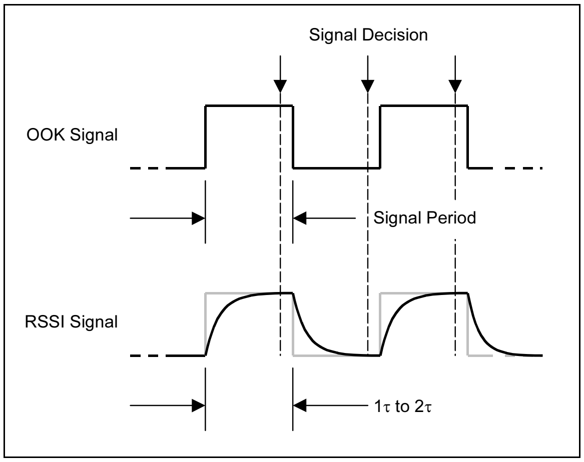


FIGURE 6: NEAR END OF THE SIGNAL PERIOD DECISION RSSI LOW-PASS FILTERING



Once the signal decision time and time period of the signal period are known, then capacitor C1 can be selected. Appendix C describes the selection process and lists common capacitor values with corresponding time periods to aid in the selection process. Once C1 is selected, the designer should observe the RSSI signal (TP1) with an oscilloscope and perform operational and/or bit error rate testing to confirm receiver performance.

COMPARATOR

Second, the RSSI signal is compared with a reference voltage to determine the logic level of the received signal. The reference voltage is dynamic and is derived by averaging the received signal with low-pass filter, R1 and C2

The setting of the R1-C2 time constant depends on the ratio of logical ones versus zeros and a trade off in stability versus receiver reaction time. If the received signal has an even number of logical ones versus zeros, the time constant can be set relatively short. Thus the reference voltage can react quickly to changes in the received signal amplitude and differences in transmitters; however, it may not be as stable and can fluctuate with the ratio of logical ones and zeros. If the time constant is set long, the reference voltage will be more stable; however, the receiver cannot react as quickly upon the reception of a received signal.

Selection of component values for R1 and C2 is an iterative process. First start with a time constant between 10 to 100 times the signal rate. Appendix D has a table of values that the designer can start with. Second, view the reference voltage (TP2) against the RSSI signal (TP1) to determine if the values are suitable.

Figure 7 is an oscilloscope screen capture of an incoming RF square wave modulated signal (ASK on-off keying). The top trace is the data output of Op Amp (Pin 18). The two bottom traces are the RSSI signal (TP1, bottom square wave) and generated reference voltage (TP2, bottom trace centered in the RSSI square wave). The goal is to select values for R1 and C2 such that the reference voltage is in the middle of the RSSI signal. This reference voltage level provides the optimum data comparison (data slicing) of the incoming data signal.

Finally, conduct bench and/or operational testing.

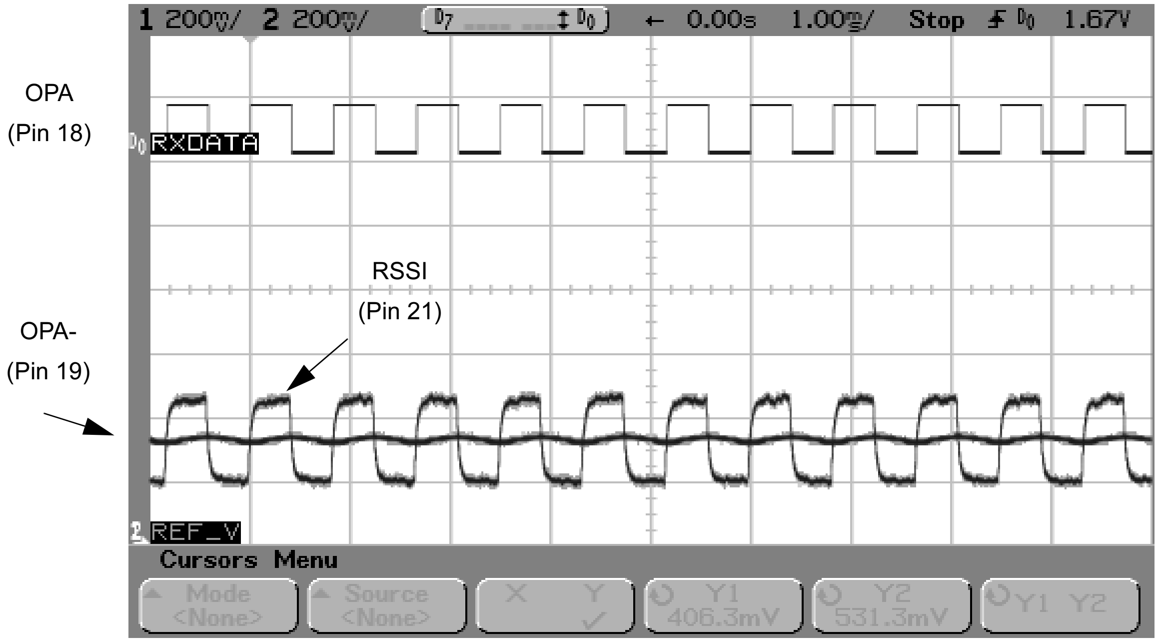
Bypass Capacitors and Power Supply Filtering

