5
Quartz Crystal Resonators

The importance of quartz crystal resonators in electronics results from their extremely high Q, relatively small size, and excellent temperature stability.

A quartz crystal resonator utilizes the piezoelectric properties of quartz. If a stress is applied to a crystal in a certain direction, electric charges appear in a perpendicular direction. Conversely, if an electric field is applied, it will cause mechanical deflection of the crystal. In a quartz crystal resonator, a thin slab of quartz is placed between two electrodes. An alternating voltage applied to these electrodes causes the quartz to vibrate. If the frequency of this voltage is very near the mechanical resonance of the quartz slab, the amplitude of the vibration will become very large. The strain of these vibrations causes the quartz to produce a sinusoidal electric field which controls the effective impedance between the two electrodes. This impedance is strongly dependent on the excitation frequency and possesses an extremely high Q.

Electrically, a quartz crystal can be represented by the equivalent circuit of Figures 5-1 and 5-2 where the series combination R_1, L_1, and C_1 represent the quartz, and C_0 represents the shunt capacitance of the electrodes in parallel with the holder capacitance. The inductor L_1 is a function of the mass of the quartz, while C_1 is associated with its stiffness. The resistor R_1 results from the loss in the quartz and in the mounting arrangement. The parameters of the equivalent circuit can be measured quite accurately using the crystal impedance (CI) meters,* vector voltmeters,[14,49] or bridge measurement tech-

*RFL Industries, Boonton, NJ, Model 5950, with plug-in units to cover frequency of interest. Old crystal impedance meters are TS-710/TSM, 10–1100 kHz, TS-630/TSM, 1–15 MHz; TS-683/TSM, 10–140 MHz; and AN/TSM-15, 75–200 MHz.

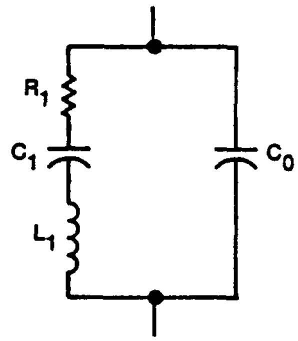


Figure 5-1. Simplified diagram of the equivalent circuit of a quartz crystal

niques.[19] A reactance-frequency plot of the equivalent circuit is given in Figure 5-3, and a reactance-resistance plot is given in Figure 5-4. The portions circled on these figures are expanded in Figure 5-5.

Several equations have been derived in Appendix K which are useful when using the equivalent circuit. The results are presented below. Several frequencies are marked in Figures 5-4 and 5-5. The first of these is f_s. This is the frequency at which the crystal is series resonant, and is given by

$$f_s = \frac{1}{2\pi\sqrt{L_1 C_1}} \tag{5-1}$$

where

f_s = series resonant frequency in hertz,
L_1 = motional arm inductance in henrys, and
C_1 = motional arm capacitance in farads.

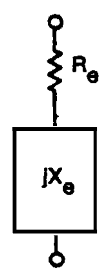


Figure 5-2. Impedance representation of a quartz crystal.

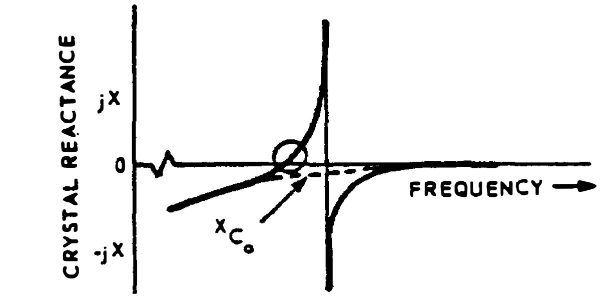


Figure 5-3. Plot of reactance versus frequency for a quartz crystal.

