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Understanding Crystal Oscillators

Crystal oscillators aren't as simple as the circuit diagrams make them appear. Understanding how they operate can help to eliminate faulty operation, or no operation at all.

Various types of crystal oscillators are in common use, but I will describe only the two most common ones among experimenters -- notably the Pierce and the Colpitts. We will also look at 3rd and 5th overtone oscillators, along with some VXO (variable crystal oscillator) circuits.

The Keys to Surefire Oscillation

A quality, active crystal is mandatory for proper circuit performance. This truism may seem trite, but I have known many tinkerers who experienced circuit failure because they tried to use old surplus crystals from bygone days and WW-II.

These crystals are contained in nonconductive molded cases, and the quartz crystal elements are sandwiched between two metal plates that have wires leading to the plug pins on the case.

The FT-243 style of holder is one example of the kinds of crystals I am discussing. Residue can build up within the crystal holder, owing to years of air pollution surrounding the crystal holder. Despite rubber gaskets, which some holders have under the cover plate, gasses enter the holder and coat the crystal and the metal contact plates.

Some of these sluggish or inoperative crystals can be restored by removing the quartz element (carefully!), then washing it and the metal plates with hot soapy water, followed by a thorough rinsing with clear, hot water. I have had good results also when cleaning them with denatured alcohol.

I recommend modern plated crystals in metal holders. These are found in a variety of sizes that range from the most common HC-6/U case to the smaller HC-18/U unit with wire leads. Plated crystals have their electrodes bonded to the quartz element, and the crystal floats on two small wires within the holder. These crystals are more fragile than their older brothers in FT-243 and similar holders, so try not to bump or drop them.

The next consideration for surefire oscillation is the proper feedback ratio in your oscillator. Feedback is obtained by sampling some of the oscillator RF output voltage and feeding it back to the input of the oscillator.