Bypass capacitors are placed as physically close as possible to V_{CC} pins 8, 14, 17, 27, and 32 respectively. Additional bypassing and board level low-pass filtering of the power supply may be required depending on the application.

SUMMARY

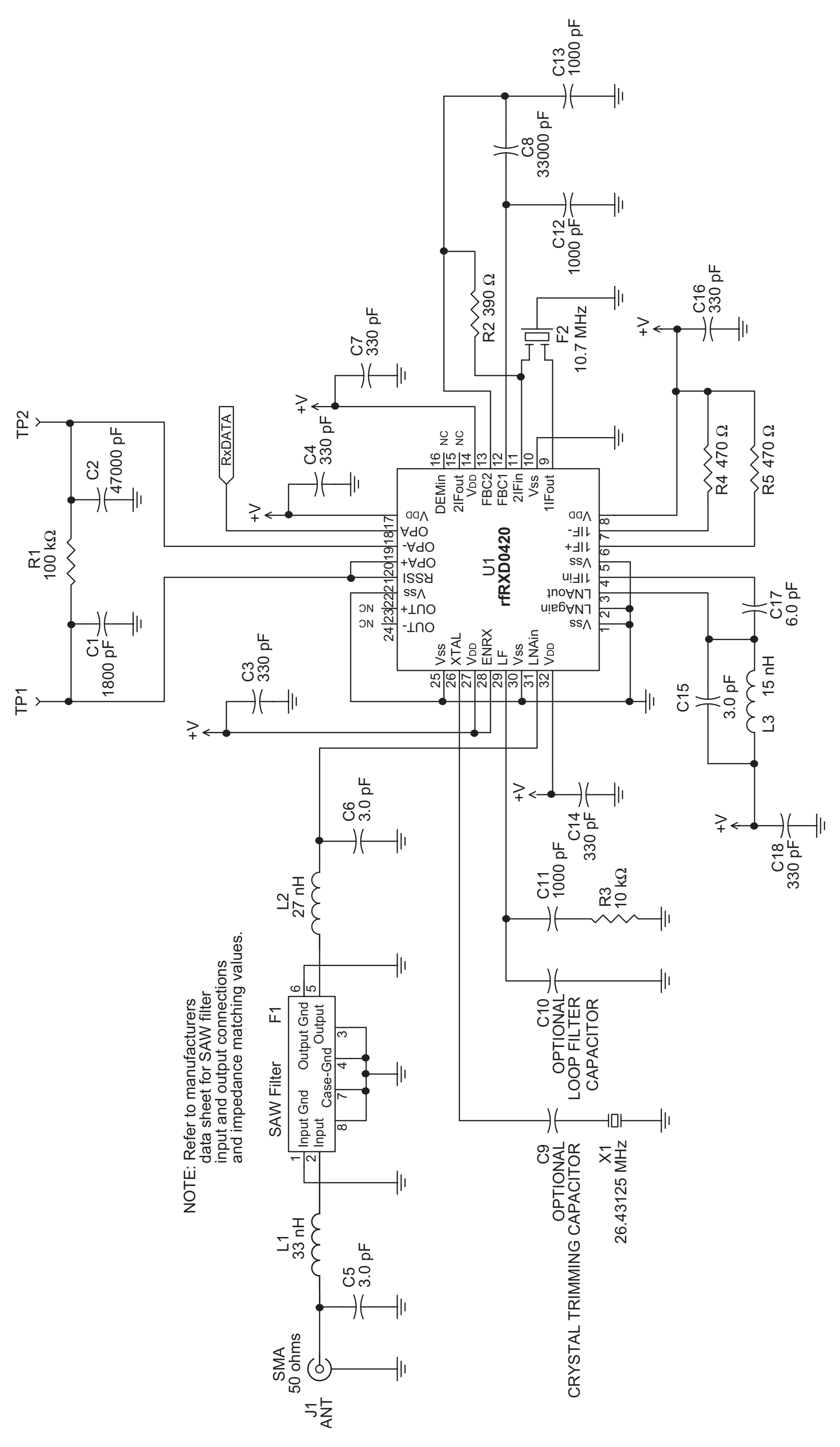
This application note described the design and construction of a low cost, high performance UHF short-range receiver based on the rfRXD0420 receiver.