The second point, f_r, represents the frequency at which the crystal appears purely resistive ($X_e = 0$). Point f_r is different from f_s only because of the presence of C_0, and for practical purposes can be considered equal to f_s. The third point labeled, f_L, is the frequency at which the crystal is antiresonant with a given external capacitor C_L. If Δf is the frequency shift ($f_L - f_s$) between series resonance and this load point, then

$$\frac{\Delta f}{f_s} = \frac{C_1}{2(C_0 + C_L)} \tag{5-2}$$

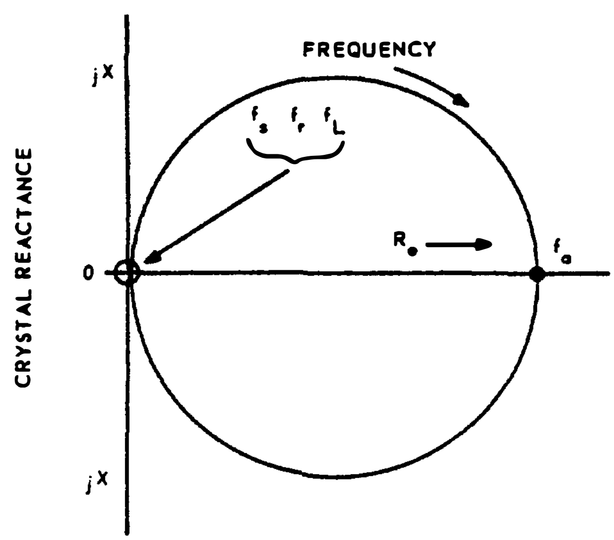


Figure 5-4. Plot of reactance versus resistance for a quartz crystal.

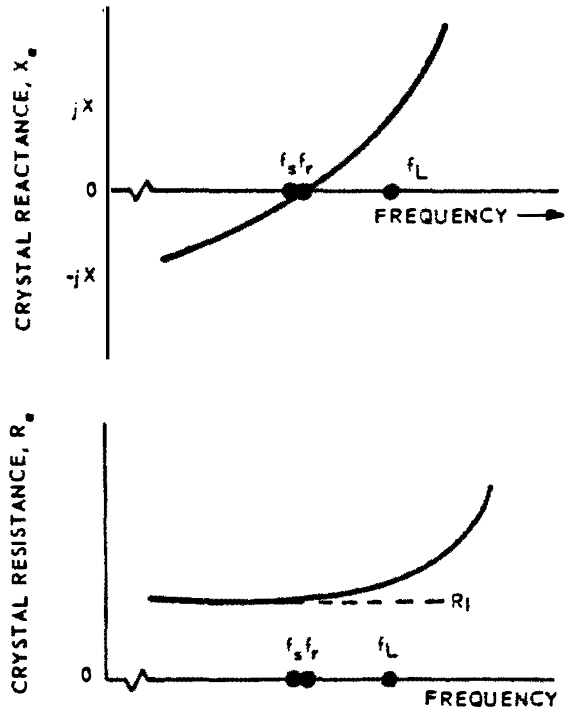


Figure 5-5. Expanded portions of crystal reactance (A) and resistance, (B). (See Figures 5-3 and 5-4).

where

Δf = frequency shift

(f_L - f_s) in hertz,

C_1 = motional arm capacitance in picofarads,
C_0 = crystal holder capacitance in picofarads, and
C_L = external load capacitance in picofarads.

The point labeled f_a is the antiresonant frequency of the crystal with its own holder capacitance C_0. It is given by

$$f_a = f_s \left[1 + \frac{C_1}{2C_0}\right] \tag{5-3}$$

where

f_a = antiresonant frequency in hertz,
f_s = series resonant frequency in hertz,
C_1 = motional arm capacitance in picofarads, and
C_0 = crystal holder capacitance in picofarads.

Furthermore, it can be shown (see Appendix K) that the equivalent resistance R_e in the region between series (f_s) and antiresonance (f_a) is given by

$$R_e = R_1 \left(\frac{C_L + C_0}{C_L}\right)^2 \tag{5-4}$$

provided the assumption $\left| X_{C_0}\left(\frac{C_L}{C_0 + C_L}\right)\right| >> R_1$ is true, where

$$X_{C_0} = -\frac{1}{2\pi f C_0}.$$

Normally a crystal is operated between its series resonant frequency and its antiresonant frequency so that the reactance X_e is either zero or inductive.

To help the engineer acquire a practical grasp of the equivalent circuit, Table 5-1 is included to give a rough idea of the magnitude of the various equivalent circuit components.

The parameters of a quartz crystal resonator may be varied greatly by the angle at which the crystal blank is cut from the raw quartz and by the mode of vibration. This is primarily a concern of the crystal manufacturer and will not be discussed in detail here. (An excellent

Table 5-1. Typical Crystal Parameter Values.

