

# Mixed Signal PICtail<sup>TM</sup> Demo Board User's Guide

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### Preface

### NOTICE TO CUSTOMERS

All documentation becomes dated, and this manual is no exception. Microchip tools and documentation are constantly evolving to meet customer needs, so some actual dialogs and/or tool descriptions may differ from those in this document. Please refer to our web site (www.microchip.com) to obtain the latest documentation available.

Documents are identified with a "DS" number. This number is located on the bottom of each page, in front of the page number. The numbering convention for the DS number is "DSXXXXA", where "XXXXX" is the document number and "A" is the revision level of the document.

For the most up-to-date information on development tools, see the MPLAB<sup>®</sup> IDE on-line help. Select the Help menu, and then Topics to open a list of available on-line help files.

#### INTRODUCTION

This chapter contains general information that will be useful to know before using the Mixed Signal PICtail<sup>™</sup> Demo Board. Items discussed in this chapter include:

- About This Guide
- Conventions Used in this Guide
- Recommended Reading
- The Microchip Web Site
- Customer Support

#### **ABOUT THIS GUIDE**

#### **Document Layout**

This document describes how to use the Mixed Signal PICtail<sup>™</sup> Demo Board. The manual layout is as follows:

- Chapter 1. Product Overview Important information about the Mixed Signal PICtail™ Demo Board.
- Chapter 2. Installation and Operation Includes instructions on how to get started with this demo board and a detailed description of each function of the demo board.
- Appendix A. Schematics and Layouts Shows the schematic and layout diagrams for the Mixed Signal PICtail™ Demo Board.
- Appendix B. Bill-Of-Materials (BOM) Lists the parts used to build the Mixed Signal PICtail™ Demo Board.
- Appendix C. MixedSignal\_V100.asm Description Example "Main" assembly firmware for the PIC16F767-I/SS microcontroller used to demonstrate the various features of the supported analog products.
- Appendix D. DAC\_dtmf.asm Source Code Example assembly source firmware used to generate Dual Tone Multiple Frequency (DTMF) signals. This firmware is utilized by the "Main" firmware, MixedSignal\_v100.ASM.
- Appendix E. MixedSignal\_16f767i.lkr Source Code Linker script file used to build the example PIC16F767 firmware.
- Appendix F. DTMF Scope Captures Oscilloscope screen captures of the various DTMF tones displaying their FFT to illustrate the quality of the DTMF tones.
- Appendix G. Scope Probe Noise Captures Isolating scope probe noise is challenging. These scope captures illustrate the difference between using a standard scope probe and using coaxial cable directly from the board into the scope.
- Appendix H. Sine Wave and Filtered DTMF Scope Captures Oscilloscope screen capture of the 32-step sine wave routine and the DTMF waveform. The DTMF waveform illustrates the non-filtered DAC output and a simple RC-filtered output.
- Appendix I. MPLAB® IDE Screen Capture MPLAB IDE 6.3x was used to generate the example source firmware. This screen capture illustrates the tool, the project files and the included Watch windows.

### CONVENTIONS USED IN THIS GUIDE

This manual uses the following documentation conventions:

#### DOCUMENTATION CONVENTIONS

Description Represents		Examples	
Arial font:		·	
Italic characters	Referenced books	MPLAB <sup>®</sup> IDE User's Guide	
	Emphasized text	is the only compiler	
Initial caps	A window	the Output window	
	A dialog	the Settings dialog	
	A menu selection	select Enable Programmer	
Quotes	A field name in a window or dialog	"Save project before build"	
Underlined, italic text with right angle bracket	A menu path	<u>File&gt;Save</u>	
Bold characters	A dialog button	Click OK	
	A tab	Click the <b>Power</b> tab	
ʻb <i>nnn</i>	A binary number where <i>n</i> is a digit	ʻb00100, ʻb10	
Text in angle brackets < >	A key on the keyboard	Press <enter>, <f1></f1></enter>	
Courier font:			
Plain Courier	Sample source code	#define START	
	Filenames	autoexec.bat	
	File paths	c:\mcc18\h	
	Keywords	_asm, _endasm, static	
	Command-line options	-Opa+, -Opa-	
	Bit values	0, 1	
Italic Courier	A variable argument	<i>file.o</i> , where <i>file</i> can be any valid filename	
0xnnnn	A hexadecimal number where <i>n</i> is a hexadecimal digit	0xFFFF, 0x007A	
Square brackets []	Optional arguments	<pre>mcc18 [options] file [options]</pre>	
Curly brackets and pipe character: {   }	Choice of mutually exclusive arguments; an OR selection	errorlevel {0 1}	
Ellipses	Replaces repeated text	<pre>var_name [, var_name]</pre>	
	Represents code supplied by user	void main (void) { }	

#### **RECOMMENDED READING**

This user's guide describes how to use the Mixed Signal PICtail<sup>™</sup> Demo Board. Other useful documents are listed below. The following Microchip documents are available and recommended as supplemental reference resources.

#### MCP4921/22, "12-Bit DAC with SPI™ Interface" Data Sheet (DS21897)

Provides detailed information regarding the MCP492X devices.

### TC1320, "8-Bit Digital-to-Analog Converter with Two-Wire Interface" Data Sheet (DS21386)

Provides detailed information regarding the TC1320 device.

### TC1321, "10-Bit Digital-to-Analog Converter with Two-Wire Interface" Data Sheet (DS21387)

Provides detailed information regarding the TC1321 device.

### MCP3302/3304, "13-Bit Plus Sign Differential Input 2.7V Low-Power A/D Converter with SPI™ Serial Interface" Data Sheet (DS21697)

Provides detailed information regarding the MCP3302 and MCP3304 devices.

## MCP3204/3208, "2.7V 12-Bit A/D Converters with SPI™ Serial Interface" Data Sheet (DS21298)

Provides detailed information regarding the MCP3204 and MCP3208 devices.

#### MCP1525/1541, "2.5V and 4.096V Voltage Reference" Data Sheet (DS21653)

Provides detailed information regarding the MCP1525 and MCP1541 devices.

### TC55, "1 μA Low-Dropout Positive Voltage Regulator" Data Sheet (DS21653)

Provides detailed information regarding the TC55 device.

#### MCP1700, "Low-Quiescent Current LDO" Data Sheet (DS21826)

Provides detailed information regarding the MCP1700 device.

## MCP616/617/618/619, "2.3V to 5.5V Micropower Bi-CMOS Op Amps" Data Sheet (DS21613)

Provides detailed information regarding the MCP616, MCP617, MCP618 and MCP619 devices.

### PIC16F737, PIC16F747, PIC16F767, PIC16F777, "PIC16F7X7 Data Sheet" (DS30498)

Provides detailed information regarding the PIC16F737, PIC16F747, PIC16F767 and PIC16F777 devices.

#### THE MICROCHIP WEB SITE

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- Product Support Data sheets and errata, application notes and sample programs, design resources, user's guides and hardware support documents, latest software releases and archived software
- General Technical Support Frequently Asked Questions (FAQ), technical support requests, online discussion groups and Microchip consultant program member listing
- Business of Microchip Product selector and ordering guides, latest Microchip press releases, listing of seminars and events, listings of Microchip sales offices, distributors and factory representatives

#### **CUSTOMER SUPPORT**

Users of Microchip products can receive assistance through several channels:

- Distributor or Representative
- · Local Sales Office
- Field Application Engineer (FAE)
- Technical Support
- · Development Systems Information Line

Customers should contact their distributor, representative or field application engineer (FAE) for support. Local sales offices are also available to help customers. A listing of sales offices and locations is included in the back of this document.

Technical support is available through the web site at: http://support.microchip.com

In addition, there is a Development Systems Information Line which lists the latest versions of Microchip's development systems software products. This line also provides information on how customers can receive currently available upgrade kits.

The Development Systems Information Line numbers are:

1-800-755-2345 - United States and most of Canada

1-480-792-7302 - Other International Locations

NOTES:



### Mixed Signal PICtail<sup>™</sup> Demo Board User's Guide

### **Chapter 1. Product Overview**

#### 1.1 INTRODUCTION

This chapter provides an overview of the Mixed Signal PICtail<sup>™</sup> Demo Board and covers the following topics:.

- Purpose and utility of the Mixed Signal PICtail<sup>™</sup> Demo Board
- Contents of the Mixed Signal PICtail<sup>™</sup> Demo Board Kit

#### 1.2 PURPOSE AND UTILITY OF THE MIXED SIGNAL PICtail™ DEMO BOARD

The Mixed Signal PICtail<sup>™</sup> Demo Board allows the system designer to quickly evaluate the suitability of several Microchip analog products for their product's design. Microchip's Digital-to-Analog Converters (DACs), Analog-to-Digital Converters (ADCs), V<sub>REF</sub>s, Low Dropout Output (LDO) regulators and the PIC16F7X7 devices are supported. Evaluating precision analog products for specific applications can be challenging for practical reasons. First, many products are only available in surface-mount packages. Secondly, analog circuits tend to be affected adversely by system noise. Common breadboarding techniques are not practical for these reasons. The Mixed Signal PICtail<sup>™</sup> Demo Board utilizes a 4-layer Printed Circuit Board (PCB), with attention paid to reducing system noise.

The Mixed Signal PICtail<sup>™</sup> Demo Board can isolate a specific device's performance to establish baseline performance. The board can be customized quickly for specific system requirements.