FIGURE 7: RSSI AND REFERENCE VOLTAGE COMPARISON



APPENDIX A: SCHEMATIC AND PCB LAYOUT DIAGRAMS

FIGURE A-1: SCHEMATIC DIAGRAM (SHEET 1 OF 2)



SCHEMATIC DIAGRAM (SHEET 2 OF 2)

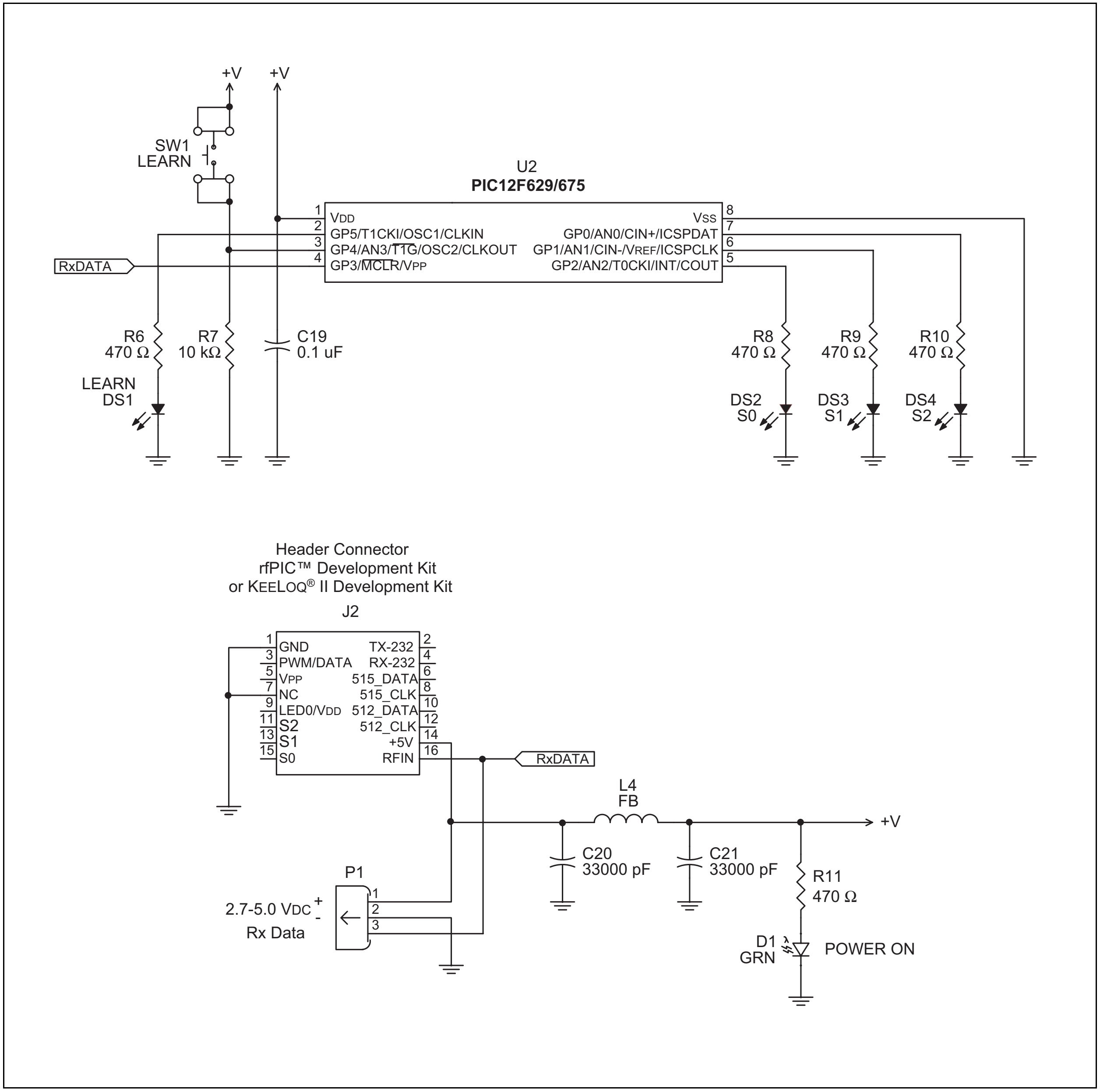