Parameters	200-kHz[31] fundamental	2-MHz[31] fundamental	30-MHz[31] third overtone	90-MHz fifth overtone
R_1	2 kΩ	100 Ω	20 Ω	40 Ω
L_1	27 H	520 mH	11 mH	6 mH
C_1	0.024 pF	0.012 pF	0.0026 pF	0.0005 pF
C_0	9 pF	4 pF	6 pF	4 pF
Q	18×10^3	54×10^3	10^5	85×10^3

treatment of crystal cuts is given in reference 6.) Several properties of crystal resonators are of concern to the designer of crystal oscillators and will be discussed in the following paragraphs.

5.1 LOAD CAPACITANCE

From Figures 5-3, 5-4, and 5-5 it can be seen that the frequency of the crystal will vary to some extent depending upon the reactance that the crystal must present to an external circuit. Since the frequency difference between series and antiresonance ($f_a - f_s$) may be on the order of 1 percent for some crystals, it is important that the crystal be ground to frequency at the load reactance value with which it will be used in the oscillator. Four load conditions have become standard and are nearly always used. With the first two of these, the crystal acts like an inductive reactance which will resonate with either 30 or 32 pF at the operating frequency. Hence, the load capacitance C_L = 30 pF or C_L = 32 pF. Crystals of this type must be used in parallel resonant oscillators. A second common load point is series resonance, where the crystal acts like the resistor R_1. Crystals of this type must be used with series resonant oscillators. A fourth load point, C_L = 20 pF, is sometimes used for crystals below 500 kHz.

5.2 PIN-TO-PIN CAPACITANCE

Pin-to-pin capacitance (C_0 of Figure 5-1) refers to the capacity of the electrodes on the quartz as well as that of the holder itself. The holder capacitance is usually around 0.5 pF and the remaining capacitance is due to the electrodes plated on the quartz. C_0 should be restricted to about 5 pF for AT-cut* crystals while it may be somewhat higher for low-frequency cuts. It becomes important to minimize C_0 for VHF crystals, where it may cause the oscillator to free-run (to oscillate not crystal-controlled). C_0 may be reduced in crystal manufacture by reducing the electrode spot size on the crystal blank. However, this tends to increase the resistance R_1.

*The AT-cut is the basic high-frequency crystal normally used in the range from 1 to 150 MHz.

5.3 RESISTANCE

The resistance of a crystal is specified at the rated load capacitance, although this usually does not differ grossly from the series resistance R_1. The maximum allowable resistance for a given crystal type may vary from about 40 Ω for VHF crystals to approximately 500 kΩ for audio-frequency crystals. It is important to make certain that an oscillator will function properly with a crystal of the maximum specified resistance.

5.4 RATED OR TEST DRIVE LEVEL

Drive level refers to the power dissipated in the crystal. Rated or test drive level is the power at which all requirements of the crystal specification must be met. The drive level specification should reasonably duplicate the actual drive level at which the crystal will be used because frequency is somewhat dependent on drive level. AT-cut crystals generally can withstand a considerable overdrive without physical damage; however, the electrical parameters are degraded at excessive drive. Low-frequency crystals (especially flectural mode crystals) may fracture if overdriven. Drive level ratings vary from 5 μW below 100 kHz to about 10 mW in the 1- to 20-MHz region for fundamental mode crystals. Overtone crystals which are generally used above 20 or 30 MHz are often rated at 1–2 mW of drive.

5.5 FREQUENCY STABILITY

The frequency stability of a crystal generally is limited by its temperature coefficient and aging rate. AT-cut crystals have a better temperature coefficient than most other cuts. Common frequency tolerance specifications are ±0.005 percent or ±0.0025 percent from −55°C to +105°C. These include calibration tolerance; thus, the actual temperature coefficient is slightly better. Improved temperature coefficients can be obtained if the temperature range is limited. This can be seen in Figure 5-6, which gives frequency–temperature curves for AT-cut crystals. These curves may be represented by cubic equations and are strongly dependent on the angle of cut of the quartz blank from the mother crystal. The points of zero temperature coefficient

