AN1288

Design Practices for Low-Power External Oscillators

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INTRODUCTION

Many Microchip microcontrollers have internal circuitry to drive a 32.768 kHz external crystal to provide an asynchronous clock signal to the Timer1 internal counter. Timer1 is a 16-bit counter which can be used to create a Real-Time Clock (RTC) with a precise, 1-second overflow interrupt for system timing.

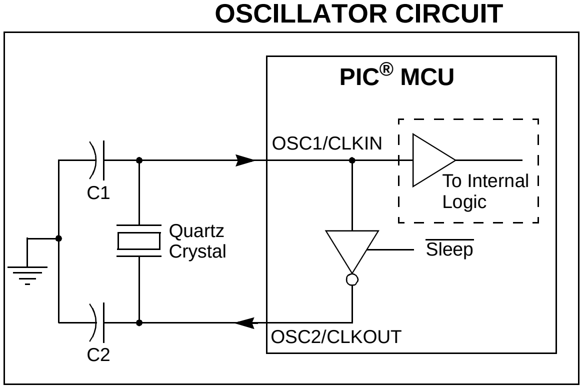
OUTLINE

Extremely low-power oscillator circuits, by their nature, do not have high-power drive capability; and as a result, they require attention to detail of low-power design practices and techniques to ensure robust operation. A poorly designed oscillator circuit will have reduced frequency accuracy and may not function correctly over temperature and voltage ranges.

Key features for robust operation are:

1. Dry and moisture-free circuit boards
2. Clean circuit boards that are free of contaminants
3. A quality low-power crystal
4. Load capacitors matched to the crystal and circuit board
5. The crystal supplier's characterization report

FIGURE 1: EXTERNAL CRYSTAL OSCILLATOR CIRCUIT



PROBING THE CIRCUIT

Oscillator circuits are highly sensitive to capacitance; therefore, special care needs to be taken when examining signals. A regular oscilloscope probe has 10-12 pF of capacitance, which can be sufficient to stop oscillations. It is recommend that low-capacitance probes be used, preferably with a JFET input, and that the OSC2 pin be probed instead of OSC1.

Many new devices incorporate Automatic Gain Control (AGC) for the crystal oscillator drive circuit; where, to conserve power, the amplitude of the signal is reduced when the circuit is operating as intended. When examining the waveforms, this needs to be considered, as the AGC may be attempting to compensate for an imperfect circuit by increasing the peak to peak drive signal. When adding additional load to the circuit, such as an oscillator probe, the amplitude of the signal will initially be reduced. The AGC will then compensate and increase the amplitude back to its earlier level. This response occurs slow enough to be visible on an oscilloscope.

Dry and Moisture-Free Circuit Boards

Damp circuit boards or moisture condensing onto them at low temperatures can establish leakage paths to ground, which, given the low power of the oscillator drive circuit, can load the circuit greater than the drive strength of the circuit can overcome.

If the circuit boards have been washed, it is then recommended they be allowed to dry thoroughly before being assembled into the system. For low-temperature operation, where moisture condensing may be an issue, conformal coating is recommended (see **Section "Conformal Coating"**).

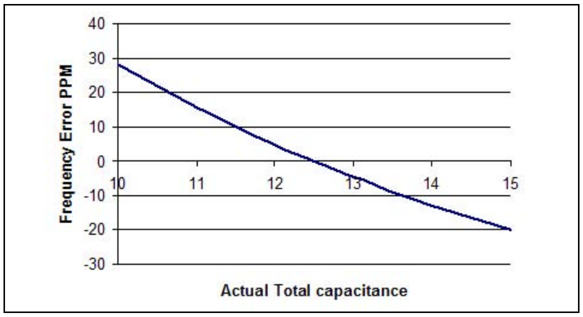
Clean Circuit Boards that Are Free of Contaminants

Solder flux may leave a residue on the board, which may not easily wash off. Flux remover and scrubbing the board may be required to remove this residue and should remove other contaminants. Some flux residues are weakly conductive; and in the presence of moisture can become highly conductive creating leakage paths.