FIGURE A-2: PCB LAYOUT - SILKSCREEN

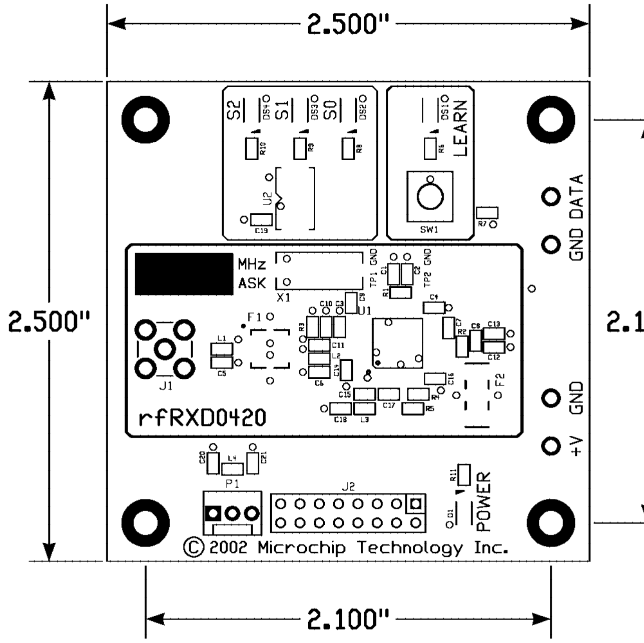


FIGURE A-3: PCB LAYOUT - TOP LAYER

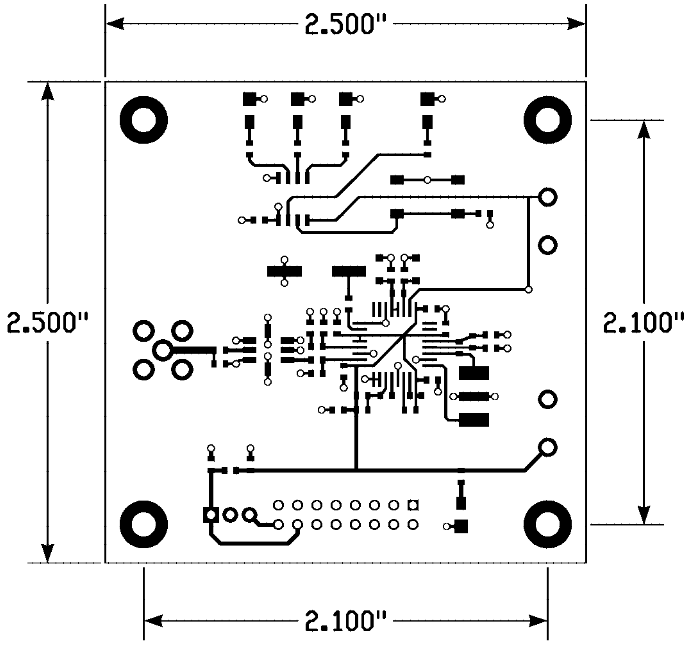
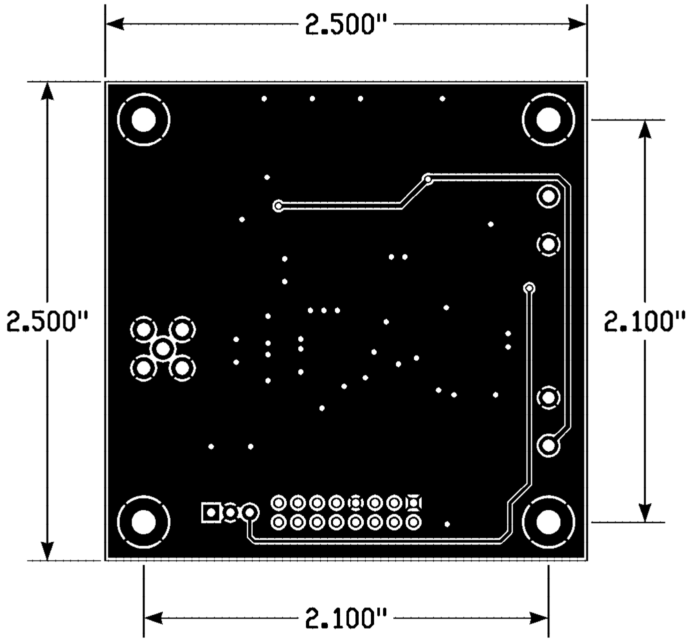