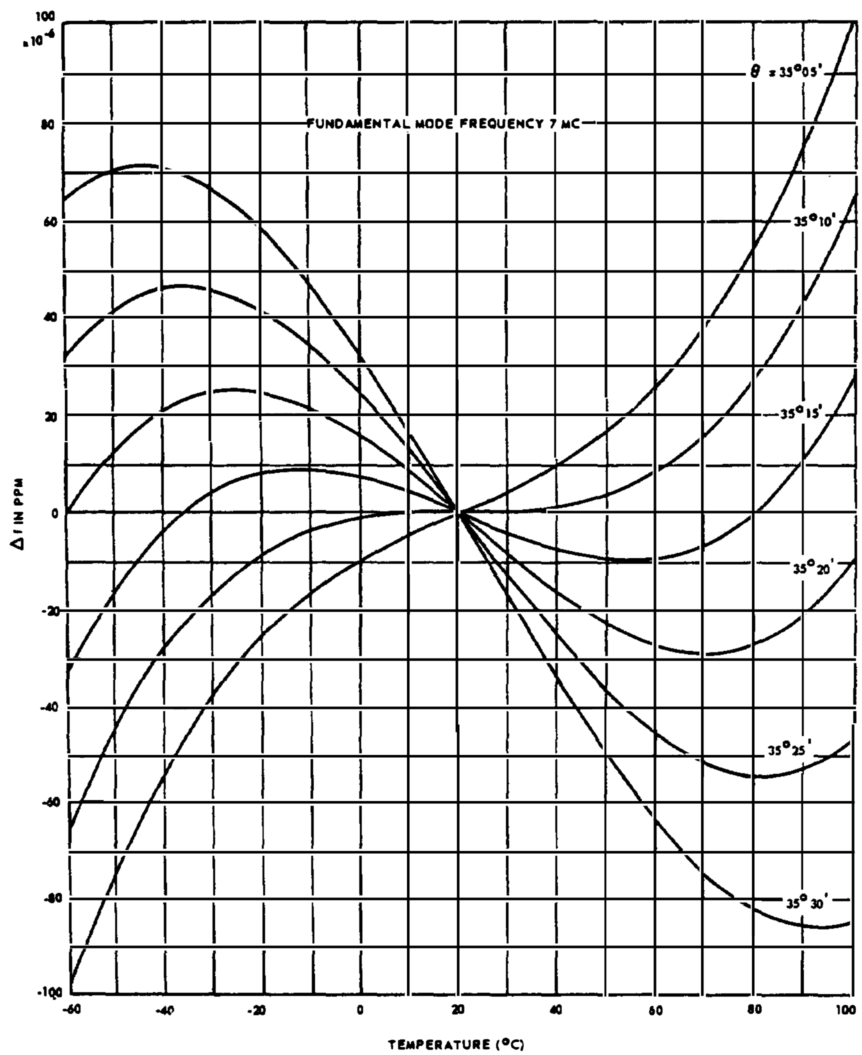


Figure 5-6. Frequency-temperature-angle characteristics of plated AT-type natural quartz crystal resonators.[4]

are called the turning points (lower and upper turning-point temperatures). One turning point can be placed where desired by selecting the angle of cut; the other turning point then is determined, since the turning points are symmetrical about a point in the 20–30°C range.

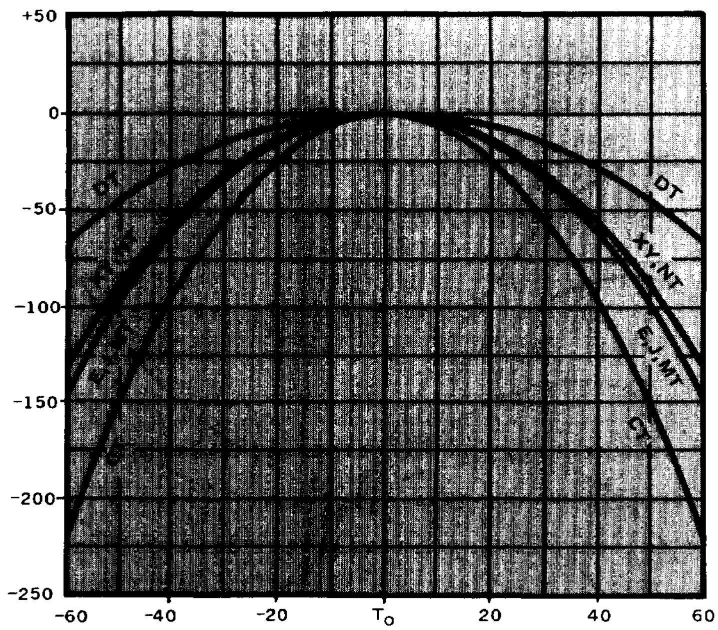


Figure 5-7. Frequency-temperature characteristics of low-frequency crystal cuts. (Courtesy Northern Engineering Laboratories)

