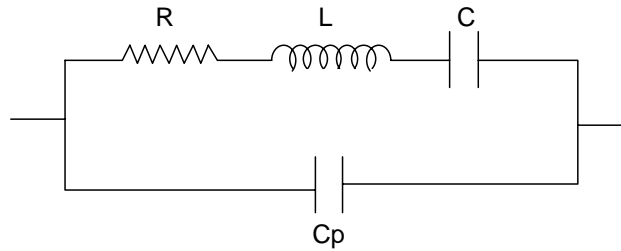


# MX•COM, INC. MiXed Signal ICs

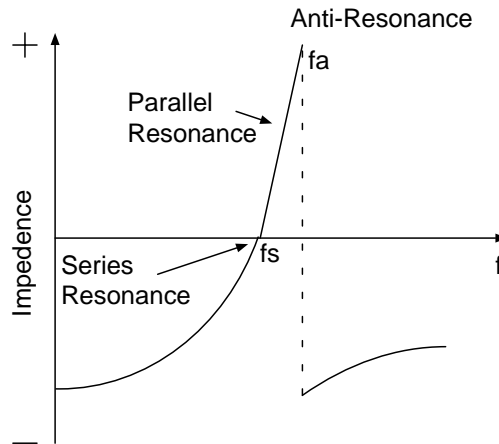
## APPLICATION NOTE

# Crystal Oscillator Circuit Design

In this application note we shall discuss our recommended crystal oscillator circuit, explain each component in the circuit and provide some guidelines on selecting values for these components. Finally, we shall give a few precautions to take in order to avoid in-stability and start-up problems.



**Figure 1. Crystal equivalent Circuit.**



**Figure 2. Reactance Vs Frequency plot of a crystal.**

Figure 1. shows the crystal equivalent circuit. R is the effective series resistance, L and C are the motional inductance and capacitance of the crystal.  $C_p$  is the shunt capacitance due to the crystal electrodes. Figure 2. shows the reactance-frequency plot of the crystal. When a crystal is operating at series resonance it looks purely resistive and the reactances of the inductor and the capacitor are equal ( $X_L = X_C$ ). The series resonance frequency is given by the equation

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

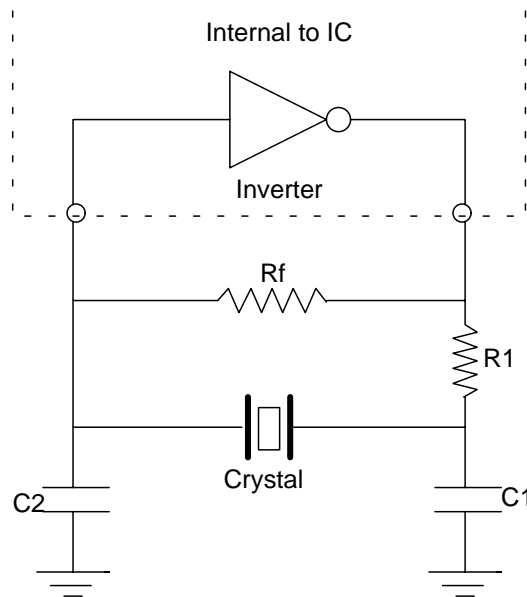
When the crystal is operating in parallel resonant mode it looks inductive. The frequency of operation in this mode is defined by the load on the crystal. The crystal manufacturer should specify the load capacitance  $C_L$  for parallel resonant crystals. In this mode the frequency of oscillation is given by the equation.

$$f_a = \frac{1}{2\pi\sqrt{L \frac{C_L C_p}{C_L + C_p}}}$$

In parallel resonance mode the crystal can be made to oscillate anywhere on the  $f_s - f_a$  slope of the reactance plot, shown in Figure 2, by varying the load of the crystal. All of MX-COM's crystal oscillator circuits recommend using parallel resonant mode crystals.