#### 1.3 CONTENTS OF THE MIXED SIGNAL PICtail DEMO BOARD KIT

This Mixed Signal PICtail<sup>™</sup> Demo Board includes:

- The Mixed Signal PICtail™ Demo Board PCB
- PIC16F767 firmware that demonstrates how to configure and write to the MCP492X, MCP482X and TC132X DAC products
- PIC16F767 firmware demonstrating DTMF generation using a DAC
- PIC16F767 firmware demonstrating sine-wave generation using a DAC
- PIC16F767 firmware to configure and read the MCP330X/320X SAR ADCs
- PIC16F767 firmware that configures and reads the MCP3551 Sigma-Delta ADC
- MCP617 dual op amp (standard 8-pin dual layout) that can be configured as an input signal filter (ADC) or an output signal conditioning stage for the DACs
- Four DIP switches allow simple firmware mode selection
- Two indicator LEDs (red and green) for visual feedback
- PICkit<sup>™</sup> 1 Flash Starter Kit's 14-pin header provides an interface to Microchip's 8- and 14-pin PICmicro<sup>®</sup> microcontroller devices

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### Mixed Signal PICtail<sup>™</sup> Demo Board User's Guide

### **Chapter 2. Installation and Operation**

#### 2.1 INTRODUCTION

The Mixed Signal PICtail<sup>™</sup> Demo Board demonstrates several Microchip analog products in a signal chain configuration. The product families demonstrated include DACs, ADCs, V<sub>REF</sub>s, LDOs and PICmicro<sup>®</sup> microcontroller devices. Evaluating precision analog products for specific applications can be challenging due to noise sources related to the PCB layout and not the silicon under evaluation. The Mixed Signal PICtail<sup>™</sup> Demo Board provides the necessary hardware and firmware to exercise each of these devices in real-world applications. Users can quickly modify the existing hardware and firmware to validate functionality for their specific system needs.

#### 2.2 FEATURES

The Mixed Signal PICtail<sup>™</sup> Demo Board has the following features:

- Printed Circuit Board (PCB) is a 4-layer board designed to minimize external noise
- A 28-pin PICmicro (PIC16F767) microcontroller footprint is provided to permit code development. In-Circuit Debugger is supported via the RJ11 connector
- The 14-pin header is designed to seamlessly interface to the PICkit<sup>™</sup> 1 Flash Starter Kit
- Firmware demonstrating DTMF generation on the MCP492X/482X DAC is included
- Firmware demonstrating a precision sine-wave generation on the TC132X DAC is included
- Firmware to configure and read the MCP330X/320X SAR ADCs is included
- Two precision voltage references (V<sub>REF</sub>s) are supported (can compare noise)
- Flexible amplifier circuit layout supports a dual op amp in multiple configurations for either an input signal filter (ADC) or an output signal-conditioning stage for the DACs
- Four DIP switches allow simple firmware mode selection are supported
- · Two indicator LEDs (red and green) are supported
- Can be powered by either the PICkit<sup>™</sup> 1 Flash Starter Kit or by an external 9V supply

#### 2.3 GETTING STARTED

The Mixed Signal PICtail<sup>™</sup> Demo Board is assembled and tested for evaluation and demonstration of the MCP492X, MCP482X, TC132X, MCP3551, MCP3302, MCP3204, MCP1541, MCP1701, PIC16F767 and MCP617 features. Additional product samples with footprints supported by this board are included. A block diagram of the demo board is shown in Figure 2-1. Refer to **Appendix A. "Schematics and Layouts"** and **Appendix B. "Bill-Of-Materials (BOM)**" for more detailed circuit information.

### Mixed Signal PICtail<sup>™</sup> Demo Board User's Guide



FIGURE 2-1: Mixed Signal PICtail™ Demo Board Block Diagram.

#### 2.3.1 The Hardware

Figure 2-2 shows the layout of the Mixed Signal PICtail<sup>™</sup> Demo Board with indicators to points of interest, while Table 2-1 details the PICkit<sup>™</sup> 1 Flash Starter Kit Header connections. Jumpers JP1-JP5 are fully described in **Section 2.3.2 "The Embedded System Firmware"**.





PINS					
Pin Name	Pin Number	Pin Type	Buffer Type	Description	
V <sub>SS</sub>	14	_		Electrical Ground. Both analog and digital.	
V <sub>IN</sub>	13		_	Power Supply Input. Refer to <b>Note 2</b> in <b>Appendix A</b> " <b>Schematics and Layouts</b> ". Do not plug in 9V supply and connect to PICkit™ 1 Flash Starter Kit.	
CS0	12	0	_	SPI™ Chip Select signal for the external ADCs. Do not populate both the MCP3551 and the MCP3302 as they share the same CS0 signal.	
SCK/SCL	11	0	ST	SPI Clock or $I^2C^{TM}$ Clock Signal. Note that external weak pull-up $R_{20}$ connects this signal to $V_{DD2}$ .	
SDI/SDA	10	I/O	ST	SPI Data In or I <sup>2</sup> C Data signal (Data Out on ADC). Note that external weak pull-up $R_{14}$ connects this signal to $V_{DD2}$ .	
SDO	9	0	—	SPI Data Out Signal (Data In on DAC and ADC)	
CS1	8	0	_	SPI Chip Select Signal for the External DACs. Do no populate both the MCP492X and the MCP482X as they share the same CS0 signal.	
LDAC	7	0	—	Latches the DAC Output When Low. Note the weak pull-down resistor $R_5$ if the firmware doesn't drive the pin to a desired state.	
V <sub>REF_ADC</sub>	6	Ι		JP4 selects the V <sub>REF</sub> source to use as the ADC reference signal. The PICmicro <sup>®</sup> microcontroller on the PICkit™ 1 Flash Starter Kit may use this for its internal ADC's V <sub>REF</sub> .	
LED0/TX	5	0	—	Active High Red LED Signal. This I/O also has the USART's TX signal multiplexed on it.	
LED1/RX	4	I/O	—	Active High Green LED Signal. This I/O also has the USART's RX signal multiplexed on it.	
SW0	3	Ι	—	S1's Switch 1. This pin uses the internal pull-up resistor to determine when the switch is open.	
SW1	2	Ι	—	S1's Switch 2. This pin uses the internal pull-up resistor to determine when the switch is open.	
SW2	1	Ι	—	S1's Switch 3. This pin uses the internal pull-up resistor to determine when the switch is open.	

#### **TABLE 2-1:** PICkit™ 1 FLASH STARTER KIT 14-PIN HEADER INTERFACE PINS

I = Input

O = Output

#### 2.3.2 The Embedded System Firmware

The Mixed Signal PICtail<sup>™</sup> Demo Board firmware utilizes PICmicro<sup>®</sup> microcontroller assembly language, Microchip MPASM<sup>™</sup> assembler and MPLINK<sup>™</sup> linker to build the.HEX machine file. MixedSignal\_v100.asm, DAC\_dtmf.asm, p16F767.inc and MCP492X\_16f767i.lkr files are needed in your project to build the MixedSignalPICtail.hex.

MixedSignal\_v100.asm contains the main program and most of the subroutines. After initialization of critical PICmicro microcontroller peripherals (including the internal oscillator to 8 Mhz), the main loop polls the four DIP switches to determine the selected mode of operation. The DIP switches create a 4-bit binary number from 0 to 15. If a change of mode is detected for 100 ms during 500 ms of scanning, a new mode is selected and the LEDs are alternately flashed for two seconds. Most of the modes will time-out and re-scan the DIP switches periodically.

Refer to **Appendix C. "MixedSignal\_V100.asm Description**" for the commented source code further describing each mode.

Modes 0XXX primarily utilize the MCP492X DAC modes:

- Mode0000: Use the DTMF generation subroutine (located in DAC\_dtmf.asm) to dial a phone number stored in memory. Analyze output on V<sub>OUTB</sub> or V<sub>OUTD</sub>'s SMA connector. See Appendix F. "DTMF Scope Captures" for resulting waveform frequency analysis.
- Mode0001: Send 000h and FFFh commands to generate a 100 Hz R-R output on the MCP492X. Probe V<sub>OUTA</sub> and V<sub>OUTB</sub> to see the resulting waveforms.
- 3. **Mode0010:** Send 400h and BFFh commands to generate a 100 Hz output on the MCP492X. Probe V<sub>OUTA</sub> and V<sub>OUTB</sub> to see the resulting waveforms.
- 4. **Mode0011:** DACA = SHDN, DACB = SHDN, PIC = SLEEP. This mode demonstrates the low-power nature of the DAC, the PICmicro microcontroller, the op amp and the LDO. A power cycle is required after the mode switch is changed to exit this mode.
- 5. Mode0100: DACB and DACA = 800h and Read w/PIC16F767 10b ADC, "broad-cast on USART". This mode is useful for evaluating the PICmicro microcontroller's ADC. A<sub>IN\_B</sub> can be injected with an alternative signal and the result can be analyzed through the 19200 baud async, 9-bit transmission. Microchip's Data View analysis tool, along with the MCP3551 USB evaluation board, provide a "canned" analysis solution.
- 6. Mode0101: DACB = 801h, DACA = 800h and Read w/MCP3302 13b Dif, "broad-cast on USART". This mode is useful for evaluating the MCP3302 or the MCP3204 ADC. A<sub>IN\_B</sub> can be injected with an alternative signal and the result can be analyzed through the 19200 baud async, 9-bit transmission. Microchip's Data View analysis tool, along with the MCP3551 USB evaluation board, provide a "canned" analysis solution.
- 7. Mode0110: DACB and DACA = 800h and Read w/MCP3551, "broadcast on USART". This mode is useful for evaluating the MCP3551 ADC or the MCP1541 V<sub>REF</sub>. A<sub>IN\_B</sub> can be injected with an alternative signal and the result can be analyzed through the 19200 baud async, 9-bit transmission. Microchip's Data View analysis tool, along with the MCP3551 USB evaluation board, provide a "canned" analysis solution.
- 8. Mode0111: Open for user to define their own routine.