The slope between the turning points becomes smaller as the turning points move together. Crystals designed for use in an oven should be cut so that a turning point occurs at the oven temperature. Figure 5-7 shows the frequency-temperature curves for several low-frequency cuts. The J-cut is used below 10 kHz, while an XY-cut may be used from about 3 kHz to 85 kHz. An NT-cut may be used in the 10 kHz to 100 kHz range. A DT-cut is applicable from 100 kHz to about 800 kHz and a CT from perhaps 300 kHz to 900 kHz.

5.6. FINISHING OR CALIBRATION TOLERANCE

Finishing tolerance is the maximum allowable error in frequency of a crystal at some specified temperature. If ±0.005-percent crystals are used, it is often desirable to specify a room temperature finishing tolerance of, e.g., ±0.0015 percent so that oscillators can be tuned conveniently to frequency in production. If oscillators are to be tuned to frequency, the finishing tolerance must be less than the tuning range of the oscillator. In the case of temperature controlled crystals, the finishing tolerance is specified at the nominal operating temperature of the oven. Another use of finishing tolerance is with an alternative method of specifying the overall frequency tolerance of a crystal. It is sometimes desirable to specify a room temperature finishing tolerance and a maximum deviation from the room temperature frequency over the temperature range. This method may be used in place of specifying a frequency tolerance as described in section 5.5.

5.7. CRYSTAL AGING

Crystal aging is caused primarily by a gradual transfer of mass to or from the crystal blank and by a relaxation of stresses. Generally it is slowed down by operating the crystal at low drive level and at low temperature; however, it is most important that the crystal be kept clean. For this reason, it is essential that the hermetic seal of the crystal be preserved. Aging of cold-weld and glass enclosed crystals is significantly slower than that of crystals in solder sealed cans, since they can be kept cleaner. Glass enclosed crystals usually age up in frequency due to an apparent reduction in the mass of the quartz blank, while metal enclosed crystals age down in frequency because impurities settle on the blank.

Aging rate specifications are generally ± 0.0005 percent per month for standard military-type (MIL-type) crystals; however, it is possible to achieve aging rates as low as 1 part in 10^{11} per day for precision crystals. Ordinary crystals enclosed in cold-weld holders can be expected to age 1–5 parts in 10^8 per week after the first year. Aging is not accounted for in the overall temperature specification as discussed previously.

5.8. *Q* AND STIFFNESS OF CRYSTALS

The Q of ordinary or MIL-type crystals is normally not specified, but for standard units, it usually falls between 20,000 and 200,000. Precision crystals may have Q values as high as 5×10^6. Q is defined as X_L/R_1, where X_L is the reactance of L_1 at the operating frequency.

The C_0/C_1 ratio of a crystal usually is not specified. It is a measure of the stiffness of the crystal, as can be seen from equation (5-3). When the pulling characteristics of a crystal are important, it should be specified. Typical C_0/C_1 ratios may be on the order of 1000, although it is possible to achieve C_0/C_1 ratios from 125 to over 35,000.

5.9. MECHANICAL OVERTONE CRYSTALS

The AT-cut crystals may be operated on their fundamental frequency or on odd mechanical overtones, notably the third and the fifth overtones. Overtone crystals normally are used above 20 MHz. They have higher Q values, better aging rates, and are electrically stiffer than fundamental crystals of the same frequency. A tuned circuit is necessary in the oscillator to ensure operation on the proper overtone. Overtone crystals are nearly always operated at series resonance. The overtone responses of a crystal should not be confused with harmonics of the fundamental frequency. They are two different phenomena. The overtone responses of a crystal are in general not exactly multiples of the fundamental frequency, although they are close. These overtone responses are depicted in Figure 5-8 which shows, in general, the various responses which may be expected in a typical AT-cut crystal. The spurious responses are discussed in section 5.10.