Load Capacitors Matched to the Crystal and Circuit Board

The crystal needs to see a specific capacitance on either side for maximum frequency accuracy and reliable operation. This should be specified by the crystal manufacturer in the crystal data sheet. Common capacitances are 12.5 pF, 9 pF and 7 pF. Figure 2 shows the affect of capacitance for a 12.5 pF crystal on frequency tolerance.

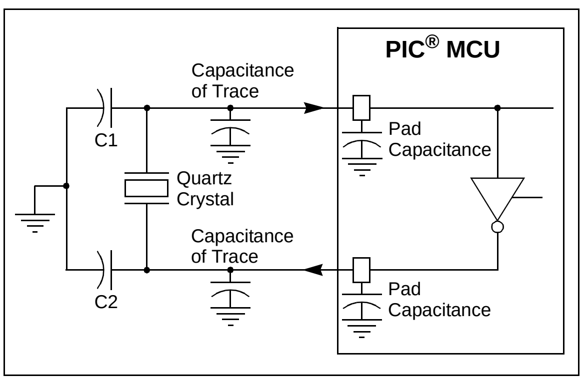
FIGURE 2: MATCHING OF CAPACITANCE TO CRYSTAL PARAMETERS



For details on the purpose of these capacitors, please see application note AN943, "*Practical PICmicro® Oscillator Analysis and Design.*"

The capacitor values are very small; and as a result, their value is affected by the capacitance of the bond pads on the microprocessors silicon die and the capacitance of the traces and pads on the circuit board (see Figure 3).

FIGURE 3: REAL OSCILLATOR CIRCUIT DIAGRAM



If the traces to the oscillator are kept short, under 10 mm-long each, their capacitance will be very low and almost negligible.

EQUATION 1:

$$\text{Crystal capacitance} = (\text{pad capacitance})/2 + \text{board capacitance} + (C1*C2)/(C1+C2)$$

For example, for 8 mm-long traces, the capacitance was measured as 0.85 pF (this is dependant on board layout, material dielectric and thickness). In many cases, the board capacitance can be negligible when the traces are short and surface mount devices are used.

The pad capacitance varies from device to device; but as an example for the PIC18F14K50, the pad capacitance is approximately 2.5 pF per pad.

For example, if a low-power 9 pF crystal in a surface mount package (MS3V-T1R 32.768 kHz 9 pF) is used, then the capacitor values are calculated as follows:

EQUATION 2:

$$9 = 2.5/2 + 0.85 + (C1*C2)/(C1+C2)$$

As we are using equal value loading capacitors the math can be simplified to:

EQUATION 3:

$$9 = 1.25 + 0.85 + (C1)/2 \text{ and } C1 = C2$$

Solving:

EQUATION 4:

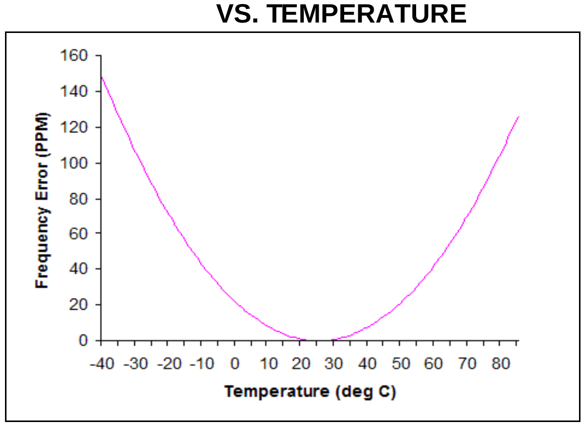
$$C1 = C2 = 13.6\ pF$$

Selecting the lowest available standard capacitor value, because of trace capacitance, should give us near the ideal total capacitance seen by the crystal.

A Quality Low-Power Crystal (of the Correct Capacitance) is Used

Low-power external oscillator circuits typically use a 32.768 kHz tuning fork crystal. These crystals are highly accurate. However, their frequency tolerance does vary with temperature, as seen in Figure 4.