FIGURE A-4: PCB LAYOUT - BOTTOM LAYER



APPENDIX B: BILL OF MATERIALS

Qty	Designator	Description	Value	Comments
3	C5, C6, C15	Capacitor, Ceramic Chip, NP0, SMT 0603	3.0 pF	
1	C17	Capacitor, Ceramic Chip, NP0, SMT 0603	6.0 pF	
6	C3, C4, C7, C14, C16, C18	Capacitor, Ceramic Chip, NP0, SMT 0603	330 pF	
3	C11, C12, C13	Capacitor, Ceramic Chip, NP0, SMT 0603	1000 pF	
1	C8	Capacitor, Ceramic Chip, X7R, SMT 0603	33000 pF	
1	C1	Capacitor, Ceramic Chip, X7R, SMT 0603	1800 pF	Value depends on signal data rate
1	C2	Capacitor, Ceramic Chip, X7R, SMT 0603	47000 pf	Value depends on signal data rate
1	C9	Capacitor, Ceramic Chip, NP0, SMT 0603	0 ohm	Value depends on crystal trim frequency
1	C10	Capacitor, Ceramic Chip, NP0, SMT 0603		Optional, do not place
1	R2	Resistor, SMT 0603	390 ohm	
2	R4, R5	Resistor, SMT 0603	470 ohm	
1	R3	Resistor, SMT 0603	10K ohm	
1	R1	Resistor, SMT 0603	100K ohm	
1	F1	SAW Filter	EPCOS B3550 or Abracon AFS433E	
1	F2	Ceramic Filter, SMT	muRata SFECV10M7FA00-R0 or Abracon ASFC10.7MA	
1	L3	Inductor, SMT, 0603	15 nH	
1	L2	Inductor, SMT, 0603	27 nH	
1	L1	Inductor, SMT, 0603	33 nH	
1	U1	rfRXD0420		
1	X1	Crystal	26.43125 MHz Crystek Corp. P/N 016985	
1	J1	Jack, SMA, Straight PCB		

Auxillary Components

Qty	Designator	Description	Value	Comments
2	C20, C21	Capacitor, Ceramic Chip, X7R, SMT 0603	33000 pF	
1	C19	Capacitor, Ceramic Chip, X7R, SMT 0603	0.1 uF	
5	R6, R8, R9, R10, R11	Resistor, SMT 0603	470 ohm	
1	R7	Resistor, SMT 0603	10K ohm	
1	L4	Ferrite Bead or Chip Inductor		
5	DS1, DS2, DS3, DS4, D1	LED, Surface Mount		
1	U2	PIC12F629/675		
1	J2	16-pin Header Jack		
1	SW1	Momentary Pushbutton Switch		
1	P1	3-Pin Molex Connector		
1		PCB		

COMPONENT SUPPLIERS

Abracon Corporation (http://www.abracon.com)

- SAW Filters
- Ceramic Filters
- Crystals

Crystek Corporation (http://www.crystek.com)

- Crystals

EPCOS (http://www.epcos.com)

- SAW Filters

MuRata Manufacturing Company, Ltd.

(http://www.murata.com)

- Ceramic Filters

APPENDIX C: RSSI LOW-PASS FILTER CAPACITOR SELECTION

Refer to the RSSI FILTERING section for an explanation of the RSSI filtering circuitry.

Table C-1 lists standard capacitor values for C1 in column 1, the associated RC (R = 36 kΩ) time constant (τ) in column 2 and two times the RC (R = 36 kΩ) time constant (2τ) in column 3. Column 4 lists common signal periods that equate to common baud and bps formats. Column 5 lists common baud and bps formats if the signal decision is on the center of the signal period. Column 6 if the signal decision is the full signal period.

Once the signal period (baud rate) and signal decision time are known, select the 2τ (column 3) value that is less than or equal to this value. Common baud rates and KEELOQ TE values are listed in columns 5 and 6. The associated standard capacitor value is listed in column 1.

The choice of 2τ provides the design engineer with a initial value for capacitor C1. Capacitor C1 can be increased to 1τ as performance and operational testing is conducted to find the its optimum value. Keep in mind that if the time constant of the RC filter is set too short there is little noise filtering benefit. However, if the time constant of the RC filter is set too long the data pulses will become elongated causing inter-symbol interference. Once C1 is selected, the designer should observe the RSSI signal (TP1) with an oscilloscope and perform operational and/or bit error rate testing to confirm receiver performance.

Example - The data rate of the received signal for this reference design is 2400 bits per second Manchester encoded and the signal decision time is the center of the signal period. The resulting signal rate is 4800 baud and the shortest signal period is 208 μs. Therefore, we desire a 2τ time constant that is less than or equal to one half 208 μs which is 104 μs. From Table C-1, we see that an initial value for C1 is 1200 pF results in 2τ = 86.4 μs which is less than 104 μs. The value of C1 can be incrementally increased to 2700 pF which equates to a τ = 97.2 μs. The value of C1 = 1800 pF was selected for this reference design as a median value for an average application. The designer should perform operational and/or bit error rate testing to confirm receiver performance for the designed application.