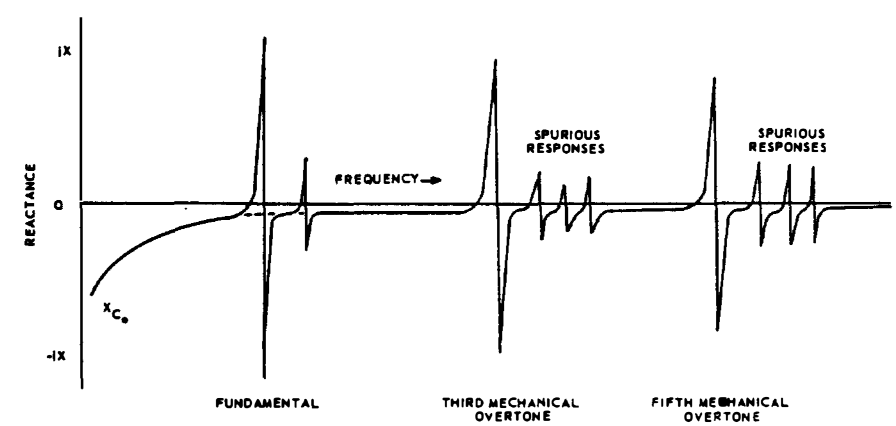


Figure 5-8. Overtone response of a quartz crystal.

As a general rule, third-overtone crystals are used from 20 to 60 MHz and fifth overtones from 60 to 125 MHz.*

5.10. SPURIOUS OR UNWANTED MODES

There are always a number of spurious responses in a quartz crystal in addition to the response of interest. This results from the fact that various modes of vibration are possible in any given quartz blank. Although the number, magnitude, and frequencies of the unwanted modes vary from crystal to crystal, an arbitrary arrangement is shown in Figure 5-8. Most of the spurious responses have a high resistance compared to the main response; however, a few low-resistance responses usually exist. They are almost always higher in frequency than the main response, and for AT-cut crystals very often fall within 200 kHz of the main response. If a spurious response has a resistance which is too low with respect to the main response, the oscillator circuit may operate on the frequency of the spurious rather than on the main response.

Generally, no problem with spurious responses is encountered using fundamental-mode crystals. With overtone crystals, however, problems frequently are encountered. It is desirable to specify a large spurious-to-main-response resistance ratio to avoid the possibility of trouble. Practically, however, it is difficult to eliminate the unwanted responses, although several techniques are available to reduce them. With third overtone crystals, a 2-to-1 spurious ratio specification is fairly common, although often inadequate, while a 4-to-1 ratio is practical even in large production quantities. With fifth-overtone crystals, it is somewhat more difficult to make the spurious resistance high, but a 3-to-1 minimum ratio is still practical. It is often desirable to specify not only a minimum ratio but also a minimum permissible spurious resistance. This results from the fact that a larger spurious ratio is required when the crystal resistance is low. For a discussion of the spurious effects in oscillator circuits, the reader is referred to section 9.5.