Modes 1XXX primarily utilize TC132X DAC modes:

- Mode1000: Generate a 100 Hz 32-step sine wave on the TC132X. Analyze output on V<sub>OUTC</sub>. See Appendix H. "Sine Wave and Filtered DTMF Scope Captures" for resulting unfiltered waveform.
- 2. **Mode1001:** Send 000h and FFFh commands to generate a 100 Hz R-R output on the TC132X. Probe V<sub>OUTC</sub> to see the resulting waveforms.
- Mode1010: Send 400h and BFFh commands to generate a 100 Hz output on the TC132X. Probe V<sub>OUTC</sub> to see the resulting waveforms.
- Mode1011: DAC = SHDN, PIC = SLEEP. This mode demonstrates the low-power nature of the DAC, the PICmicro microcontroller, the op amp and the LDO. A power cycle is required after the mode switch is changed to exit this mode.
- Mode1100: DAC = 200h and Read with PIC16F767 10b ADC, "broadcast on USART". A<sub>IN\_C</sub> can be analyzed using Microchip's Data View analysis tool, which, along with the MCP3551 USB evaluation board, provides a "canned" analysis solution.
- Mode1101: DAC = 200h and Read with MCP3302 13b single-ended, "broadcast on USART". A<sub>IN\_C</sub> can be analyzed using Microchip's Data View analysis tool, which, along with the MCP3551 USB evaluation board, provides a "canned" analysis solution.
- 7. Mode1110: Open for user to define their own routine.
- 8. Mode1111: Open for user to define their own routine.

Refer to **Appendix C. "MixedSignal\_V100.asm Description**" to view source code and comments.

Refer to **Appendix D. "DAC\_dtmf.asm Source Code**" to view source code and comments.

Refer to Appendix E. "MixedSignal\_16f767i.lkr Source Code" to view the script.

Refer to the p16F767.inc standard include file located in your "\MPLAB IDE\MCHIP\_Tools\" folder.

#### 2.4 RUNNING THE DEMOS

The Mixed Signal PICtail<sup>™</sup> Demo Board was designed to utilize the PIC16F767 located on the PCB or a PICmicro microcontroller operating on the PICkit<sup>™</sup> 1 Flash Starter Kit board. This Mixed Signal PICtail<sup>™</sup> Demo Board User's Guide will only discuss the stand-alone operation utilizing the PIC16F767.

#### 2.4.1 Power

The Mixed Signal PICtail<sup>™</sup> Demo Board can be powered by either the PICkit<sup>™</sup> 1 Flash Starter Kit's V<sub>DD</sub> and V<sub>SS</sub> signals or by a DC power supply 9V (5V minimum and 10V maximum). The onboard TC55 5.0V LDO produces a regulated 5.0V supply to operate the analog devices under test. The Mixed Signal PICtail<sup>™</sup> Demo Board User's Guide assumes the standard 9V power supply that comes with many of Microchip's development tools (including the MPLAB<sup>®</sup> ICD 2) is utilized. The standard 9V DC connector is provided for your convenience.

With the default firmware programmed into the PIC16F767, the LED's should alternately flash for approximately two seconds upon power-up.

#### 2.4.2 Selecting the Mode

 $S_1$  is a 4-position DIP switch numerically labeled 1, 2, 3 and 4. These contact switches have one terminal tied to  $V_{SS}$  and one terminal connected to a 1 k $\Omega$  resister in series with the PIC16F767 PORTB<4:7> I/O port. These pins have an internal weak pull-up to prevent the I/O from floating when the corresponding DIP switch is open. The DIP switch is labeled with an arrow indicating the "on" (or closed) position of the switch. When the DIP switch is on, the I/O pin is pulled down to  $V_{SS}$ . The default firmware will interpret this as a "0". The binary combination of these four DIP switches determine the mode of operation.

**Note:** Selecting the mode requires the user to not "read" the switches as a binary number. Switch 1 is on the left, while switch 4 is on the right. Typically, the most significant digit is on the left, unlike this configuration. In addition, the "on" position represents a "0", which is also counterintuitive. The user could alter the default firmware to interpret the mode switches differently (change the jump table's order) or simply look at the board with the 14-pin header located at the top.

Refer to **Section 2.3.2 "The Embedded System Firmware"** for operational details for each mode.

#### 2.4.3 Jumper JP1 Selection

Jumper JP1 is located in the center of the board closest to the PICmicro microcontroller and its MPLAB ICD 2 connector. JP1 consists of three pairs of jumper pins. The lower-two pins are connected to  $A_{IN\_C}$ . The two center pins are connected to  $V_{OUTC}$ . The top-two pins are connected to  $A_{IN\_D}$ .

Refer to Figure 2-2 and Appendix A. "Schematics and Layouts".

If the user would like to read the output of Microchip's TC132X DAC using either the MCP3302 or MCP3204, place a jumper from one of the middle two pins to either of the outer pins, depending on which ADC input channel you are using.

Note: The default firmware Mode1101 requires JP1 to be connected to A<sub>IN C</sub>.

#### 2.4.4 Jumper JP2 Selection

Jumper JP2 is located in the center of the board above JP1. JP2 consists of three pairs of jumper pins. The lower two pins are connected to  $A_{IN\_A}$ . The middle two pins are connected to  $V_{OUTA}$ . The top two pins are connected to  $\overline{A_{IN\_C}}$ . Refer to Figure 2-2 and **Appendix A. "Schematics and Layouts"**.

If the user would like to read Microchip's MCP492X or MCP482X DAC A output with either the MCP3302 or MCP3204, place a jumper from one of the middle two pins to either of the outer pins, depending on which ADC input channel you are using.

#### 2.4.5 Jumper JP3 Selection

Jumper JP3 is located in the center of the board just above the 8-pin, dual op amp MCP617 and to the right of the SMA connector's footprint. JP3 consists of three pairs of jumper pins. The lower two pins are connected to  $A_{IN_D}$ . The middle two pins are connected to  $V_{OUTB}$ . The top two pins are connected to  $A_{IN_B}$ . Refer to Figure 2-2 and **Appendix A. "Schematics and Layouts"** to view the schematic.

If the user would like to read Microchip's MCP492X or MCP482X DAC B output with either the MCP3302 or MCP3204, place a jumper from one of the middle two pins to either of the outer pins, depending on which ADC input channel you are using.

Note: The default firmware Mode0101 requires JP3 to be connected to  $A_{IN_B}$  to read  $V_{OUTB}$  with the MCP3302 or MCP3204.

#### 2.4.6 Jumper JP4 Selection

Jumper JP4 is located in the center of the board, farthest away from the PICmicro microcontroller and its MPLAB ICD 2 connector. JP4 consists of three pairs of jumper pins. The lower two pins are connected to the MCP1541's 4.1V V<sub>REF</sub> output. The top two pins are connected to the REF198G's 4.1V V<sub>REF</sub> output. The middle two pins are NOT connected, similar to J1, J2 or J3. The middle left pin selects the V<sub>REF\_ADC</sub> source while the middle right pin selects the V<sub>REF\_DAC</sub> source. Refer to Figure 2-2 and **Appendix A. "Schematics and Layouts"**.

If the user employs the REF19G as the V<sub>REF</sub> source for Microchip's MCP492X or TC132X DACs, a jumper connecting the top right pin with the middle right pin is required. If the user would like to use the MCP1541 as the V<sub>REF</sub> source for Microchip's MCP492X, MCP482X or TC132X DACs, a jumper connecting the bottom right pin with the middle right pin is required.

**Note:** The default firmware requires a V<sub>REF\_DAC</sub> jumper to function for almost all modes.

If the user employs the REF19G as the V<sub>REF</sub> source for Microchip's MCP3302, MCP3204 or PIC16F767 ADCs, a jumper connecting the top right pin with the middle right pin is required. If the user employs the MCP1541 as the V<sub>REF</sub> source for Microchip's MCP492X, MCP482X or TC132X DACs, a jumper connecting the bottom right pin with the middle right pin is required.

**Note:** The default firmware Modes0100, 0101, 1100 and 1101 require V<sub>REF\_ADC</sub> to be selected in order to function.

#### 2.4.7 Jumper JP5 Selection

Jumper JP5 is located along the right side of the board, just above the 14-pin MCP492X footprint. JP5 consists of three jumper pins.

JP5 is used to configure the board for the Microchip SPI DAC that gets soldered onto the board. Refer to Figure 2-2 and **Appendix A. "Schematics and Layouts"**.

- If the MCP4922 is used, no jumper is required.
- If the MCP4921 is used, a jumper on the right two pins is required.
- If the MCP4822 is used, no jumper is required.
- If the MCP4821 is used, a jumper on the left two pins is required.

#### 2.4.8 Probe Connections

The most commonly probed signals are available using the surface-mount test points located along the sides of the board. These test points are labeled by the silk-screen. Note that four of these test points are oversized (2x) and are on both sides of the board. This is convenient for connecting probe ground "alligator" clips. These ground connections are critical for minimizing probe noise. The MCP3551 22b ADC is sensitive enough to "see" these noise signals enough to significantly reduce performance. J7 is a SMA connector to allow a fully-shielded connection from the ADC input (V<sub>OUTD</sub>) to your scope. **Appendix G. "Scope Probe Noise Captures"** illustrates the difference between a normal probe connection and the SMA connection. As you can see, the noise is a product of the scope connection, not the op amp buffer or ADC.

