9
Other Topics

9.1. CRYSTAL SWITCHES

It is sometimes desirable to use a single oscillator with a number of crystals and a switching mechanism. This usually presents no problem at HF frequencies where the stray capacitance and inductance of the switch have negligible effects. At VHF frequencies, however, these strays can be extremely detrimental to the circuit performance.

There are two methods of lessening the problem and usually both are necessary in order to achieve satisfactory performance. First, an oscillator type which is reasonably tolerant of strays should be used. Second, every possible effort should be made to minimize the strays. The most effective means of accomplishing this is to build the crystal switch small. In the case of printed circuit switches, the use of small pads reduces capacitance. The switch collector rings often can be placed to minimize coupling to other parts. It may not be desirable to make the collector rings too narrow, however, as this adds to the stray inductance. It is very desirable to use a switch wafer which has a low dielectric constant. Teflon base materials are considerably superior to glass epoxy or phenolic boards in this respect. The bond strength is somewhat lower, however.

Depending on the oscillator type being used, stray capacitance in some locations may be more detrimental than in others. For example, in the impedance-inverting Pierce oscillator, stray capacitance from the base side of the crystal to ground is only of secondary importance, while capacitance across the crystal is very important. Lead inductance is not as critical for this oscillator as it is in the grounded-base oscillator. In general, the circuit should be examined to see which strays will cause the most harm; then they should be minimized, even at the expense of other strays.

A concept which is often forgotten in crystal switching is that unused crystals must be effectively removed from the circuit. If this is not accomplished, the unused crystals may absorb power from the oscillator should they have spurious responses near the frequency of the oscillating crystal. This may result in serious degradation of performance or even cause spurious frequencies in some cases. Perhaps the most effective method of eliminating coupling to the unused crystals is to short them to ground. If this cannot be done, then the stray capacitance to unused crystals must be kept very low.

Stray coupling is often quite severe if diode switching is used. The diodes themselves usually are quite good but switching schemes which save diodes usually are not good. Often, systems employ ingenious methods to switch a number of crystals with relatively few diodes. They usually have several sneak paths through the C_0's of the unused crystals which may cause serious trouble or even oscillation on the wrong crystal. It is, therefore, recommended that a thorough investigation of stray paths in a diode switch be made if fewer diodes than quartz crystals are being used. It is sometimes possible to tune out stray capacitance by the use of an inductor in parallel with it. This also may be done to resonate out sneak paths in diode switches.

Switching of crystals should be discouraged above 100 MHz since the oscillators themselves are very critical. A switch merely makes a bad situation even worse.

If crystal switching in the VHF range is necessary it may be desirable to examine the impedance-inverting Pierce oscillator, since it is less susceptible to stray inductance than the grounded-base oscillator.

The availability of frequency synthesizers on a single chip in certain frequency ranges (for example, the CB band) may well make the crystal switch obsolete within the near future, and the application of these devices should not be overlooked before making the decision to use a crystal bank with switches.

9.2. PULLABLE OSCILLATORS

It is sometimes necessary to vary the frequency of an oscillator by a small amount and yet require that the oscillator be quite stable. This can be done using a crystal oscillator provided the pullability requirements are not too severe. The frequency can usually be varied several hundred parts per million without much difficulty. If extreme measures are taken, the pullability may be as high as several thousand parts per million. Pullability and stability are opposing requirements, and even in a crystal oscillator the stability will suffer as the pullability is increased.

Perhaps the best way to pull a crystal oscillator is to put a voltage-variable capacitor in series with the crystal, an example of which is shown in Figure 9-1.

The pullability is determined primarily by two factors: the reactance–frequency slope of the crystal, and the reactance–voltage curve of the varactor. Since the frequency of oscillation will be near the crystal frequency, the other reactances in the oscillator circuit may, for practical purposes, be considered to be constant. From equation (5-3), which gives the antiresonant frequency of the crystal as $f_a = f_s[1 + (C_1/2C_0)]$, we see that the pullability of the crystal is larger if the C_0/C_1 ratio is small. A table of the C_0/C_1 ratio for some fundamental and overtone crystals appears in Table 9-1.