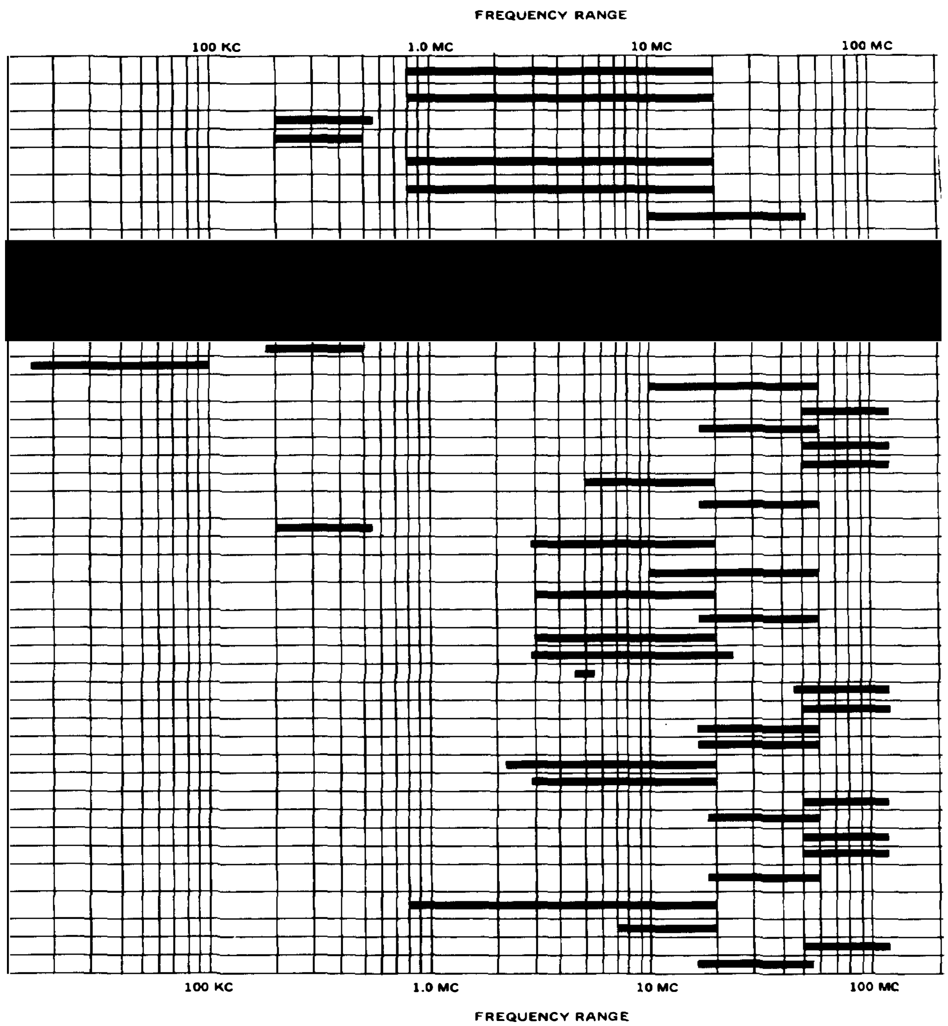
*A considerable amount of research is being conducted in the area of surface acoustic wave resonators. These devices, which may be represented by the same equivalent circuit as the bulk wave resonators discussed in this section, show promise of extending the frequency range of crystal oscillators into the low gigahertz region. The C_0/C_1 ratio of these devices is roughly equivalent to a fifth overtone AT-cut; however, the TC is parabolic in shape.

Table 5-2. Summary of Selected MIL Crystals (compiled from MIL-STD-683D).