#### 2.4.9 MPLAB ICD 2 Header J4

When using the PIC16F767 (or any other Flash, 28-pin, PICmicro microcontroller with compatible footprint) the MPLAB ICD 2 is a low-cost development tool that can be utilized for code development. The MPLAB ICD 2 has defined a standard connector to simplify In-Circuit Debugging and In-Circuit Serial Programming (ICSP<sup>™</sup>) of the PICmicro microcontroller.

The MPLAB ICD 2 system is particularly advantageous when developing mixed signal solutions. The MPLAB ICD 2 does not introduce any stray inductance or capacitance typical of emulators' adapters, cables and interface boards. The PICmicro microcontroller can be soldered onto the board just as it would for standard production. The MPLAB ICD 2 signals remain static during normal operation, therefore adding no noise to the system while executing code.

This RJ11 connector would not be used if the PICkit<sup>™</sup> 1 Flash Starter Kit is used for development.

NOTES:



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### **Appendix A. Schematics and Layouts**

#### A.1 INTRODUCTION

This appendix contains the schematics and layouts for the Mixed Signal PICtail™ Demo Board.

Diagrams included in this appendix:

- Board Schematic
- Board Top + Silk Screen Layer
- Board Power Layer
- Board Top Layer
- · Board Bottom Layer
- · Board Ground Layer

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Notes: Note 1: Note 2: Note 4: R10 if a Note 5: VREF\_D SHDN to ISHDN to

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per = MCP4921 = MCP4821

DAC to VC to VOUT

: MCP4922

U5 or U10, but J5 or J1 & L1, U3 or U6/U8, R10 or R18, bu ပ



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#### FIGURE A-4: BOARD LAYOUT - TOP LAYER







#### FIGURE A-6: BOARD LAYOUT - GROUND LAYER



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### Appendix B. Bill-Of-Materials (BOM)

Qty	Reference	Description	Manufacturer	Part Number
1	C1	Capacitor, Ceramic, 1000 pf 50V, 5%, C0G 0805	Murata Electronics <sup>®</sup> North America	GRM2165C1H102JA01D
11	C4, C5, C9, C10, C12, C13, C15, C21, C22, C27, C28	Capacitor, 10000 pf, 50V Ceramic, X7R 0805	Kemet <sup>®</sup>	C0805C103K5RACTU
6	C3, C8, C11, C16, C17, C24	Capacitor, .1 uf, 16V, Ceramic X7R 0805	Panasonic <sup>®</sup> - ECG	ECJ-2VB1C104K
4	C2, C14, C23, C26	Capacitor, 1 uf, 16V, Ceramic Y5V 0805	Panasonic - ECG	ECJ-2VF1C105Z
4	C6, C18, C19, C20	Capacitor, Ceramic 100 pf, 50V, NP0 0805	Kemet	C0805C101J5GACTU
1	C25	Capacitor, 10 uf, 16V, SMT	Panasonic VS series	ECEV1CS100SR
1	D2	LED, Green, 565 nm, PLCC, 120 deg	Lite-On Trading USA, Inc.	LTST-T670GKT
1	D1	LED, 2.8x3.2 mm, 635 nm, Red, CLR SMD	Lumex <sup>®</sup> Opto/ Components Inc.	SML-LX2832IC-TR
2	J1, J2	Conn, Header, 14pos, .100 Vert Tin	Molex <sup>®</sup> /Waldom <sup>®</sup> Electronics Corp.	22-28-4140
1	J4	Conn, Mod Jack, 6-6 R/A, PCB 50AU	AMP/Tyco Electronics	520470-3
1	J5	Conn, Power Jack, 2.5 mm, PCB CIRC	CUI Inc	PJ-102B
1	J7	Do Not Populate Connectors, RF, Jack, SMA	SPC Technology	SPC10611
4	JP1, JP2, JP3, JP4	Conn, Header, 6pos, .100, Vert Gold	Molex/Waldom Electronics Corp.	10-89-1061
1	JP5	Conn, Header, 3pos, .100, Vert Tin	Molex/Waldom Electronics Corp.	22-28-4030
1	L1	Inductor, Fixed, 10 uh, Type 7BA	Toko America	144LY-100J
1	P1	Conn, Header, 14pos, .100, R/A Tin	Molex/Waldom Electronics Corp.	22-28-8140
3	R23, R29, R30	Resistor, 0.0Ω, 1/8w, 5%, 0805 SMD	Panasonic - ECG	ERJ-6GEY0R00V
6	R1, R2, R3, R4, R11, R12	Resistor, 1.00 kΩ, 1/10w, 1% 0805 SMD	Panasonic - ECG	ERJ-6ENF1001V
2	R18, R22	Resistor, 1.00 mΩ, 1/10w, 1% 0805 SMD	Panasonic - ECG	ERJ-6ENF1004V
4	R25, R26, R27, R28	Resistor, 4.99 k $\Omega$ ,1/10w, 1% 0805 SMD	Panasonic - ECG	ERJ-6ENF4991V
2	R10, R31	Do Not Populate		
6	R5, R6, R14, R20, R24	Resistor, 10.0 kΩ, 1/10w, 1% 0805 SMD	Panasonic - ECG	ERJ-6ENF1002V

Qty	Reference	Description	Manufacturer	Part Number
5	R9, R13, R15, R16, R17	Resistor, 100Ω, 1/10w, 1% 0805 SMD	Panasonic - ECG	ERJ-6ENF1000V
2	R7, R8	Resistor, 470Ω, 1/8w, 5% 0805 SMD	Panasonic - ECG	ERJ-6GEYJ471V
1	R21	Resistor, 0.0Ω, 1/4w, 5% 1206 SMD	Yageo America	9C12063A0R00JLHFT
1	S1	Switch, Dip 4-pos, Top Slide SMT	CTS Corporation Resistor/Electrocom ponents	204-4ST
12	TP1, TP2, TP3, TP4, TP5, TP6, TP7, TP8, TP9, TP10, TP11, TP12	PC, Test Point, Miniature SMT	Keystone Electronics <sup>®</sup>	5015
1	U1	Microcontroller, 8-bit, CMOS Flash with 10-bit A/D	Microchip Technology Inc.	MCP16F767-I/SS
1	U4	Low Dropout Positive Voltage Regulator	Microchip Technology Inc.	TC55RP5001ECB713
1	U7	10-bit Digital-to-Analog Converter	Microchip Technology Inc.	TC1321EUA
1	U9	Voltage Reference, 4.096V	Microchip Technology Inc.	MCP1541-I/TT
1	U11	IC Volt Ref, LDO, 4.096V, 8-pin SOIC	Analog Devices Inc.	REF198GS

#### TABLE B-1: BILL-OF-MATERIALS (BOM) (CONTINUED)



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### Appendix C. MixedSignal\_V100.asm Description

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#### TABLE C-1: MIXEDSIGNAL\_V100.ASM

TITLE "Mixed Signal PICtail(TM) Board Firmware" ; Author: Jim Simons ; Tools: MPLAB(R) IDE 6.62 using MPLINK(tm) Linker ; Editor: ComicSans 8pt w/8 character Tabs MixedSignal\_v100.asm ; Files: DAC\_dtmf.asm ; MixedSignal\_16f767i.lkr ; p16f767inc ; ; Description: Use the DIP Switches to select the mode of operation. The PIC(R) MCU then ; polls for changes in the DIP switches. If a change is detected for 100mS during 500ms of ; scanning, a new mode is selected. MCP4922 DAC modes ; ; Mode0000: Flash LEDs and Dial a phone number stored in memory. ; Mode0001: Send 000h & FFFh commands to generate a 100Hz R-R output on the MCP4922. ; Mode0010: Send 400h & BFFh commands to generate a 100Hz output on the MCP4922. ; Mode0011: DACA = SHDN, DACB = SHDN, PIC = SLEEP ; Mode0100: DACB & DACA = 800h & Read w/PIC16F767 10b ADC, "broadcast on USART" ; Mode0101: DACB = 801h, DACA = 800h & Read w/MCP3302 13b Dif, "broadcast on USART" ; Mode0110: DACB & DACA = 800h & Read w/MCP3551, "broadcast on USART" ; Mode0111: Open for user to define their own routine. TC132X DAC modes (MUST DEFINE WHICH SPECIFIC DEVICE BELOW) ; Mode1000: Flash LEDs and generate a 100Hz 32step sine wave on the TC1321. ; Mode1001: Send 000h & FFFh commands to generate a 100Hz R-R output on the TC1321. ; Mode1010: Send 400h & BFFh commands to generate a 100Hz output on the TC1321. ; Mode1011: DAC = SHDN, PIC = SLEEP ; Model100: DAC = 200h & Read w/PIC16F767 10b ADC, "broadcast on USART" ; Model101: DAC = 200h & Read w/MCP3302 13b single-ended, "broadcast on USART" ; Model110: Open for user to define their own routine. ; Model111: Open for user to define their own routine. 

Due to file size, only the first page of MixedSignal\_V100.asm is shown in Table C-1. Please refer to the Microchip web site at www.microchip.com to download and view the latest version of this firmware.

