Recommended Watch Crystals for Microchip's PIC® Microcontrollers in XLP Mode

Author: *Mayank Prasad*
Microchip Technology Inc.

INTRODUCTION

This document is designed to serve as a starting point when designing the Timer1 low-power oscillator circuits using tuning fork crystals. The design of Microchip's eXtreme Low Power (XLP) technology has made the component selection, board layout and assembly process more important, as there is less design margin when running at sub-microwatt levels.

To facilitate the user selection of crystals and load capacitors, three test boards with different PIC16 microcontrollers were created and supplied to various tuning fork crystal manufacturers on which the manufacturers performed various tests using their crystals. The results are summarized in this application note.

TIMER1 IN XLP MODE

Timer1 module is a 16-bit timer/counter in most PIC® microcontrollers capable of running in XLP mode. Timer1 can run on internal clock, external clock input or an external crystal oscillator.

A dedicated low-power 32.768 kHz oscillator circuit is built in between pins T1OSI (input) and T1OSO (amplifier output), which can be used in conjunction with an external crystal when Timer1 is configured to be used with an external clock oscillator. The oscillator circuit is a modified Pierce oscillator designed with several features that allow the crystal oscillator to start up and run at very low amplitude to keep operating current very low.

Once enabled, the oscillator will continue to run even when the microcontroller shuts everything off and goes to Sleep, hence being able to operate in XLP mode. The timer has the ability to wake the microcontroller when an interrupt occurs.

For more information on crystal oscillator theory and application, consult Microchip application note *AN826, Crystal Oscillator Basics and Crystal Selection for rfPIC™ and PICmicro® Devices* (DS00826).

CONSIDERATIONS

The oscillation circuit requires the use of load capacitors that are matched to the C_L specification of the crystal. Equation 1 can be used to derive the correct load capacitor that matches the specified crystal.

EQUATION 1: LOAD CAPACITOR CALCULATION

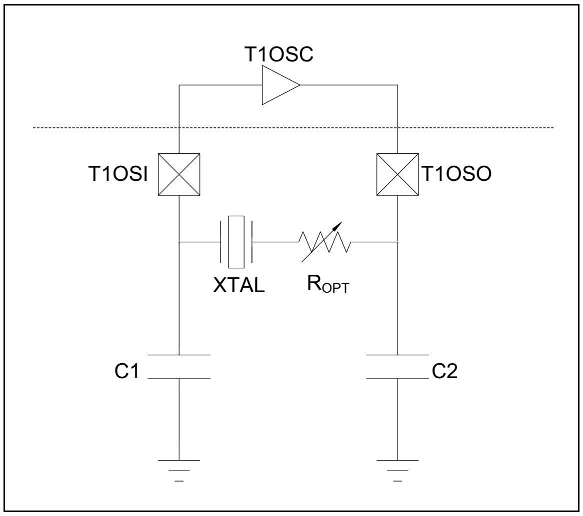
$$C_L = \frac{C_{x2} \cdot C_{x1}}{C_{x2} + C_{x1}} + C_{stray}$$

Where: C_{x1} = Capacitor value on pin X1 + C_{pin}
C_{x2} = Capacitor value on pin X2 + C_{pin}
C_{stray} = Trace capacitance
C_{pin} = 3 pF typical

TEST PROCEDURE

Five leading crystal manufacturers were provided with three different boards with different PIC16 microcontrollers and a crystal pad layout to facilitate the user selection of crystals and load capacitors. The manufacturers selected representative crystals and calculated the load capacitors for each device selected. The manufacturers then performed negative resistance testing at room temperature and several operating voltages to determine the oscillation allowance of the test circuit. Consult application note *AN949, Making Your Oscillator Work* (DS00949) for a detailed description of the negative resistance test procedure.

FIGURE 1: EXAMPLE TEST CIRCUIT



TEST RESULTS

The crystals listed in Table 1 have been tested with different PIC16 microcontrollers by the manufacturers. The results provided are to aid the development process and are not guaranteed to work in every board design. Additional tests will be required to validate the oscillator circuit in the end application. Users are encouraged to perform their own test on their layout to validate the schematic as per *AN949, Making Your Oscillator Work* (DS00949).