Figure 3. shows the recommended Crystal oscillator circuit diagram. In this type of setup the crystal is expected to oscillate in parallel resonant mode. The inverter which is internal to the chip acts as class AB amplifier and provides approximately  $180^\circ$  phase shift from input to the output and the  $\pi$  network formed by the crystal,  $R_1$ ,  $C_1$  and  $C_2$  provides additional  $180^\circ$  phase shift. So the total phase shift around the loop is  $360^\circ$ . This satisfies one of the conditions required to sustain oscillation. The other condition, for proper startup and sustaining oscillation is the closed loop gain should be  $\geq 1$ .

The resistor  $R_f$  around the inverter provides negative feedback and sets the bias point of the inverter near mid-supply operating the inverter in the high gain linear region. The value of this resistor is high, usually in the range of a  $500K\Omega \sim 2M\Omega$ . Some of MXCOM's ICs have this resistor internal, refer to the external component specifications in the data sheet of a particular chip.



**Figure 3. Crystal oscillator circuit.**

The capacitors  $C_1$  and  $C_2$  form the load capacitance for the crystal. The optimum load capacitance ( $C_L$ ) for a given crystal is specified by the crystal manufacturer. The equation to calculate the values of  $C_1$  and  $C_2$  is

$$C_L = \frac{C_1 * C_2}{C_1 + C_2} + C_s$$

Where  $C_s$  is the stray capacitance on the printed circuit board, typically a value of 5pf can be used for calculation purposes. Now  $C_1$  and  $C_2$  can be selected to satisfy the above equation. Usually  $C_1$  and  $C_2$  are selected such that they are approximately equal. Large values of  $C_1$  and/or  $C_2$  increases frequency stability but decreases loop gain and may cause start-up problems.

$R_1$  is the drive limiting resistor, the primary function of this resistor is to limit the output of the inverter so that the crystal is not over driven.  $R_1$  and  $C_1$  form a voltage dividing circuit, the values of these components are chosen in such a way that the output of the inverter goes close to rail-to-rail and the input to the crystal is 60% of rail-to-rail, usual practice is to make resistance of  $R_1$  and reactance of  $C_1$  equal at the operating frequency, i.e.  $R_1 \approx XC_1$ . This makes the input to the crystal half that of the inverter output. Always make sure that the power dissipated by the crystal is within the crystal manufacturer's specifications. Over-driving the crystal may damage the crystal. Please refer to the crystal manufacturer's recommendations.

Ideally the inverter provides  $180^\circ$  phase shift, but the inherent delay of the inverter provides additional phase shift proportional to the delay. In order to ensure the total phase shift of  $n360^\circ$  around the loop, the  $\pi$  network should provide  $180^\circ$  less the phase shift due to the inverter delay.  $R_1$  can be varied to accomplish this. With fixed  $C_1$  and  $C_2$ , the closed loop gain and phase can be altered by varying  $R_1$ . In some applications  $R_1$  can be ignored if the above two conditions are met.

Some ICs have all the external components ( $R_f$ ,  $R_1$ ,  $C_1$ , and  $C_2$ ) internal to the chip, thus eliminating worries to the circuit designer. In this case simply connect the crystal across the XTAL and XTAL pins.

**Hints:**

Select a crystal with low effective series resistance (ESR), which helps with crystal start-up problems. Lower ESR increases the loop gain.

Reduce the stray capacitance on the board layout by shortening the traces. This would help with startup problem and as well as the frequency of oscillation.

Always test the circuit in applicable temperature and voltage ranges to ensure the crystal starts and sustains oscillations and tweak the component values if necessary.

For best results, a crystal oscillator design should drive the clock inverter input with signal levels of at least 40% of  $V_{dd}$ , peak to peak. Tuning fork crystals generally cannot meet this requirement. To obtain further crystal oscillator design assistance, consult your crystal manufacturer.

The recommended way to optimize  $R_1$  is first calculate  $C_1$  and  $C_2$  as explained earlier and connect a potentiometer in place of  $R_1$ , set its initial setting at approximately equal to  $XC_1$ , then vary the potentiometer setting if required until the crystal starts under all conditions and sustains oscillation under steady state condition.

This datasheet has been download from:

[www.datasheetcatalog.com](http://www.datasheetcatalog.com)

Datasheets for electronics components.