NOTES:



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### Appendix D. DAC\_dtmf.asm Source Code

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#### TABLE D-1: DAC\_DTMF.ASM

```
#include "p16F767.inc"
******************
 DTMF SUBROUTINE using a Rolling Loop Timer
;
 Program memory = 149 words for 32 step tone subroutine
;
                 = 133 words for 16 step tone subroutine
;
                 = 12 registers for tone subroutine
 Data memory
;
 ; THEORY OF OPERATION - ROLLING LOOP TIMER
; 2's complement subtraction of a marked time and a continuous timer
; (overflows from OFFh to 0h) provides an elapsed time which can then
; be compared to some threshold value (another subtraction). The
; result of the compare (<, > or =) can then be used to perform some
; periodic event. The fewest possible cycles per loop is desired to
; achieve the least amount of error from the "zero" cycle (when the
; result of the compare is "="). One major advantages of this
; technique is the ability to use only one timer to keep track of
; several independent periodic events with relatively few instructions
; and instruction cycles.
; THEORY OF OPERATION - DISTORTION
; This routine works with relatively low distortion because the
; statistical distribution of the possible error cycles doesn't peak
; at the "zero" cycle but at some repeatable value relative to the
; "zero" cycle. Error cycles will be +-X from the distribution's
; peak instead of from the "zero" cycle.
; THEORY OF OPERATION - LOOP TIMING
 LOW - No update yet = 6 cycles
;
     - Update output w/o resetting Sine_Table = 18
;
     - Update output w/reset of Sine_Table = 19
;
 HIGH- No update yet = 6 cycles
;
     - Update output w/o resetting Sine_Table = 18
;
     - Update output w/reset of Sine_Table & ToneLength = 22
;
      (Note: end of Tone until Repeat_tone re-enters >11 cycles
;
      depending upon user's code)
```

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```
; OUTPUT - 5 cycles
; THEORY OF OPERATION - CHOOSING # OF STEPS
; Using the above #s:
   Minimum loop = 17 cycles
   Maximum loop = 46 cycles
   Maximum Low distortion = 5 + 22 + 5 = 32
   Maximum High distortion = 5 + 19 + 5 = 29
;
; These numbers need to be taken into consideration when choosing Fosc
; and the # of steps. Obviously, there is a balance between adding
; more steps (doesn't have to be 2^X # of steps) and the distortion
; caused by not executing the minimum loop very often. The user could
; model this with most mathematical software packages to determine
; what is best for their system.
DTMF
               UDATA
F_Low
               RES 1 ;# of cycles for the low frequency
F_Low_Rolling RES 1 ;last value of TMR0 when F_Low_Out was updated
F_Low_Step RES 1 ;SINE table index
F_Low_Out
             RES 1 ;Output duty cycle for F_Low
F_High
             RES 1 ;# of cycles for the high frequency
F_High_Rolling RES 1 ;last value of TMR0 when F_High_Out was updated
F_High_Step
              RES 1 ;SINE table index
F_High_Out
             RES 1 ;Output duty cycle for F_High
              RES 1 ;Output for DAC
DTMF_Out
              RES 1 ;# of F_High cycles used for delay
ToneLength
Key_Value
              RES 1 ; what # to dial?
GLOBAL F_Low, F_Low_Rolling, F_Low_Step, F_Low_Out, F_High, F_High_Rolling
GLOBAL F_High_Step, F_High_Out, DTMF_Out, ToneLength, Key_Value
GLOBAL Tone, Repeat_tone
EXTERN DAC_MSB, DAC_LSB, WriteToMCP492X
DTMF_SUB
          CODE
; Conditional Assembly Control Words
       ;No = 0, Yes = 1
#DEFINE Fosc_8000000
                    1 ;8MHz oscillator
#DEFINE Fosc_4000000 0 ;4MHz oscillator
                   0 ;3.57MHz oscillator
#DEFINE Fosc_3570000
#DEFINE ToneLength_150 0 ;150 ms tone per subroutine call
#DEFINE ToneLength_100 0 ;100 ms tone per subroutine call
#DEFINE ToneLength_50 1 ;50 ms tone per subroutine call
 if Fosc_8000000
#DEFINE _32_steps
                    0 ;32 steps per cycle
#DEFINE _16_steps
                    1 ;16 steps per cycle
 endif
 if Fosc_4000000 | Fosc_3570000
                 0 ;32 steps per cycle
#DEFINE _32_steps
#DEFINE _16_steps
                    1 ;16 steps per cycle
 endif
 if _32_steps
; This is a 32 level lookup table of a 7 bit SINE wave
```
```
Y = 7 bit result X = step #
; Y = 63 + 64 * Sin (X * 360 / 32)
SINE_Table_7bit ;32 step
 addwf PCL,F
 nop ;this location is never used since W != 0
DT .63, .75, .87, .99, .108, .116, .122, .126
 DT .127, .126, .122, .116, .108, .99, .87, .75
 DT .63, .51, .39, .27, .18, .10, .4, .1
DT .0,
       .1, .4, .10, .18, .27, .39, .51
 endif
; if _32_steps & _8_bit
;**********************
                                               *****
* *
; 32 step lookup table of an 8 bit SINE wave
  Y = 8 bit result
;
  X = step #
;
; Y = 127 + 128 * Sin (X * 360 / 32)
;SINE_Table_32step_8bit
; addwf PCL,F
; nop ; this location is never used since W != 0
; DT .127, .152, .176, .198, .218, .233, .245, .253
; DT .255, .253, .245, .233, .218, .198, .176, .152
                       .56, .36, .21, .9,
.21, .36, .56, .78,
     .127, .102, .78,
; DT
                                                .1
; DT .0,
           .1,
                 .9,
                                                .102
; endif
 if _16_steps
;
; This is a 16 level lookup table of a 7 bit SINE wave
; Y = 7 bit result X = step #
; Y = 63 + 64 * Sin (X * 360 / 16)
SINE_Table_7bit
               ;16 step
 addwf PCL,F
 nop
        ;this location is never used since W != 0
DT .63,
        .87, .108, .122
 DT .127, .122, .108, .87
 DT .63, .39, .18, .4
 DT .0,
        .4, .18, .39
 endif
;
                         ******
 * * * * * * * * * * * * * * * * * * *
;
       DTMF Frequency Tables
;
   Key Low High
;
   0 941 1336
;
   1 697 1209
;
   2 697 1336
;
   3 697 1477
;
   4 770 1209
;
;
   5 770 1336
;
   6 770 1477
```

7 852 1209 ; 8 852 1336 ; 9 852 1477 ; A 697 1633 ; B 770 1633 ; C 852 1633 D 941 1633 ; \* 941 1209 ; # 941 1477 ; if ((\_32\_steps) & (Fosc\_8000000)) | ((\_16\_steps) & (Fosc\_4000000)) ; ; \* ; Delay Calculation for Frequency Generation ; ; Fosc = 8MHz #steps = 32 ; OR Fosc = 4MHz; #steps = 16 X = Fosc / (4 \* #steps \* Ftone); F\_Low\_table addwf PCL,F ;X Actual Desired %Error retlw .66 ;947.0 941 .63% retlw .90 ;694.4 697 .37% retlw .90 ;694.4 697 .37% retlw .90 ;694.4 697 .37% retlw .81 ;771.6 770 .21% retlw .81 ;771.6 770 .21% .21% retlw .81 ;771.6 770 retlw .73 ;856.2 852 .49% retlw .73 ;856.2 852 .49% 852 retlw .73 ;856.2 .49% retlw .90 ;694.4 697 .37% 770 retlw .81 ;771.6 .21% retlw .73 ;856.2 852 .49% retlw .66 ;947.0 941 .63% retlw .66 ;947.0 941 .63% retlw .66 ;947.0 941 .63% F\_High\_table addwf PCL,F ;X Actual Desired %Error retlw .47 ;1329.8 1336 .47% retlw .52 ;1201.9 1209 .59% retlw .47 ;1329.8 1336 .47% retlw .42 ;1488.1 1477 .75% retlw .52 ;1201.9 1209 .59% retlw .47 ;1329.8 1336 .47% retlw .42 ;1488.1 1477 .75% retlw .52 ;1201.9 1209 .59% retlw .47 ;1329.8 1336 .47% .75% retlw .42 ;1488.1 1477 .72% retlw .38 ;1644.7 1633 retlw .38 ;1644.7 1633 .72% retlw .38 ;1644.7 1633 .72% retlw .38 ;1644.7 1633 .72% retlw .52 ;1201.9 1209 .59%

```
retlw .42 ;1488.1
                   1477
                           .75%
 endif
 if _16_steps & Fosc_8000000
;
;
   Delay Calculation for Frequency Generation
;
   Fosc = 8MHz
;
               #steps = 16
;
   X = Fosc / (4 * #steps * Ftone)
;
;
;
F_Low_table
 addwf
        PCL,F
   ;X Actual
                Desired %Error
 retlw .133 ;939.8 941
                           .12%
 retlw .179
            ;698.3
                      697
                            .19%
 retlw .179
                     697
            ;698.3
                            .19%
 retlw .179 ;698.3
                      697
                            .19%
                            .21%
 retlw .162 ;771.6
                      770
                            .21%
 retlw .162 ;771.6
                      770
 retlw .162 ;771.6
                      770
                           .21%
 retlw .147 ;850.3
                           .19%
                      852
 retlw .147 ;850.3
                      852
                           .19%
 retlw .147 ;850.3
                      852
                           .19%
 retlw .179 ;698.3
                      697
                            .19%
 retlw .162 ;771.6
                      770
                            .21%
 retlw .147 ;850.3
                      852
                            .19%
 retlw .133
            ;939.8
                      941
                            .12%
 retlw .133 ;939.8
                      941
                            .12%
                            .12%
 retlw .133 ;939.8
                      941
F_High_table
 addwf PCL,F
   ;X Actual
                 Desired
                             %Error
             ;1329.8
 retlw .94
                     1336
                              .47%
 retlw .103
            ;1213.6
                      1209
                              .37%
 retlw .94
             ;1329.8
                      1336
                              .47%
 retlw .85
             ;1470.6
                      1477
                               .43%
 retlw .103
            ;1213.6
                      1209
                              .37%
 retlw .94
             ;1329.8
                      1336
                              .47%
 retlw .85
             ;1470.6
                      1477
                              .43%
                              .37%
 retlw .103 ;1213.6
                      1209
 retlw .94 ;1329.8
                      1336
                              .47%
 retlw .85
            ;1470.6
                      1477
                              .43%
 retlw .77
            ;1623.4
                      1633
                              .59%
                                     ; may run out of tcy and be too slow
 retlw .77
            ;1623.4
                              .59%
                                    ; may run out of tcy and be too slow
                      1633
 retlw .77
             ;1623.4
                     1633
                              .59%
                                     ; may run out of tcy and be too slow
 retlw .77
             ;1623.4
                     1633
                              .59%
                                     ; may run out of tcy and be too slow
 retlw .103
            ;1213.6
                      1209
                              .37%
 retlw .85
             ;1470.6
                      1477
                              .43%
 endif
```

if \_16\_steps & Fosc\_3570000

;