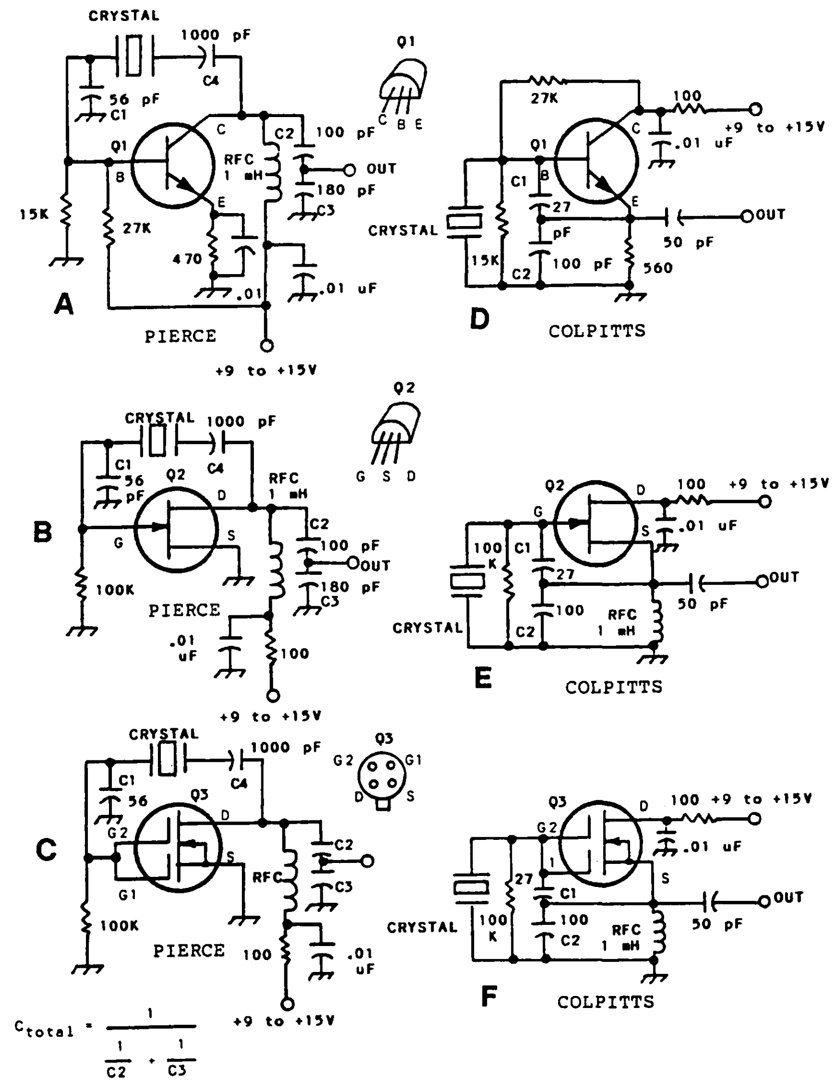

Figure 1

Examples of simple oscillators you can experiment with. The circuits at A, B and C show the Pierce oscillator arrangement for a bipolar, FET or dual-gate MOSFET device. Circuits D, E and F are Colpitts oscillators for the three semiconductor devices. The text covers circuit design and performance.

In essence, an oscillator is an amplifier that we cause to oscillate by way of feedback energy. Normally, no more than 1/4 the output power is used for feedback. Too much feedback can cause an oscillator to "squegg," and this leads to the development of spurious frequencies along with the desired one. Excessive feedback can cause the crystal to overheat and change frequency, and it may damage the crystal. Too much feedback can lead to transistor overheating and subsequent damage.

Finally, proper oscillation depends upon the upper frequency rating (f T) of the transistor versus the oscillator operating frequency. Try to select a transistor that has an f T rating no less than five times the crystal frequency; e.g., a 50-MHz f T for a 10 MHz crystal.

An excellent bipolar transistor for crystal oscillators and VFOs is the CATV 2N5179. It has an f T of 1200 MHz! Similarly, a 2N4416 JFET offers good performance because of its UHF rating. Dual-gate MOSFETS, like the RCA 40763 and 3N211, are good choices for the same reason. If the f T is near the crystal frequency the oscillator may not operate.

Some Practical Circuits

Six common oscillators are depicted schematically in Figure 1. Circuits A, B and C are Pierce oscillators. The output is untuned and the crystal is bridged between the input and output of the transistor. C1, C2 and C3 of Fig. 1A regulate the feedback. C4, depending upon its value, may also be selected for feedback control. C2 and C3 form a voltage divider to provide a takeoff point for the output energy.

The ratio of these capacitor values can be varied to provide a high- or low-impedance output characteristic. A 10:1 capacitance ratio (larger value at C3) yields a low impedance output, whereas the reverse (largest capacitor at C2) provides a high-impedance output.

In-between ratios may be used to obtain midrange impedances between 50 and several thousands of ohms. Generally, this is not critical to derive. In any event, C2 and C3 in series should have the same net value as that at C1.

Fig. 1B shows how to use a JFET (junction field-effect transistor) in a Pierce configuration. Gates 1 and 2 are simply tied together, as shown.

Examples of Colpitts oscillators are given in Fig. 1 at D, E and F. C1 and C2 are the feedback capacitors. Increasing the capacitance value at C1 provides greater feedback. This may be necessary if oscillation does not occur.

Some Colpitts oscillators require a C1/C2 ratio of 1:1. This depends on the quality of the crystal, the f T of the transistor and the gain (beta) of the Q1 transistor. The FET gain is measured in transconductance (gm).

The component values provided in Fig. 1 should ensure good performance when using crystals from 1 to 20 MHz fundamental crystals.

Overtone Oscillators

We can cause a fundamental crystal to oscillate at odd harmonics. This is called "overtone" oscillation. The most common cases call for 3rd or 5th-overtone oscillation. This prevents the crystal from oscillating on its fundamental frequency.

For example, we can cause a 10-MHz crystal to oscillate at approximately 30 MHz by using the circuits of Fig. 2A and 2B. The overtone frequency is seldom exactly three or five times the fundamental frequency, but it will be reasonably close for most experimental work.

Overtone oscillators require a tuned circuit at the output (L1 and C1). This circuit is tuned to the desired overtone frequency, at which time oscillation commences. Reliable oscillator starting can be ensured by tuning C1/L1 slightly higher in frequency than the setting that causes oscillation. Output reduction is minor when this is done.

Most crystal manufacturers provide products that are designed specifically for overtone operation. The frequency marked on the holder is correct, even though it may not be precisely three or five times the fundamental frequency of the quartz element.