From this table, it is obvious that a fundamental crystal is most desirable. However, as the frequency is increased, the thickness of the crystal blank decreases and the unit becomes very fragile. The use of fundamental-mode AT-cut crystals is not recommended above 30 MHz.

The reactance–frequency curve of a quartz crystal is shown in Figure 5-3 and is fairly nonlinear because of the presence of the holder capacitance (see Figure 5-1). If an inductor is placed across the crystal to tune out the C_0, then the curve acquires another pole below series resonance and there is a relatively large region between

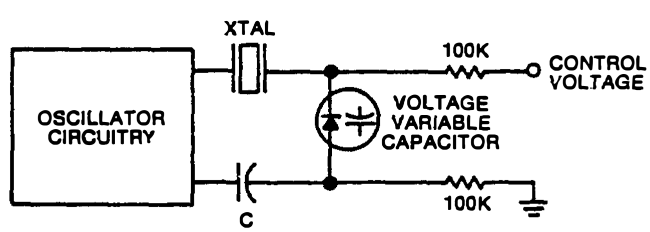

Figure 9-1. Typical pullable crystal oscillator: simplified diagram.

the two poles where the curve is linear. This slope is given approximately by:

$$\frac{dX}{df} = 4\pi L_1 \ \Omega/\text{Hz} \qquad (9\text{-}1)$$

where L_1 is in henrys.

Perhaps the best way to study the reactance–frequency curve for a crystal is to use the equivalent circuit of Figure 5-1, with an inductance in parallel with C_0, and to write a short computer program for the reactance. This was done for a 30-MHz crystal with the following parameters:

$R_1 = 20\ \Omega$
$C_0 = 6$ pF
$C_1 = 0.03$ pF

The results are plotted in Figure 9-2 for the crystal alone and also for the crystal shunted by a 4.6-μH inductor. As can be seen, the curve is nearly a straight line. If a hyper-abrupt varactor with an exponent of unity is used in series with the crystal, a linear frequency–voltage curve results. Stray capacitance between the crystal and the varactor often reduces the pullability and linearity of a VCXO, and an advantage can be obtained by using two varactors in connection with series inductors. This arrangement, shown in Figure 9-3, allows

Table 9-1. Typical C_0/C_1 Ratios for Quartz Crystals.

Frequency (MHz)	Fundamental or overtone	C_0/C_1 ratio
0.2	fund.	400
2.0	fund.	270
6.9	fund.	230
8.8	fund.	220
12.5	fund.	200
31.0	third	2500
50.0	third	3000
60.0	third	3500
50.0	fifth	6200
60.0	fifth	6500