```
Fosc = 3.57 MHz
                     \#steps = 16
   X = Fosc / (4 * #steps * Ftone)
;
F_Low_table
 addwf
         PCL,F
   ;X Actual
              Desired
                          %Error
 retlw .59 ;945.5
                    941
                          .47%
 retlw .80 ;697.3
                    697
                          .04%
                          .04%
 retlw .80 ;697.3
                    697
 retlw .80 ;697.3
                    697
                          .04%
 retlw .72 ;774.7
                    770
                          .72%
 retlw .72 ;774.7
                    770
                          .72%
 retlw .72 ;774.7
                    770
                          .72%
 retlw .65 ;858.2
                    852
                          .65%
 retlw .65 ;858.2
                    852
                          .65%
 retlw .65 ;858.2
                    852
                          .65%
 retlw .80 ;697.3
                     697
                          .04%
 retlw .72 ;774.7
                    770
                          .72%
 retlw .65 ;858.2
                    852
                          .65%
 retlw .59 ;945.5
                    941
                          .47%
 retlw .59 ;945.5
                    941
                          .47%
 retlw .59 ;945.5
                    941
                          .47%
F_High_table
 addwf PCL,F
   ;X Actual
               Desired
                          %Error
 retlw .42 ;1328.1 1336
                           .59%
 retlw .46 ;1212.6
                   1209
                            .30%
 retlw .42 ;1328.1
                    1336
                            .59%
                            .61%
 retlw .38 ;1467.9
                    1477
                   1209
                            .30%
 retlw .46 ;1212.6
                            .59%
 retlw .42 ;1328.1
                   1336
 retlw .38 ;1467.9 1477
                            .61%
 retlw .46 ;1212.6
                   1209
                            .30%
 retlw .42 ;1328.1
                   1336
                            .59%
 retlw .38 ;1467.9
                   1477
                            .61%
 retlw .34 ;1640.6
                   1633
                            .47%
 retlw .34 ;1640.6
                    1633
                            .47%
 retlw .34 ;1640.6
                    1633
                            .47%
 retlw .34 ;1640.6
                    1633
                            .47%
 retlw .46 ;1212.6
                    1209
                            .30%
 retlw .38 ;1467.9
                    1477
                            .61%
 endif
;
   Tone Length Calculation
;
   How many high cycles does it take to meet the desired timeout?
; ToneLength = desired_length / (1/Freq_high)
 if (ToneLength_150)
ToneLength_table
 addwf
         PCL,F
 retlw .200
 retlw .181
 retlw .200
 retlw .222
 retlw .181
 retlw .200
```

retlw .222
retlw .181
retlw .200
retlw .222
retlw .245
retlw .245
retlw .245
retlw .245
retlw .181
retlw .222
endif
if ToneLength_100
ToneLength_table
addwf PCL, F
retlw .134
retlw .121
retlw .134
retlw .148
retlw .121
retlw .134
retlw .148
retlw .121
retlw .133
retlw .148
retlw .163
retlw .163
retlw .163
retlw .163
retlw .121
retlw .148
endif
endri
if mentioneth 50
if ToneLength_50
ToneLength_table
addwf PCL,F
retlw .67
retlw .60
retlw .67
retlw .74
retlw .60
retlw .67
retlw .74
retlw .60
retlw .67
retlw .74
retlw .82
retlw .82
retlw .82 retlw .82
retlw .82 retlw .82
retlw .82 retlw .82 retlw .60
retlw .82 retlw .82 retlw .60 retlw .74
retlw .82 retlw .82 retlw .60
retlw .82 retlw .82 retlw .60 retlw .74 endif
<pre>retlw .82 retlw .60 retlw .74 endif ;************************************</pre>
<pre>retlw .82 retlw .82 retlw .60 retlw .74 endif ;************************************</pre>
<pre>retlw .82 retlw .82 retlw .60 retlw .74 endif ;************************************</pre>
<pre>retlw .82 retlw .82 retlw .60 retlw .74 endif ;************************************</pre>
<pre>retlw .82 retlw .82 retlw .60 retlw .74 endif ;************************************</pre>
<pre>retlw .82 retlw .82 retlw .60 retlw .74 endif ;************************************</pre>

movlw .32 endif if \_16\_steps movlw .16 endif movwf F\_Low\_Step movwf F\_High\_Step movlw 01Fh F\_Low\_Out movwf movwf F\_High\_Out movf TMR0,W movwf F\_Low\_Rolling movwf F\_High\_Rolling movlw 0Fh Key\_Value,F andwf movf Key\_Value,W call F\_Low\_table movwf F\_Low movf Key\_Value,W call F\_High\_table movwf F\_High ;Call here to repeat the tone for ToneLength Repeat\_tone ;The following inits the ToneLength delay reg's movf Key\_Value,W call ToneLength\_table movwf ToneLength test\_F\_Low ;Low frequency tone loop timer movf F\_Low\_Rolling,W subwf TMR0,W ;result = time since last update subwf F\_Low,W ;Carry bit determines if enough time has elapsed btfsc STATUS,C goto test\_F\_High ;do not update the SINE wave yet movf F\_Low,W addwf F\_Low\_Rolling,F ;Very Important to add to the last reference ; instead of using the actual timer value decfsz F\_Low\_Step,F ;update the step count goto no\_reset\_F\_Low\_Step if \_32\_steps movlw .32 endif if \_16\_steps movlw .16 endif movwf F\_Low\_Step no\_reset\_F\_Low\_Step movf F\_Low\_Step,W call SINE\_Table\_7bit ; fetch the corresponding Sin value movwf F\_Low\_Out ;store result test\_F\_High ;High frequency tone loop timer movf F\_High\_Rolling,W subwf TMR0,W ;result = time since last update subwf F\_High,W ;Carry bit determines if enough time has elapsed btfsc STATUS, C update\_output ;do not update the SINE wave yet qoto movf F\_High,W F\_High\_Rolling, F ;Very Important to add to the last reference addwf ; instead of using the actual timer value decfsz F\_High\_Step,F ;update the step count

goto no\_reset\_F\_High\_Step if \_32\_steps movlw .32 endif if \_16\_steps movlw .16 endif movwf F\_High\_Step ;ToneLength timer decfsz ToneLength,F goto no\_reset\_F\_High\_Step ;ToneLength time expired, Exit subroutine retlw 00h no\_reset\_F\_High\_Step movf F\_High\_Step,W call SINE\_Table\_7bit ;fetch the corresponding Sin value movwf F\_High\_Out ;store result ;Sum the 2 7-bit SINE outputs & refresh the D/A converter update\_output ;We can output one frequency at a time for test purposes ;w/o changing any timing! (Notice the sine wave quality) movf F\_High\_Out,W ; comment this line for Low frequency Only ; addwf ;uncomment this line for High frequency Only F\_High\_Out,W ; movf F\_Low\_Out,W ;uncomment this line for Low frequency Only addwf F\_Low\_Out,W ; comment this line for High frequency Only DTMF\_Out movwf xorwf DAC\_LSB,W btfsc STATUS,Z ; nothing changed so continue looping goto test\_F\_Low ; Use this if seeking an 8b result ; movf DTMF\_Out,W PORTB ; Use this if R2R on PortB ; movwf ; movwf CCPR1L ; Use this if utilizing a HW PWM... shifted R for speed. DTMF\_Out,W ; Use this for L shift 8b -> 12b result swapf movwf DAC\_LSB ; should mask the 4 LSBs... if we were getting picky iorlw b'11110000' ; Use this for 12b result , set DAC B, Vref Buffered, ; 1x Gain DAC\_MSB ; Use this for 12b result, otherwise let it default to movwf ; preload call WriteToMCP492X ; takes 30 Tcy using HW SPI goto test\_F\_Low

tone\_done

end

NOTES:



## Appendix E. MixedSignal\_16f767i.lkr Source Code

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#### TABLE E-1: MIXEDSIGNAL\_16F767I.LKR

 $\ensuremath{{\prime}}\xspace$  // Sample ICD2 linker command file for 16F767 LIBPATH .

CODEPAGE	NAME=vectors	START=0x0	$END=0\times3$	PROTECTED
CODEPAGE	NAME=interrupt	START=0x4	END=0x0FF	110120122
CODEPAGE	NAME=page0_1	START=0x100	END=0x1FF	
CODEPAGE	NAME=page0_2a	START=0x200	END=0x22F	
CODEPAGE	NAME=page0_2b	START=0x230	END=0x2FF	
CODEPAGE	NAME=page0_3	START=0x300	END=0x3FF	
CODEPAGE	NAME=page0_4	START=0x400	END=0x4FF	
CODEPAGE	NAME=page0_5	START=0x500	END=0x5FF	
CODEPAGE	NAME=page0_6_7	START=0x600	END=0x7FF	
CODEPAGE	NAME=page1	START=0x800	END=0xFFF	
CODEPAGE	NAME=page2	START=0x1000	END=0x17FF	