TABLE 1: CRYSTAL OSCILLATOR TEST RESULTS

Crystal Vendor	Microchip Part Number	Crystal Part Number	VDD (V)	Max ESR (kΩ)	CLOAD (pF)	C1 (pF)	C2 (pF)	PPM Error (at 25°C)	Negative Resistance (kΩ)	Oscillation Allowance = Negative Resistance / Max ESR
Golledge	PIC16F1827	CM7V-T1A	2.0	70.0	12.5	12.0	12.0	23.2	440.4	6.3
			3.3	70.0	12.5	12.0	12.0	23.8	455.4	6.5
			5.0	70.0	12.5	12.0	12.0	24.4	468.4	6.7
	PIC16F1828	CM7V-T1A	2.0	70.0	9.0	10.0	10.0	6.0	857.0	12.2
			3.3	70.0	9.0	10.0	10.0	7.5	867.0	12.4
			5.0	70.0	9.0	10.0	10.0	13.0	900.0	12.9
			2.0	70.0	12.5	15.0	15.0	16.1	346.8	5.0
			3.3	70.0	12.5	15.0	15.0	16.2	359.8	5.1
			5.0	70.0	12.5	15.0	15.0	17.0	386.8	5.5
	PIC16F1938	CM7V-T1A	2.0	70.0	12.5	12.0	12.0	45.1	392.6	5.6
			3.3	70.0	12.5	12.0	12.0	45.8	408.6	5.8
			5.0	70.0	12.5	12.0	12.0	46.4	425.6	6.1
Citizen Finetech Miyota	PIC16F1827	CM315D	2.0	70.0	6.0	7.0	7.0	-2.2	400.0	5.7
			3.3	70.0	6.0	7.0	7.0	0.9	410.0	5.9
			5.0	70.0	6.0	7.0	7.0	2.6	430.0	6.1
		CMR200T	2.0	50.0	7.0	7.0	8.0	-1.8	360.0	7.2
			3.3	50.0	7.0	7.0	8.0	1.0	370.0	7.4
			5.0	50.0	7.0	7.0	8.0	2.1	370.0	7.4
		CM200C	2.0	50.0	7.0	7.0	8.0	-0.5	360.0	7.2
			3.3	50.0	7.0	7.0	8.0	0.3	360.0	7.2
			5.0	50.0	7.0	7.0	8.0	1.1	370.0	7.4
		CM130SH	2.0	65.0	7.0	7.0	8.0	-1.7	360.0	5.5
			3.3	65.0	7.0	7.0	8.0	-0.9	360.0	5.5
			5.0	65.0	7.0	7.0	8.0	0.8	360.0	5.5
	PIC16F1828	CM315D	2.0	70.0	6.0	8.0	10.0	0.4	370.0	5.3
			3.3	70.0	6.0	8.0	10.0	0.8	370.0	5.3
			5.0	70.0	6.0	8.0	10.0	0.9	380.0	5.4
		CMR200T	2.0	50.0	7.0	8.0	8.0	0.6	360.0	7.2
			3.3	50.0	7.0	8.0	8.0	0.9	370.0	7.4
			5.0	50.0	7.0	8.0	8.0	1.2	370.0	7.4
		CM200C	2.0	50.0	7.0	8.0	8.0	0.9	360.0	7.2
			3.3	50.0	7.0	8.0	8.0	1.2	360.0	7.2
			5.0	50.0	7.0	8.0	8.0	1.4	370.0	7.4
		CM130SH	2.0	65.0	7.0	8.0	8.0	1.3	360.0	5.5
			3.3	65.0	7.0	8.0	8.0	1.7	360.0	5.5
			5.0	65.0	7.0	8.0	8.0	1.9	360.0	5.5
	PIC16F1938	CM315D	2.0	70.0	6.0	10.0	10.0	-2.4	360.0	5.1
			3.3	70.0	6.0	10.0	10.0	0.9	370.0	5.3
			5.0	70.0	6.0	10.0	10.0	1.6	380.0	5.4
		CMR200T	2.0	50.0	7.0	8.0	10.0	-1.7	340.0	6.8
			3.3	50.0	7.0	8.0	10.0	-0.3	350.0	7.0
			5.0	50.0	7.0	8.0	10.0	0.5	360.0	7.2
		CM200C	2.0	50.0	7.0	8.0	10.0	-0.6	350.0	7.0
			3.3	50.0	7.0	8.0	10.0	0.9	350.0	7.0
			5.0	50.0	7.0	8.0	10.0	1.4	360.0	7.2
		CM130SH	2.0	65.0	7.0	8.0	10.0	-0.9	350.0	5.4
			3.3	65.0	7.0	8.0	10.0	0.6	350.0	5.4
			5.0	65.0	7.0	8.0	10.0	1.5	360.0	5.5

