Design Ideas

Techniques for Cancelling C_0 in Crystals

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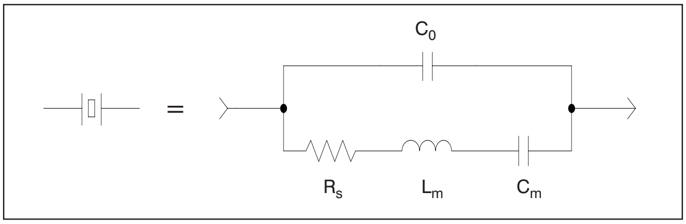
Quartz crystals remain valuable radio-frequency components, even though they were first developed many years ago. They offer high Q and excellent, predictable stability for oscillators and filters. Crystals are not ideal components, however, and this note addresses one aspect of their deviation from "perfect," C_0, the capacitance created by their electrodes.

Figure 1 shows the equivalent circuit of a crystal. L_m and C_m are the motional inductance and capacitance and R_s is the series resistance, combining all losses into a single term. These parameters are the effective electrical characteristics that result from the crystal's vibration. C_0 is the capacitance created by the electrodes that connect the crystal to an external circuit.

C_0 has a value on the order of 4 to 10 pF, depending on the crystal type, typically 7 pF for most common types. While a crystal is a series-resonant device, C_0 introduces an additional parallel resonance at a frequency slightly higher than series resonance. This extra resonance can introduce spurious responses. Another problem is the highpass characteristic of a capacitor, which restricts a designer's ability to achieve symmetry in a crystal filter passband.

How do we get rid of C_0? The most obvious way is to design a circuit with external capacitance in parallel with the crystal. Then, C_0 can be absorbed into the total circuit capacitance. This method, of course, severely limits the available circuit topologies.

A more universal method is to employ a balanced circuit like Figure 2. This is a transformer-coupled push-pull circuit that drives a crystal and a capacitor equal in value to C_0. At the output the "inverted capacitance" effectively cancels C_0.

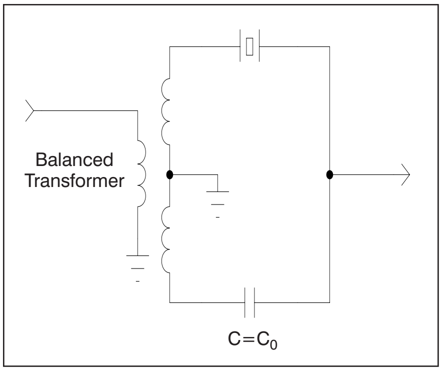


■ **Figure 1. Equivalent circuit of a quartz crystal.**

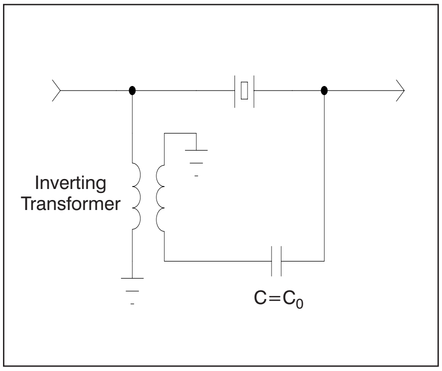
A simpler "inverted capacitance" circuit is shown in Figure 3. Here, a phase-reversing transformer and capacitor are used to cancel C_0. If the impedance of the transformer winding is much higher than the circuit impedance, this arrangement can act very much like an ideal crystal — *within the frequency range where the transformer approaches ideal performance*. This limitation applies to all transformer circuits, including the previous example (Figure 2).

Perhaps the most common approach for dealing with C_0 is to place an inductor across the crystal, as in Figure 4(a). L is selected to resonate with C_0 at the crystal's series-resonant frequency. The high impedance of this parallel-tuned network effectively removes C_0, but its band-reject frequency response means that it will pass both lower and higher frequencies, as shown in Figure 4(b). Additional selectivity is needed in the external circuit to deal with this response. Often, this is an acceptable trade for improved performance.

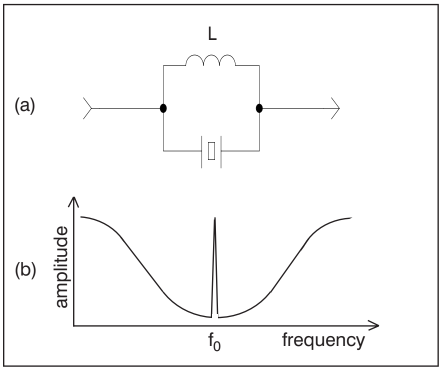
The value of quartz crystals is increased with techniques like these. They are among the methods that can be employed when performance demands exceed unmodified crystal behavior. ■



■ **Figure 2. Balanced transformer network with "inverted capacitance."**



■ **Figure 3. Alternate scheme for "inverted capacitance" cancellation.**



■ **Figure 4. (a) Parallel resonant circuit and (b) its frequency response.**