CODEPAGE	NAME=page3	START=0x1800	END=0x1EFF	
CODEPAGE	NAME=debug	START=0x1F00	END=0x1FFF	PROTECTED
CODEPAGE	NAME=.idlocs	START=0x2000	END=0x2003	PROTECTED
CODEPAGE	NAME=.test_vect	START=0x2004	END=0x2005	PROTECTED
CODEPAGE	NAME=.device_id	START=0x2006	END=0x2006	PROTECTED
CODEPAGE	NAME=.config	START=0x2007	END=0x2009	PROTECTED
CODEPAGE	NAME=.test	START=0x200A	END=0x203F	PROTECTED
DATABANK	NAME=sfr0	START=0x0	END=0x1F	PROTECTED
DATABANK	NAME=sfr1	START=0x80	END=0x9F	PROTECTED
DATABANK	NAME=sfr2	START=0x100	END=0x10F	PROTECTED
DATABANK	NAME=sfr3	START=0x180	END=0x18F	PROTECTED
DATABANK	NAME=gpr0	START=0x20	END=0x5F	
DATABANK	NAME=DTMF	START=0x60	END=0x6F	
DATABANK	NAME=gpr1	START=0xA0	END=0xEF	
DATABANK	NAME=gpr2	START=0x110	END=0x164	
DATABANK	NAME=dbgspr2	START=0x165	END=0x16F	PROTECTED
DATABANK	NAME=gpr3	START=0x190	END=0x1EF	
CULADEDANK	NAME-dbaann	START=0x70	$END=0 \times 70$	
SHAREBANK	NAME=dbgspr		$END=0 \times F0$	PROTECTED
SHAREBANK	NAME=dbgspr	START=0xF0	END=0xF0 END=0x170	PROTECTED
SHAREBANK	NAME=dbgspr	START=0x170 START=0x1F0	$END=0\times170$ $END=0\times1F0$	PROTECTED
SHAREBANK	NAME=dbgspr	STARI=0XIF0	FIND=OXTE0	PROTECTED

SHAREBANK SHAREBANK SHAREBANK SHAREBANK	NAME=gprs STA NAME=gprs STA	RT=0xF1 E RT=0x171 E	DD=0x7F DD=0xFF DD=0x17F DD=0x1FF
SHAREBANK SECTION SECTION SECTION SECTION SECTION SECTION SECTION SECTION SECTION SECTION SECTION SECTION SECTION SECTION SECTION SECTION SECTION	NAME=GPIS SIA NAME=RESET NAME=INTERRUPT NAME=MAIN NAME=MODE0000 NAME=DTMF_SUB NAME=MODE1000 NAME=OPEN NAME=OPEN NAME=PROG1 NAME=PROG2 NAME=PROG3 NAME=IDLOCS NAME=IDLOCS NAME=TEST_VECT NAME=DEVICEID NAME=CONFIG NAME=TEST	ROM=vectors ROM=interru ROM=page0_1 ROM=page0_2 ROM=page0_2 ROM=page0_3 ROM=page0_4 ROM=page0_5	<pre>s // Reset vectors apt // ROM code space -interrupt . // ROM code space 2a // ROM code space 2b // ROM code space 2b // ROM code space 3 // ROM code space 4 // ROM code space 5 // R</pre>



### **Appendix F. DTMF Scope Captures**



Withhard all the 쉐

FIGURE F-3: DTMF Tone 2 (697 Hz, 1336 Hz).

(697 Hz, 1209 Hz).



FIGURE F-4: DTMF Tone 3 (697 Hz, 1477 Hz).



**FIGURE F-5:** DTMF Tone 4 (770 Hz, 1209 Hz).



**FIGURE F-6:** DTMF Tone 5 (770 Hz, 1336 Hz).



**FIGURE F-7:** DTMF Tone 6 (770 Hz, 1477 Hz).



FIGURE F-9: DTMF Tone 8 (852 Hz, 1336 Hz).



FIGURE F-8: DTMF Tone 7 (852 Hz, 1209 Hz).



FIGURE F-10: DTMF Tone 9 (852 Hz, 1477 Hz).



### **Appendix G. Scope Probe Noise Captures**



**FIGURE G-1:** Oscilloscope screen capture of  $V_{OUT\_B}$  using a standard scope probe and short ground lead. This illustrates the noise picked up by the scope probe and ground lead.



**FIGURE G-2:** Oscilloscope screen capture of  $V_{OUT\_D}$  using the SMA connector and coaxial cable directly to the scope. This is the same as Figure G-1, except the scope probe on  $V_{OUT\_B}$  is turned off. This highlights how critical test connections are to properly evaluating the "real" noise in a system.

NOTES:



**Appendix H. Sine Wave and Filtered DTMF Scope Captures** 



FIGURE H-1: Mode1000b generates a 100 Hz, 32-step sine wave on V<sub>OUT C</sub> using the TC132X.



**FIGURE H-2:** Mode0000b generates DTMF waveforms to repeatedly dial a phone number.  $V_{OUT\_B}$  illustrates the MCP4922's unfiltered output while  $V_{OUT\_D}$  illustrates a simple low-pass filter's ability to "clean" up the signal.

NOTES:



# Appendix I. MPLAB<sup>®</sup> IDE Screen Capture

Ord_s100.451         Disc_bit and         HeadSignal_TEXTERS         History for           Description:         Use the ODP Sections to indext the roots of pointees. The FLC free point for changes in the DDP sections:         Image: Section free         DOC_bit and           ModelBBDD:         Read 1000 A EFF consecution for thread in exemute parameter is 1000 to FP consecution for the ACMAD22.         Image: Section free         DOC_bit and           ModelBBDD:         Section for the command to generate a 1000 to FP command.         DOC_bit and         DOC_bit and         DOC_bit and           ModelBBDD:         Section for the command to generate a 1000 to FP command.         DOC_bit and         DOC_bit and         DOC_bit and           ModelBBDD:         Section for the command to generate a 1000 to FP command.         DOC_bit and	2日12世纪	ant		₩ 邻世	b 11 00 円 P (F B	B Checksun:	Uccde1	12 12 e	
bescription:         Use the DDP Setting to interfere node of operation. The NLC from polit for daryest in the DDP to induces. If a sharpe is consisted for 160x 6 fbring updates a tool is to induced.	AB 10E billor			CHEROMONY .			ald at		Contraction of the local division of the loc
bescription:         Use the ODE Subtract to inside the wolds of sporeture. The KLC from point for daryes in the DDP paintees:         If a sharpe is consistent to inside the index of sporeture. The KLC from point for daryes in the DDP paintees:         If a sharpe is consistent to inside the index of sporeture, a new wolds is bisisted.           MACMED21: MC sould:         MACMED21: MC sould:         If a sharpe is consistent is paintees a toble is a spore on the MCNM022.         If a sharp the isotent is paintees a toble is a spore on the MCNM022.         If a sharp the isotent is paintees a toble is a spore on the MCNM022.         If a sharp the isotent is paintees a toble is a spore on the MCNM022.         If a sharp the isotent is paintees a toble is a spore on the MCNM022.         If a sharp the isotent isoten	Foral +100.45M DAC	dritare NiedS	and terrine P	INTERINC					
ACM 9922 bit Sectored for these winds (construction, investigat, investid, investigat, investid, investigat, investigat	2 becomption:	Lite Pro GEP Ser	itshec to palect the	mode of spendle	an. The KLC then polls for change	IS IN THE DUP SWITCHES			
Address       Address	1	If a sharpe is a	amuted for LEONS	i daring 500ws et	f asserting, a new wolls is selected	۵.	-		
ModelBBC:       Resh LEbe and BDC:       Seek 1000 A 6777 answord to guarante a 10016 & & output on the Ad24622.         ModelBD:       Seek 0000 A 6777 answord to guarante a 10016 & & output on the Ad24622.         ModelBD:       Seek 0000 A 6777 answord to guarante a 10016 & & output on the Ad24622.         ModelBD:       Seek 0000 A 6777 answord to guarante a 10016 & & output on the Ad24622.         ModelBD:       Seek 0000 A 647 answord to guarante a 10016 & & output on the Ad24622.         ModelBD:       Seek 0000 A 647 answord to guarante a 10016 & & output on the Ad24622.         ModelBD:       Seek 0000 A 647 answord to guarante a 10016 & & output on the Ad2462.         ModelBD:       Seek 0000 A 647 and with CP0000 218 bit! Threadward on USART*         ModelBD:       Seek 0000 A 647 answord to guarante a 10016 B & output on the TCDD1.         ModelBD:       Seek 0000 A 647 answord to guarante a 10016 B & output on the TCDD1.         ModelBD:       Seek 0000 A 647 answord to guarante a 10016 B & output on the TCDD1.         ModelBD:       Seek 0000 A 647 answord to guarante a 10016 B & output on the TCDD1.         ModelBD:       Seek 0000 A 647 answord to guarante a 10016 B & output on the TCDD1.         ModelBD:       Seek 2000 A 647 answord to guarante a 10016 B & output on the TCDD1.         ModelBD:       Seek 2 2000 A 6400 answord to guarante a 10016 B & output on the TCDD1.         ModelBD:       Seek 2 2000 A 6400 answord to guarante	8 (223)						-	E-Header P	law
Add.1881:       Sand 2000: A FTFN consecution generate in DDN's 8.8 output on the AdDNR22.         Add.1881:       Sand 2000: A FTFN consecution generate in DDN's 8.8 output on the AdDNR22.         Add.1881:       DACA: STORE, MACA: STORE, MACA: STORE, MCC.2			tited we have a subs	a bit and in success					
<ul> <li>Acch 1800 Sord 4000 A BF% convents to generate a 108Hz adjut in the ACN822.</li> <li>Acch 1800 Sord 4 CACA SORA, 1402A SORA, 120 SUBP</li> <li>Acch 1800 Berl 400A SORA 4 1602A SORA 1002A Baca w/160P1002 105 bit, "broadcast in USART"</li> <li>Acch 1812 Den for users of derive fills and generate a 108Hz baca w/160P1002 105 bit, "broadcast in USART"</li> <li>Acch 1800 Baca 4 200A Social w/100P1002 105 bit, "broadcast in USART"</li> <li>Acch 1800 Social 4 Baca 4 100PH &amp; Baca 4 100PH 200P102 105 bit, "broadcast in USART"</li> <li>Acch 1812 Den for users of derive fills with generate a 108Hz bit and generate</li></ul>									