TABLE C-1: C1 TIME CONSTANT AND SIGNAL PERIOD SELECTION

C1 (pF)	τ (μs)	2τ (μs)	Signal Period (μs)	Signal Decision - Center	Signal Decision - Full
150	5.4	10.8	12.5		**Maximum device baud rate** 80,000 baud NRZ 40,000 bps Manchester
180	6.5	13.0	13.0	19,200 baud NRZ 9,600 bps Manchester	76,800 baud NRZ 19,200 bps Manchester
220	7.9	15.8			
270	9.7	19.4			
330	11.9	23.8			
390	14.0	28.1			
470	16.9	33.8			
560	20.2	40.3			
680	24.5	49.0	52.1	9,600 baud NRZ 4800 bps Manchester KEELOQ TE=100μs	19,200 baud NRZ 9,600 bps Manchester
820	29.5	59.0			
1000	36.0	72.0			
1200	43.2	86.4	104.2	4,800 baud NRZ 2,400 bps Manchester KEELOQ TE=200μs	9,600 baud NRZ 4,800 bps Manchester
1500	54.0	108.0			
1800	64.8	129.6			
2200	79.2	158.4			
2700	97.2	194.4	208.3	2,400 baud NRZ 1,200 Manchester KEELOQ TE=400μs	4,800 baud NRZ 2,400 bps Manchester
3300	118.8	237.6			

C1 (pF)	τ (μs)	2τ (μs)	Signal Period (μs)	Signal Decision - Center	Signal Decision - Full
3900	140.4	280.8			
4700	169.2	338.4			
5600	201.6	403.2	416.7	1,200 baud NRZ 600 bps Manchester KEELOQ TE=800μs	2,400 baud NRZ 1,200 bps Manchester
6800	244.8	489.6			
8200	295.2	590.4			
10000	360.0	720.0	833.3	300 baud NRZ 150 bps Manchester	1,200 baud NRZ 600 bps Manchester
12000	432.0	864.0			
15000	540.0	1080.0			
18000	648.0	1296.0			
22000	792.0	1584.0			
27000	972.0	1944.0			
33000	1188.0	2376.0			
39000	1404.0	2808.0	3333.33		300 baud NRZ 150 bps Manchester
47000	1692.0	3384.0			
56000	2016.0	4032.0			
68000	2448.0	4896.0			
82000	2952.0	5904.0			
100000	3600.0	7200.0			

APPENDIX D: REFERENCE VOLTAGE RC TIME CONSTANT SELECTION

Refer to the COMPARATOR section for an explanation of the comparator circuitry.

Table D-1 contains starting values for R1 and C2.

TABLE D-1: R1 AND C2 TIME CONSTANT AND SIGNAL PERIOD SELECTION

R1 (Ω)	C2 (pF)	5τ (µs)	Signal Period (µs)	Signal Rate (baud)	Comments
100K	1000	500			
100K	1200	600			
100K	1500	750			
100K	1800	900			
100K	2200	1100	12.50	80000	Maximum device baud rate
100K	2700	1350	13.02	76800	
100K	3300	1650			
100K	3900	1950			
100K	4700	2350			
100K	5600	2800			
100K	6800	3400			
100K	8200	4100			
100K	10000	5000	52.08	19200	
100K	12000	6000			
100K	15000	7500			
100K	18000	9000	104.17	9600	
100K	22000	11000			
100K	27000	13500			
100K	33000	16500			
100K	39000	19500	208.33	4800	
100K	47000	23500			
100K	56000	28000			
100K	68000	34000			
100K	82000	41000	416.67	2400	
100K	100000	50000			
100K	120000	60000			
100K	150000	75000	833.33	1200	
100K	180000	90000			
100K	220000	110000			
100K	270000	135000			
100K	330000	165000			
100K	390000	195000			
100K	470000	235000			
100K	560000	280000	3333.33	300	
100K	680000	340000			

Note the following details of the code protection feature on Microchip devices:

- Microchip products meet the specification contained in their particular Microchip Data Sheet.
- Microchip believes that its family of products is one of the most secure families of its kind on the market today, when used in the intended manner and under normal conditions.
- There are dishonest and possibly illegal methods used to breach the code protection feature. All of these methods, to our knowledge, require using the Microchip products in a manner outside the operating specifications contained in Microchip's Data Sheets. Most likely, the person doing so is engaged in theft of intellectual property.
- Microchip is willing to work with the customer who is concerned about the integrity of their code.
- Neither Microchip nor any other semiconductor manufacturer can guarantee the security of their code. Code protection does not mean that we are guaranteeing the product as “unbreakable.”