TABLE 1: CRYSTAL OSCILLATOR TEST RESULTS (CONTINUED)

Crystal Vendor	Microchip Part Number	Crystal Part Number	VDD (V)	Max ESR (kΩ)	CLOAD (pF)	C1 (pF)	C2 (pF)	PPM Error (at 25°C)	Negative Resistance (kΩ)	Oscillation Allowance = Negative Resistance / Max ESR
Epson	PIC16F1827	MC-146	3.3	65.0	7.0	6.0	6.0	23.2	910.0	14.0
			2.0	65.0	7.0	8.0	8.0	3.9	560.0	8.6
			3.3	65.0	7.0	8.0	8.0	4.5	620.0	9.5
			5.0	65.0	7.0	8.0	8.0	5.5	680.0	10.5
			3.3	65.0	7.0	10.0	10.0	-10.1	470.0	7.2
	PIC16F1828	MC-146	3.3	65.0	7.0	10.0	10.0	10.9	510.0	7.8
			2.0	65.0	7.0	12.0	12.0	-2.8	360.0	5.5
			3.3	65.0	7.0	12.0	12.0	-5.2	390.0	6.0
			5.0	65.0	7.0	12.0	12.0	-6.8	390.0	6.0
			3.3	65.0	7.0	15.0	15.0	-22.3	270.0	4.2
	PIC16F1938	MC-146	3.3	65.0	7.0	8.0	8.0	25.3	560.0	8.6
			2.0	65.0	7.0	10.0	10.0	6.7	430.0	6.6
			3.3	65.0	7.0	10.0	10.0	7.3	430.0	6.6
			5.0	65.0	7.0	10.0	10.0	8.5	470.0	7.2
			3.3	65.0	7.0	12.0	12.0	-5.8	330.0	5.1
Microcrystal Switzerland	PIC16F1827	CM7V-T1A	2.0 - 5.0	100.0	7.0	5.6	5.6	+/-20	500.0	5.0
			2.0 - 5.0	50.0	12.5	12.0	18.0	+/-20	225.0	4.5
	PIC16F1828	CM7V-T1A	2.0 - 5.0	100.0	7.0	8.2	10.0	+/-20	500.0	5.0
			2.0 - 5.0	N/A	12.5	18.0	22.0	+/-20	175.0	N/A
	PIC16F1938	CM7V-T1A	2.0 - 5.0	100.0	7.0	10.0	10.0	+/-20	500.0	5.0
			2.0 - 5.0	N/A	12.5	22.0	22.0	+/-20	145.0	N/A
SII Crystal Technology	PIC16F1827	SC-32S	2.0	70.0	7.0	4.0	5.0	+/-20	668.0	9.5
			3.3	70.0	7.0	4.0	5.0	+/-20	678.0	9.7
			5.0	70.0	7.0	4.0	5.0	+/-20	698.0	10.0
	PIC16F1828	SC-32S	2.0	70.0	7.0	7.0	8.0	+/-20	552.0	7.9
			3.3	70.0	7.0	7.0	8.0	+/-20	552.0	7.9
			5.0	70.0	7.0	7.0	8.0	+/-20	562.0	8.0
	PIC16F1938	SC-32S	2.0	70.0	7.0	9.0	9.0	+/-20	398.0	5.7
			3.3	70.0	7.0	9.0	9.0	+/-20	408.0	5.8
			5.0	70.0	7.0	9.0	9.0	+/-20	428.0	6.1

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