ModelBits       bACA + SHEAK, bACA + SHEAK, DOD + & SUBAY, DI2 + SUBAY         ModelBits       bACA + SHEAK, bACA + BOD + & Note V/RECHAFTAR TID: ADC, "breachant on USAAT"         ModelBits       bACB + BOD, bACA + BOD + & Note V/RECHAFTAR TID: ADC, "breachant on USAAT"         ModelBits       bACB + BOD, bACA + BOD + & Note V/RECHAFTAR TID: ADC, "breachant on USAAT"         ModelBits       bACB + BOD, bACA + BOD + & Note V/RECHAFTAR TID: ADC, "breachant on USAAT"         ModelBits       bACB + BOD, bACA + BOD + & Note V/RECHAFTAR TID: ADC, "breachant on USAAT"         ModelBits       bACB + BOD, bACA + BOD + & Note V/RECHAFTAR TID: DIFTICE BELOWY         ModelBits       back - SIGN & Note V/RECHAFTAR TID: DIFTICE BELOWY         ModelBits       back - SIGN & Note V/RECHAFTAR TID: DIFTICE BELOWY         ModelBits       back - SIGN & Note V/RECHAFTAR TID: DIFTICE BELOWY         ModelBits       back - SIGN & Note V/RECHAFTAR TID: DIFTICE BELOWY         ModelBits       back - SIGN & Note V/RECHAFTAR TID: DIFTICE BELOWY         ModelBits       back - SIGN & Note V/RECHAFTAR TID: DIFTICE BELOWY         ModelBits       back - SIGN & Note V/RECHAFTAR TID: DIFTICE BELOWY         ModelBits       back - SIGN & Note V/RECHAFTAR TID: DIFTICE BELOWY         ModelBits       back - SIGN & Note V/RECHAFTAR TID: DIFTICE BELOWY         ModelBits       Collect - SIGN & Note V/RECHAFTAR TID: DIFTICE BELOW         Stat									
Add B100 B4C A B00 A Bod W ECCATE DIT 10: ACC, "breaked with SEAT"     Add B100 B4C A B00 A Bod W ECCATED 11: B1C, "breaked with SEAT"     Add B100 Dyn for user's define their can not be,     TEREY b4C and on MCD B100 B B00 B100 B10 B10, "breaked with SEAT"     Add B100 Dyn for user's define their can not be,     TEREY b4C and with SECTED SERTER SECTED SERTER B100W)     Model1000 Bard B00 A B100 B100 B100 B100 B100 B100 B10	Alade E012								
Mack RDD         bACB = 100b; bACA = 100b; 6 Read w/RCP02021 Bb; bif, "threadward on USART"         Prombigmediation           Alcobilitii:         Open for user to define their can not the.         Prombigmediation on USART"         Prombigmediation on USART"           Alcobiliti:         Open for user to define their can not the.         Prombigmediation on USART"         Prombigmediation on USART"           Alcobiliti:         Open for user to define their can not the.         Prombigmediation on USART"         Prombigmediation on USART"           Alcobiliti:         Color: 5 Mich at the came and the generate a 100He to acquire the TC1101.         Note 100He to and average a 100He to acquire the TC1101.         Note 100He to acquire the generate a 100He to acquire the TC1101.         Note 100He to acquire the to acquire to active.         Note 100He to acquire the to acquire the to acquire the to acquire the to acquire to active.           Alcobiliti:         Open for user to define their can not free.         Date: 500H to acquire the their can not free.           II:STTP-16/FT67.ProMeG32         Distriction of the to active their cam not free.         NoteDito: 100 Configuration figuration figura	Aloda BLOD	EACE & DACA.	0001 # Real w/K	LC16F767 LDb AG	"FRARM net tax MSART"				
Additional Department of the Additional Depar									
TELEX: LAC wade: (ALST billine WHECH SPECIFIC DEFICE BILOW)       Acchildo:       First LEE and parameters a DORE SPEcific DEFICE BILOW)         Model:DDD:       Samt Acoh.       Samt Acoh.       Billine and parameters a DORE SPEcific DEFICE BILOW)         Model:DDD:       Samt Acoh.       Samt Acoh.       Billine and parameters a DORE SPEcific DEFICE BILOW)         Model:DDD:       Samt Acoh.       Billine and parameters a DORE SPEcific DEFICE BILOW)       Bit TeleConst.         Model:DDD:       Samt Acoh.       Billine and an international to generative a DORE SPEcific DEFICE BILOW)       Bit TeleConst.         Model:DDD:       Samt Acoh.       Billine and an international to generative a DORE SPEcific DEFICE       Billine and an international DEFICE BILOW)         Model:DDD:       SAMC - SIGN & France and MCC.       Francebard (SECONST.       Disc.         Model:DDD:       SAMC - SIGN & Francebard (SECONST.       Disc.       Disc.         Model:DDD:       SAMC - SIGN & Francebard (SECONST.       Disc.       Disc.       Disc.         Model:DDD:       Deficit PE Televistic Deficit PE Televistic DEFICE DEFICE DEFICE DEFICE DEFICE       Disc.       Disc.       Disc.       Disc.         Model:DDD:       Deficit PE Televistic Deficit PE Televistic DEFICE DEFI				the second second	LOT OF USHRT*				
Model1000       Reds L1000 is RPP asymetry a L000H SEtting sine wase as the TC1201.       Reds L000 is RPP asymetry a L000H SEtting sine wase as the TC1201.         Model1000       Sand 0000 is RPP asymetry a L000H SEtting sine wase as the TC1201.       Bit C_000000         Model1001       Sand 0000 is RPP asymetry at L000H SEtting sine wase as the TC1201.       Bit C_000000         Model1002       Sand 0000 is RPP asymetry is generate a L00H is Adult on the TC1201.       Bit C_000000         Model1002       Sand 0000 is RPP asymetry is generate a L00H is adult on the TC1201.       Bit C_000000         Model1002       Sand 0000 is RPP asymetry is generate a L00H is adult on the TC1201.       Bit C_0000000         Model1002       Sand 0000 is RPP asymetry is generate a L00H is Redshow in USART*       Bit C_0000000         Model1002       Open for user to define their care notifie.       Bit C_00000000         Model1002       Open for user to define their care notifie.       SteepConset.       Bit C_000000000         L155T #16FFF7       COMPSG _C0MPSG1_CP_OFF & _C0FE_HC1 & _DEBUG_OFF & _NUFE_C0 & _BOREN_L1 & _BOREN_COFF & _NWRITE_OFF & MARCH20FF & _NUFE_C0FF & _AUBEL2000000000       Marketsia       Marketsia         StopConset       _C0MPSG _C0MPSG1_CP_FF & _C0FE_HC1 & _DEBUG_OFF & _NUFE_C0 & _BOREN_L1 & _BOREN_COFF & _NWRITE_OFF & _AUBEL3000000000000000000000000000000000000									
Mach1000       Sand B000h & FMP commands in generates a 100Hz B-R adjust on the TC1221.       Mach1002       Sand B000h & FMP commands in generates a 100Hz B-R adjust on the TC1221.         Mach1002       Sand B00h & FMP commands in generates a 100Hz B-R adjust on the TC1221.       DBC_B88       DDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDD								Eev Value	Deft.
Model100         Send 400h & EPR commands to generate a 100Pb subjut an the 101121.         DBC_589         DD000000           Model101         Send - 200A & Stand w/RLC97767 18h ADL "breakcart on USART"         DBC_589         DD000000           Model101         SAC - 200A & Read w/RLC97767 18h ADL "breakcart on USART"         DBC_589         DD000000           Model101         SAC - 200A & Read w/RLC97767 18h ADL "breakcart on USART"         Dgr.eCommet.         Dgr.eCommet.           Model101         SAC - 200A & Read w/RLC97002 13b sing k-ended. "breakcart on USART"         Dgr.eCommet.         Dgr.eCommet.           Model102         SAC - 200A & Read w/RLC97002 13b sing k-ended. "breakcart on USART"         Dgr.eCommet.         Dgr.eCommet.           Model103         Open for user to define their own number.         Traces         Dgr.eCommet.         Dgr.eCommet.           L2577 #-167767. #-DV#9632         DD000000         D0000000         Dgr.ecommet.         Dgr.ecommet.           #regree Configuration Register 1									
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**FIGURE I-1:** MPLAB<sup>®</sup> IDE v6.62 screen capture of an example project to build and debug the included firmware. Note the required files in the project window and the two pre-defined Watch windows that the user can open up.



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