Code protection is constantly evolving. We at Microchip are committed to continuously improving the code protection features of our products. Attempts to break microchip’s code protection feature may be a violation of the Digital Millennium Copyright Act. If such acts allow unauthorized access to your software or other copyrighted work, you may have a right to sue for relief under that Act.

Information contained in this publication regarding device applications and the like is intended through suggestion only and may be superseded by updates. It is your responsibility to ensure that your application meets with your specifications. No representation or warranty is given and no liability is assumed by Microchip Technology Incorporated with respect to the accuracy or use of such information, or infringement of patents or other intellectual property rights arising from such use or otherwise. Use of Microchip’s products as critical components in life support systems is not authorized except with express written approval by Microchip. No licenses are conveyed, implicitly or otherwise, under any intellectual property rights.

Trademarks

The Microchip name and logo, the Microchip logo, KEELOQ, MPLAB, PIC, PICmicro, PICSTART, PRO MATE and PowerSmart are registered trademarks of Microchip Technology Incorporated in the U.S.A. and other countries.

FilterLab, microID, MXDEV, MXLAB, PICMASTER, SEEVAL and The Embedded Control Solutions Company are registered trademarks of Microchip Technology Incorporated in the U.S.A.

Accuron, dsPIC, dsPICDEM.net, ECONOMONITOR, FanSense, FlexROM, fuzzyLAB, In-Circuit Serial Programming, ICSP, ICEPIC, microPort, Migratable Memory, MPASM, MPLIB, MPLINK, MPSIM, PICC, PICkit, PICDEM, PICDEM.net, PowerCal, PowerInfo, PowerTool, rfPIC, Select Mode, SmartSensor, SmartShunt, SmartTel and Total Endurance are trademarks of Microchip Technology Incorporated in the U.S.A. and other countries.

Serialized Quick Turn Programming (SQTP) is a service mark of Microchip Technology Incorporated in the U.S.A.

All other trademarks mentioned herein are property of their respective companies.

© 2003, Microchip Technology Incorporated, Printed in the U.S.A., All Rights Reserved.

Printed on recycled paper.

DNV Certification, Inc.
USA
ANSI•RAB
QMS
ACCREDITED
DNV
DNV MSC
The Netherlands
Accredited by the RvA
ISO 9001 / QS-9000
REGISTERED FIRM

Microchip received QS-9000 quality system certification for its worldwide headquarters, design and wafer fabrication facilities in Chandler and Tempe, Arizona in July 1999 and Mountain View, California in March 2002. The Company’s quality system processes and procedures are QS-9000 compliant for its PICmicro® 8-bit MCUs, KEELOQ® code hopping devices, Serial EEPROMs, microperipherals, non-volatile memory and analog products. In addition, Microchip’s quality system for the design and manufacture of development systems is ISO 9001 certified.

WORLDWIDE SALES AND SERVICE

AMERICAS

Corporate Office
2355 West Chandler Blvd.
Chandler, AZ 85224-6199
Tel: 480-792-7200 Fax: 480-792-7277
Technical Support: 480-792-7627
Web Address: http://www.microchip.com

Rocky Mountain
2355 West Chandler Blvd.
Chandler, AZ 85224-6199
Tel: 480-792-7966 Fax: 480-792-4338

Atlanta
3780 Mansell Road, Suite 130
Alpharetta, GA 30022
Tel: 770-640-0034 Fax: 770-640-0307

Boston
2 Lan Drive, Suite 120
Westford, MA 01886
Tel: 978-692-3848 Fax: 978-692-3821

Chicago
333 Pierce Road, Suite 180
Itasca, IL 60143
Tel: 630-285-0071 Fax: 630-285-0075

Dallas
4570 Westgrove Drive, Suite 160
Addison, TX 75001
Tel: 972-818-7423 Fax: 972-818-2924

Detroit
Tri-Atria Office Building
32255 Northwestern Highway, Suite 190
Farmington Hills, MI 48334
Tel: 248-538-2250 Fax: 248-538-2260

Kokomo
2767 S. Albright Road
Kokomo, Indiana 46902
Tel: 765-864-8360 Fax: 765-864-8387

Los Angeles
18201 Von Karman, Suite 1090
Irvine, CA 92612
Tel: 949-263-1888 Fax: 949-263-1338

San Jose
Microchip Technology Inc.
2107 North First Street, Suite 590
San Jose, CA 95131
Tel: 408-436-7950 Fax: 408-436-7955

Toronto
6285 Northam Drive, Suite 108
Mississauga, Ontario L4V 1X5, Canada
Tel: 905-673-0699 Fax: 905-673-6509