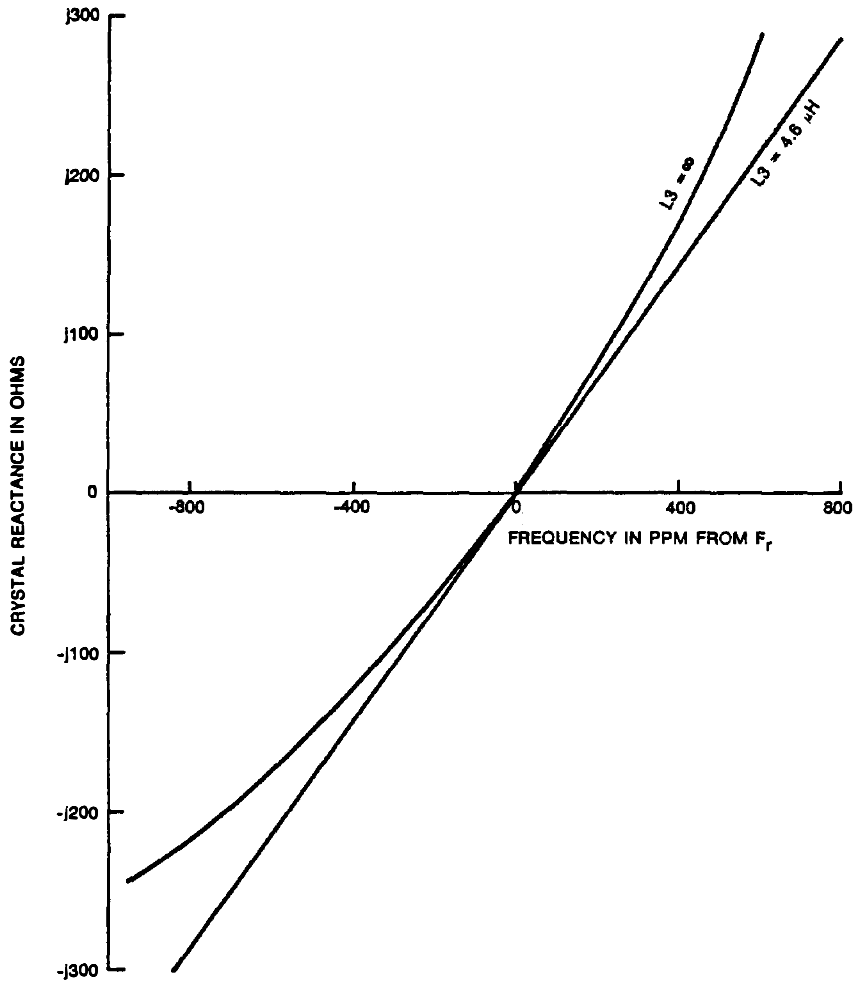

Figure 9-2. Reactance versus frequency for 30-MHz crystal.

the frequency to be pulled symmetrically above and below series resonance. A resistor is often necessary across the crystal to prevent free-running oscillations. Free-running oscillations are also minimized by using a grounded-base oscillator (see Chapter 7), since a tank circuit limits the range of oscillation to be near the crystal resonance.

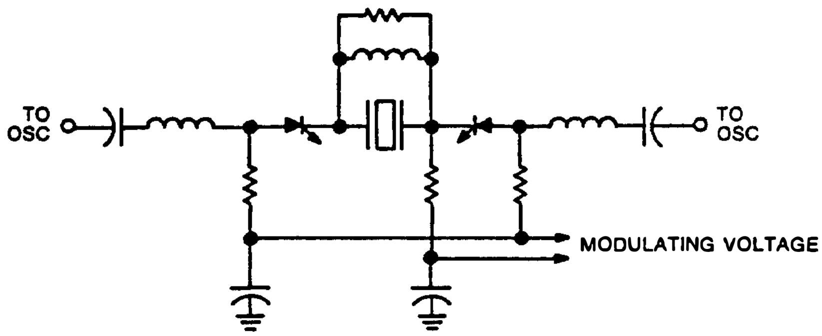

Figure 9-3. VCXO modulator schematic.

9.3. CRYSTAL OVENS

The design of crystal ovens is not considered in this book; however, it should be noted that when frequency stabilities beyond those obtainable by compensation are required, a crystal oven is often used. Crystal ovens are also used in some fixed-channel transmitters and receivers where replacing the crystal is required to change channels. A number of solid-state commercial crystal ovens are available for this purpose, and a stability in the order of 1 ppm can easily be obtained. The warmup time is usually not critical in these applications, and may be in the 5–15 min range. These ovens often accept plug-in HC-6/U or HC-35/U crystals and operate at 75°C or 85°C. If the warmup time can be tolerated, it may well be cost effective to use a solid-state oven designed to hold or clamp over the crystal.

In precision applications, both the crystal and the oscillator are usually packaged in the oven, and the oven is controlled by a thermistor sensor used in a bridge circuit with an operational amplifier. The amplifier drives a power transistor which controls the dc power to the oven heater.

A crystal oven of this type is capable of controlling the temperature of the crystal to within ±0.1°C over an ambient temperature range of -55°C to +75°C, and usually results in a temperature stability in the order of $\pm 1 \times 10^{-8}$. Various combinations of double ovens and hybrid arrangements using two heaters with a single control circuit are also available. The stability obtainable from a double oven is often in the $\pm 1 \times 10^{-10}$ region. Precision crystal ovens normally use foam insulation or a Dewar flask for insulation, while lower-precision units may use a dead air space. As discussed in section 4.1.1, crystal ovens have several major disadvantages which makes them unsuitable in some applications.