FIGURE 4: FREQUENCY TOLERANCE VS. TEMPERATURE



The crystal load capacitance needs to be matched for maximum accuracy, as discussed in **Section "Load Capacitors Matched to the Crystal and Circuit Board"**. For many low-power designs, lower capacitance crystals, 7 pF and 9 pF, are recommended. Low-power crystals with low ESR of less than 65 KOhm are recommended, as they allow for higher oscillation allowance which ensures reliable operation over temperature and voltage. For oscillation allowance, please refer to **Section "The Crystal Manufacturer's Characterization Report"**.

The Crystal Manufacturer's Characterization Report

Many crystal manufacturers can provide characterization testing of a design. For an example test report, refer to TB097, "*Interfacing a Micro Crystal MS1V-T1K 32.768 kHz Tuning Fork Crystal to a PIC16F690/SS*." The manufacturer will need a populated board with the microcontroller programmed to exercise the crystal. Crystal manufacturers typically have the equipment to measure the board and pad capacitances and determine the ideal capacitor value. Negative resistance testing can be used to determine the oscillation allowance and if there is sufficient margin for reliable operation given manufacturing tolerances of the crystal. The oscillator margin required for confident operation is dependant on the number of units tested. For a single unit, the circuit should operate correctly with 5x the crystal ESR that is added via negative resistance testing. Negative resistance testing can also be performed via the methods detailed in application note AN943, "*Practical PICmicro® Oscillator Analysis and Design*."

CONFORMAL COATING

Conformal coating can be applied to the board to prevent moisture or other contaminants from making electrical contact with the board. Microchip recommends that the sensitive traces and components for the low-power oscillator circuit be coated to prevent moisture and other contaminants from increasing the loading on the drive circuit by creating leakage paths across the board. This includes the crystal's pads or leads, the traces on the board, and the back of the board if through hole devices or vias are used. If LP Oscillator mode is used then pins OSC1 and OSC2 should be coated, or pins T1OSCI and T1OSCO if Timer1 uses different pins for an external oscillator.

Conformal coatings can be applied via:

- **Dipping**
  - Gives the best coverage but requires complicated masking
- **Spraying**
  - For most prototyping and small volume, spraying is the most common method; although, care needs to be taken to ensure thorough coverage. Both acrylic and silicone-based coatings are available in spray-can form. For large scale production, there are atomizing spray systems which can be programmed to take defined paths across the board and to cover specific areas.
- **Brushing**
  - Conformal coatings may be brushed over sensitive areas of the board; however, this is the least reliable method since brush marks may leave small gaps in the coating.

A conformal coating that luminesces under UV light is recommended to aid in quality control inspection. The coverage of vertical surfaces of the device pins and leads can be problematic with less viscous coatings; but can be improved by inverting the board to dry after spraying. Conformal coatings can also provide mechanical support for components. However, connectors and contact points will require masking off so they can be used after coating. Since only high-impedance signals and sensitive circuitry needs to be coated, the rest of the board can be masked off; although, there may be some leakage of the coating. The coating may require removal for board modifications and the method used should be recommended by the coating manufacturer, though it is usually a recommendation for a specific solvent.

The other option for harsh wet environments is to use a potting compound to seal the board. These are typically epoxy-based and removal of the compound is extremely difficult should the board require modifications or rework, and provision needs to be made to access connectors.

The boards need to be clean and dry before coating, otherwise contamination will be sealed in and may cause later problems.

Conformal coatings and potting compounds need to be adequately cured as directed by the manufacturer. Otherwise, they may have inferior electrical performance, especially in high humidity or low-temperature environments.

CONCLUSION

Low-power crystal oscillators offer extended battery life and lower current consumption for applications requiring a Real-Time Clock or to wake the device from Sleep at specific intervals.

Low-power nature crystal oscillators are less tolerant of incorrect crystal types, load capacitors and contaminants on the circuit board.

NOTES:

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