Timekeeping with Quartz Crystals

Since its introduction the 32.768kHz miniature watch crystal has become the most popular time keeping reference ever. This application note is intended to give some guidance as to the use of quartz crystals in time keeping applications.

In almost all circumstances designers will want to use simple logic gate oscillators for this application for the sake of convenience and cost. The criteria normally applied to this type of design are that it should be accurate, low in cost and low in power consumption. Using a watch crystal and CMOS logic all these criteria can be met.

In a CMOS oscillator circuit, power consumption rises with frequency and so it makes sense to reduce the operation frequency to a minimum; this is the reason for choosing 32.768kHz. The second way of reducing power consumption in a CMOS circuit is to reduce the size of any loads being driven. It is partly for this reason that watch crystals are designed to operate with typically a 12.5 pF load, instead of the more usual 20 or 30pF. It also has to do with: (a) the type of CMOS employed runs out of steam at the low voltages used in watches unless a low crystal load capacitance is used; (b) to keep the crystal drive level low while maintaining adequate inverter input voltage, and (c) to allow the use of a very tiny trimmer capacitor while still providing the necessary trimming range.

The basic requirements of a CMOS inverter oscillator can be met with a single gate and a handful of other components to provide bias and feedback. Figure 1 shows a typical circuit of this type. The load capacitance seen by the quartz crystal is the series combination of Cout and Cin together with any circuit strays including the logic gate input and output pin capacitances. The component values used in figure 1 work well and give good correlation with measured test results obtained from a Saunders 140 crystal impedance meter. The apparent load capacitance presented to the crystal is:

$$\frac{C_{out} \times C_{in}}{C_{out} + C_{in}}$$

Cout = Gate output capacitor Cin = Gate input capacitor

This gives a figure of 6.9pF load. This is well below the required figure of 12.5pF, however both the input and output pins of the logic gate present an appreciable load. These additional values need to be added to the 6.9pF. These loads will typically be in the order of 3pF to 4pF per pin but can be up to 10pF and will also depend on the logic family used. These extra loads together with any stray capacitances in circuit should add up to approximately 12.5pF.

If a trimmable oscillator is needed, the 22pF output capacitor can be replaced by a fixed 10pF capacitor in parallel with a 2pF to 22pF trimmer. For best results NPO, COG or similar low- temperature-coefficient dielectric capacitors should be used for best stability.

A frequently expressed requirement for oscillators such as this is close tolerance, often indeed in layouts in which no provision will be made for a trimmer. Apart from the effect of capacitor tolerances, it must be appreciated that because their values are low, the somewhat variable impedances attributable to the IC will result in a somewhat uncertain phase shift, hence oscillation frequency. A trimmer is recommended strongly, therefore, if precision better than, say, ±50ppm is needed, regardless of the actual crystal tolerance.

The other important effect is that due to temperature variation. Watch crystals and other similar types below 1MHz have a parabolic frequency-temperature characteristic with a design turnover

Figure 1

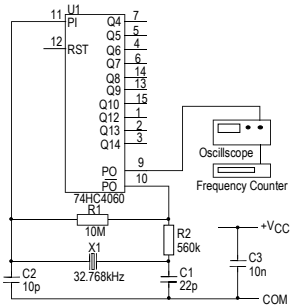


Figure 2

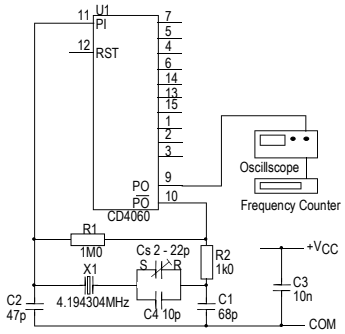
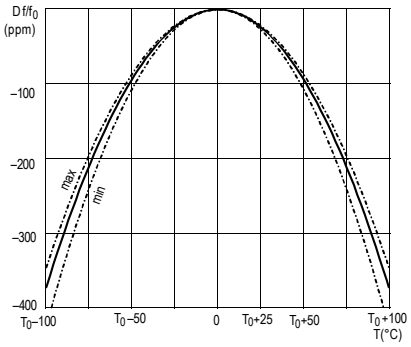


Figure 3



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temperature of 25°C (see Figure 3). The tolerance of the turnover temperature and the parabolic curvature constant, typically ±3°C and 0.038 ppm/°C2 respectively, mean that close tolerances can be maintained over only a limited temperature range. This is of little consequence in a watch, of course, since in use it is kept close to the crystal's turnover temperature, but it could render the choice of this type of crystal less cost effective than an AT-cut unit if an operating temperature range wider than 0 to 50°C is desired.

A similar circuit for 4.194304MHz (32.768kHz x 27) AT-cut crystals is illustrated in Figure 2 C3 and C4 are intended to facilitate precise frequency trimming of crystals calibrated at the standard clock crystal load of 12pF. If trimming is not required, either replace those capacitors with a 18pF or 22pF fixed unit (choose the value which results in oscillation closest to nominal frequency), or omit them altogether and specify the crystals for calibration at 30pF load.

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