Variable Frequency Crystal Oscillators

This type of oscillator is know as a VXO. We can "rubber" the crystal frequency a few kHz when using the circuits of Fig. 2C and 2D. A Pierce version is shown at 1C and a Colpitts VXO is presented at D. C1 and L1 are reactances (XC and XL) that are placed in series with the crystal.

The greater the inductance value for L1 the larger the frequency shift as C1 is adjusted. The lower the crystal frequency the smaller the frequency shift. For example, a 4.1-MHz crystal can be shifted only 1.5 kHz, typically. At 10 MHz we can expect shifts as great as 10 kHz, and at 15 MHz it is possible to obtain a 20 kHz shift. AT-cut crystals seem to rubber the best of the types available.

Too great an inductance at L1 will cause the oscillator to function like a conventional VFO, and large frequency swings will be possible. The disadvantage of this condition is that we lose the excellent frequency stability of the VXO. Miniature RF chokes are suitable for use at L1.

These are ball-park choke values versus frequency: 1-4 MHz; 50 uH. 4-7 MHz; 25 uH. 7-12 MHz; 15 uH and 12-21 MHz; 12 uH. I have found these values suitable in the circuits of Fig. 2C and D when using a 100-pF variable capacitor for C!.

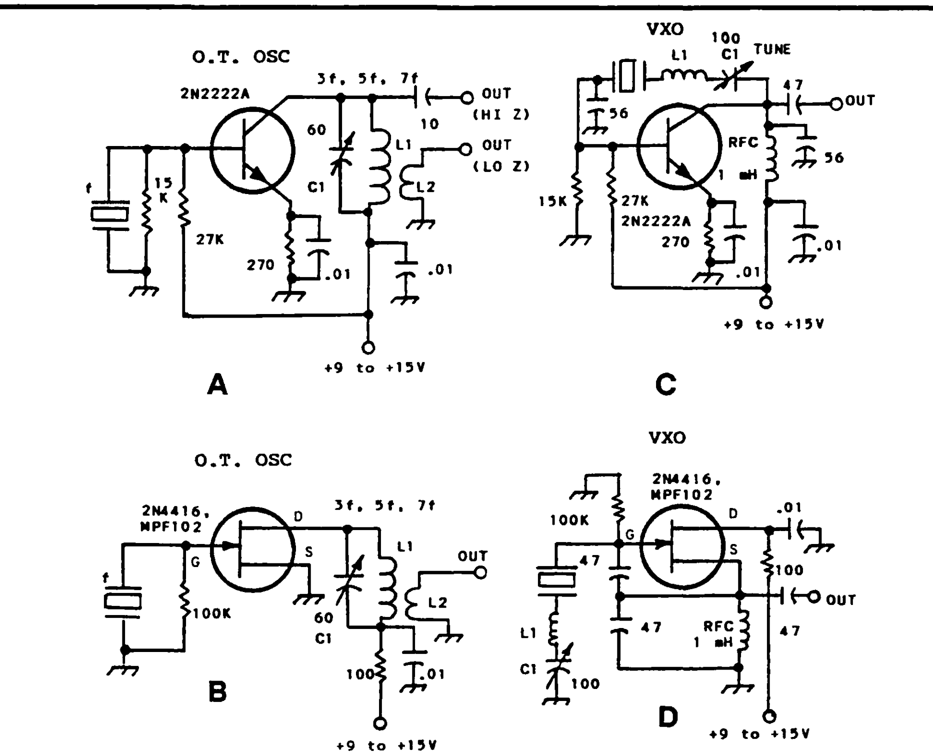

Figure 2

Examples of overtone and VXO circuits. The oscillators at A and B permit crystal oscillation at odd harmonics of the crystal fundamental by tuning the output circuit (L1/C1) to the desired overtone frequency. Circuits C and D enable you to pull or "rubber" the crystal lower in frequency by using a VXO type of circuit. C1 is the tuning control for shifting the frequency. See text for additional data.

Closing Comments

I have not discussed crystals in depth. Many additional characteristics pertain to crystals and the oscillator circuits in which they are used. Such matters as load capacitance, Q, series resistance and series - or parallel-mode oscillation are important to circuit designers.

I do not want to burden you, the beginner, with details about those parameters at this time. I urge you, however, to breadboard some of the circuits in Figs. 1 and 2. The learning exercise will provide a stepping stone to future circuit development.