9.4. SQUEGGING, SQUELCHING, OR MOTORBOATING

Squegging is a term applied to relaxation-type oscillations which sometimes occur in addition to the desired mode of oscillation. In most instances the squegging rate is much less than that of the desired oscillation. Frequency differences of one or two orders of magnitude are not uncommon. If squegging is severe, it actually may start and stop the desired oscillation at its relatively slow repetition rate. In less severe cases, it merely modulates the desired signal. Squegging can be observed most easily using an oscilloscope with a sweep rate compatible with the relaxation oscillation. The squegging then will show up as a modulation envelope on the desired signal. It also may be observed on a spectrum analyzer or a receiver as sidebands on the oscillator output.

Squegging is generally the result of several conditions. One of the strongest influences on it is the ratio of capacitance from base to ground and emitter to ground. This results from the inability of emitter voltage to follow changes in the average base voltage when C_e is too large. When this occurs, the situation often can be corrected by decreasing the value of C_e, by increasing the base-to-ground capacitance or by moving the ground return of the feedback network to the emitter directly. Other conditions have an effect on squegging also, such as the collector load and the shape of the characteristic curves for the transistor. Some transistor types therefore have a greater tendency to squeg than others. As might be expected, the tendency of a transistor to squeg is dependent upon its operating point and, in some cases, changing the Q-point may eliminate the problem. Squegging may also occur in gate oscillators, and can usually be cured by changing the values of biasing components such as shunt resistors.

9.5. SPURIOUS OSCILLATIONS

Problems are encountered occasionally with spurious oscillations in crystal oscillators. In general, the problem results when the crystal has a low-resistance spurious mode and the oscillator becomes controlled by the spurious rather than by the main response. The problem can usually be eliminated by specifying a sufficiently high crystal spurious ratio (ratio of spurious resistance to main response resistance). From an economic standpoint, this may not always be the best solution, however, and it may be desirable to design the oscillator circuit so that it has minimum tendencies toward spurious oscillation. Several factors, including the choice of circuit type, have a considerable bearing on spurious operation and are summarized here.[13]

In general the antiresonant oscillator circuits (Pierce, Colpitts, and Clapp) are less likely to cause spurious oscillation. A crystal spurious ratio only slightly greater than unity usually will prevent spurious operation. The VHF series resonant oscillators are considerably more prone to spurious oscillation. A spurious-ratio specification in the range from 1.5 : 1 to 3 : 1 may well be required to prevent spurious oscillation.

Several "spurious-causing" phenomena have been isolated which, if present in a particular circuit, will enhance the ability of the circuit to oscillate on a spurious mode. These phenomena are as follows:

a. *Excessive tank circuit Q.* This makes the oscillator circuit frequency selective and, when the tank circuit is mistuned, it may discriminate against the main response and allow operation on the spurious response.
b. *Excessive loop gain.* The circuit should be designed to have the lowest possible loop gain commensurate with operation of high-resistance crystals under worst-case conditions.
c. *Circuit elements directly in series or in parallel with the crystal.* In circuits employing a C_0 compensation inductor, the value of the inductor should be as large as practical.
d. *Interaction with other crystals.* If a bank of crystals is to be used with a crystal switch, the unconnected crystals should be shorted out if possible.
e. *Switching to an active oscillator.* In general, the possibility of

spurious oscillation is greater if a crystal is switched to an energized oscillator circuit than if the crystal is switched first and the circuit is then energized.

f. *Unequal initial excitation of main and spurious responses.* The presence of a parasitic or unintentional resonant circuit in the oscillator, which for a certain setting of the variable element is at the spurious frequency, may lead to spurious oscillation.

g. *Free-running oscillation.* Free-running oscillations or a circuit which can almost free-run may increase the possibility of spurious oscillation drastically if the free-running frequency is near the spurious-response frequency of the crystal.

In general it has been found, when analyzing spurious oscillations, that the mode which will survive is determined during the period prior to saturation when the oscillations are building up. All modes for which oscillation is possible begin to build up when the circuit is energized. The mode which builds up most rapidly causes the oscillator to saturate and the other modes to die out. To a good approximation, the oscillator may be considered linear before saturation and various modes can be analyzed independently (principle of superposition). This results in a considerable simplification if analytic treatments are to be considered in studying the behavior.