ASIA/PACIFIC

Australia
Microchip Technology Australia Pty Ltd
Marketing Support Division
Suite 22, 41 Rawson Street
Epping 2121, NSW
Australia
Tel: 61-2-9868-6733 Fax: 61-2-9868-6755

China - Beijing
Microchip Technology Consulting (Shanghai)
Co., Ltd., Beijing Liaison Office
Unit 915
Bei Hai Wan Tai Bldg.
No. 6 Chaoyangmen Beidajie
Beijing, 100027, No. China
Tel: 86-10-85282100 Fax: 86-10-85282104

China - Chengdu
Microchip Technology Consulting (Shanghai)
Co., Ltd., Chengdu Liaison Office
Rm. 2401-2402, 24th Floor,
Ming Xing Financial Tower
No. 88 TIDU Street
Chengdu 610016, China
Tel: 86-28-86766200 Fax: 86-28-86766599

China - Fuzhou
Microchip Technology Consulting (Shanghai)
Co., Ltd., Fuzhou Liaison Office
Unit 28F, World Trade Plaza
No. 71 Wusi Road
Fuzhou 350001, China
Tel: 86-591-7503506 Fax: 86-591-7503521

China - Hong Kong SAR
Microchip Technology Hongkong Ltd.
Unit 901-6, Tower 2, Metroplaza
223 Hing Fong Road
Kwai Fong, N.T., Hong Kong
Tel: 852-2401-1200 Fax: 852-2401-3431

China - Shanghai
Microchip Technology Consulting (Shanghai)
Co., Ltd.
Room 701, Bldg. B
Far East International Plaza
No. 317 Xian Xia Road
Shanghai, 200051
Tel: 86-21-6275-5700 Fax: 86-21-6275-5060

China - Shenzhen
Microchip Technology Consulting (Shanghai)
Co., Ltd., Shenzhen Liaison Office
Rm. 1812, 18/F, Building A, United Plaza
No. 5022 Binhe Road, Futian District
Shenzhen 518033, China
Tel: 86-755-82901380 Fax: 86-755-82966626

China - Qingdao
Rm. B505A, Fullhope Plaza,
No. 12 Hong Kong Central Rd.
Qingdao 266071, China
Tel: 86-532-5027355 Fax: 86-532-5027205

India
Microchip Technology Inc.
India Liaison Office
Marketing Support Division
Divyasree Chambers
1 Floor, Wing A (A3/A4)
No. 11, O'Shaugnessey Road
Bangalore, 560 025, India
Tel: 91-80-2290061 Fax: 91-80-2290062

Japan
Microchip Technology Japan K.K.
Benex S-1 6F
3-18-20, Shinyokohama
Kohoku-Ku, Yokohama-shi
Kanagawa, 222-0033, Japan
Tel: 81-45-471- 6166 Fax: 81-45-471-6122

Korea
Microchip Technology Korea
168-1, Youngbo Bldg. 3 Floor
Samsung-Dong, Kangnam-Ku
Seoul, Korea 135-882
Tel: 82-2-554-7200 Fax: 82-2-558-5934

Singapore
Microchip Technology Singapore Pte Ltd.
200 Middle Road
#07-02 Prime Centre
Singapore, 188980
Tel: 65-6334-8870 Fax: 65-6334-8850

Taiwan
Microchip Technology (Barbados) Inc.,
Taiwan Branch
11F-3, No. 207
Tung Hua North Road
Taipei, 105, Taiwan
Tel: 886-2-2717-7175 Fax: 886-2-2545-0139

EUROPE

Austria
Microchip Technology Austria GmbH
Durisolstrasse 2
A-4600 Wels
Austria
Tel: 43-7242-2244-399
Fax: 43-7242-2244-393

Denmark
Microchip Technology Nordic ApS
Regus Business Centre
Lautrup hoj 1-3
Ballerup DK-2750 Denmark
Tel: 45 4420 9895 Fax: 45 4420 9910

France
Microchip Technology SARL
Parc d'Activite du Moulin de Massy
43 Rue du Saule Trapu
Batiment A - ler Etage
91300 Massy, France
Tel: 33-1-69-53-63-20 Fax: 33-1-69-30-90-79

Germany
Microchip Technology GmbH
Steinheilstrasse 10
D-85737 Ismaning, Germany
Tel: 49-089-627-144-100
Fax: 49-089-627-144-44

Italy
Microchip Technology SRL
Via Quasimodo, 12
20025 Legnano (MI)
Milan, Italy
Tel: 39-0331-742611 Fax: 39-0331-466781

United Kingdom
Microchip Ltd.
505 Eskdale Road
Winnersh Triangle
Wokingham
Berkshire, England RG41 5TU
Tel: 44 118 921 5869 Fax: 44-118 921-5820

02/12/03