MIL CRYSTAL TYPE	HOLDER* TYPE	OVER-ALL FREQUENCY TOLERANCE (%)	OPERATING TEMP RANGE (°C)	LOAD COND	MODE	RATED DRIVE LEVEL (MW)
CR-18A/U	HC-6/U	±.005	−55 TO +105	32 PF	FUND	10 (≤10 MC) 5 (>10 MC)
CR-19A/U	HC-6/U	±.005	−55 TO +105	SERIES	FUND	10 (≤10 MC) 5 (>10 MC)
CR-25B/U	HC-6/U	±.01	−40 TO +85	SERIES	FUND	2.0
CR-26A/U	HC-6/U	±.002	+70 TO +80	SERIES	FUND	2.0
CR-27A/U	HC-6/U	±.002	+70 TO +80	32 PF	FUND	5 (≤10 MC) 2.5 (>10 MC)
CR-28A/U	HC-6/U	±.002	+70 TO +80	SERIES	FUND	5 (≤10 MC) 2.5 (>10 MC)
CR-32A/U	HC-6/U	±.002	+70 TO +80	SERIES	THIRD	2 (≤25 MC) 1 (>25 MC)
CR-35A/U	HC-6/U	±.002	+80 TO +90	SERIES	FUND	5 (≤10 MC) 2.5 (>10 MC)
CR-36A/U	HC-6/U	±.002	+80 TO +90	32 PF	FUND	5 (≤10 MC) 2.5 (>10 MC)
CR-37A/U	HC-13/U	±.02	−40 TO +70	20 PF	FUND	2.0
CR-38A/U	HC-13/U	±.012	−40 TO +70	20 PF	FUND	0.1
CR-42A/U	HC-13/U	±.003	+70 TO +80	32 PF	FUND	2.0
CR-47A/U	HC-6/U	±.002	+70 TO +80	20 PF	FUND	2.0
CR-50A/U	HC-13/U	±.012	−40 TO +70	SERIES	FUND	0.1
CR-52A/U	HC-6/U	±.005	−55 TO +105	SERIES	THIRD	4.0 (≤25 MC) 2.0 (>25 MC)
CR-54A/U	HC-6/U	±.005	−55 TO +105	SERIES	FIFTH	2.0
CR-55/U	HC-18/U	±.005	−55 TO +105	SERIES	THIRD	2.0
CR-56A/U	HC-18/U	±.005	−55 TO +105	SERIES	FIFTH	2.0
CR-59A/U	HC-18/U	±.002	+80 TO +90	SERIES	FIFTH	1.0
CR-60A/U	HC-18/U	±.005	−55 TO +105	SERIES	FUND	5.0
CR-61/U	HC-18/U	±.002	+80 TO +90	SERIES	THIRD	2.0 (≤25 MC) 1.0 (>25 MC)
CR-63B/U	HC-6/U	±.01	−40 TO +70	20 PF	FUND	2.0
CR-64/U	HC-18/U	±.005	−55 TO +105	30 PF	FUND	5.0
CR-65/U	HC-6/U	±.001	+70 TO +80	SERIES	THIRD	2.0 (≤25 MC) 1.0 (>25 MC)
CR-66/U	HC-6/U	±.002	−55 TO +105	30 PF	FUND	10.0 (≤10 MC) 5.0 (>10 MC)
CR-67/U	HC-18/U	±.0025	−55 TO +105	SERIES	THIRD	2.0
CR-68/U	HC-6/U	±.002	+70 TO +80	32 PF	FUND	5.0
CR-69A/U	HC-18/U	±.002	−55 TO +105	30 PF	FUND	5.0
CR-71/U	HC-30/U	±.00008		32 PF	FIFTH	70 UA
CR-74/U	HC-26/U	±.001	+80 TO +90	SERIES	FIFTH	1.0
CR-75/U	HC-6/U	±.001	+70 TO +80	SERIES	FIFTH	1.0
CR-76/U	HC-18/U	±.0025	−55 TO +105	SERIES	THIRD	2.0
CR-77/U	HC-25/U	±.002	−55 TO +105	SERIES	THIRD	2.0
CR-78/U	HC-25/U	±.005	−55 TO +105	30 PF	FUND	5.0
CR-79/U	HC-25/U	±.005	−55 TO +105	SERIES	FUND	5.0
CR-80/U	HC-18/U	±.003	−55 TO +105	SERIES	FIFTH	2.0
CR-81/U	HC-25/U	±.005	−55 TO +105	SERIES	THIRD	2.0
CR-82/U	HC-25/U	±.005	−55 TO +105	SERIES	FIFTH	2.0
CR-83/U	HC-25/U	±.0025	−55 TO +105	SERIES	FIFTH	2.0
CR-84/U	HC-25/U	±.002	+80 TO +90	SERIES	THIRD	2.0 (≤25 MC) 1.0 (>25 MC)
CR-85/U	HC-6/U	±.0025	−55 TO +105	SERIES	FUND	10 (≤10 MC) 5 (>10 MC)
CR-101/U	HC-35/U	±.0025	−55 TO +105	30 PF	FUND	5
CR-102/U	HC-35/U	±.0025	−55 TO +105	SERIES	FIFTH	2
CR-103/U	HC-35/U	±.0025	−55 TO +105	SERIES	THIRD	2

*FURTHER DETAILS OF THE HOLDERS ARE SHOWN IN FIGURE 5-10.

Table 5-2. (*Continued*)



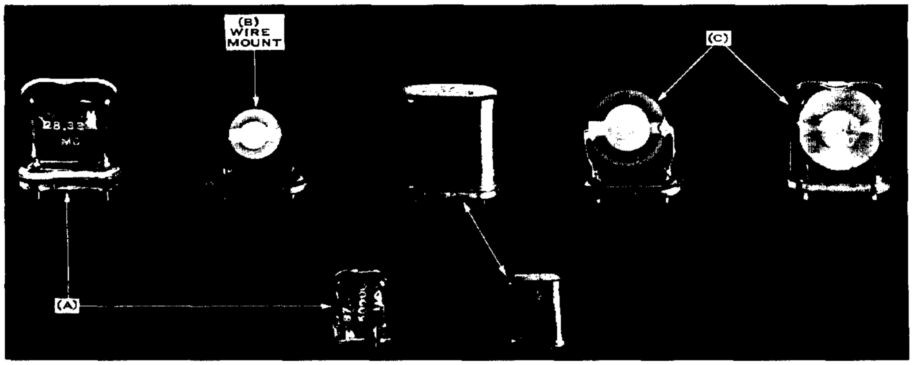


Figure 5-9. Ruggedized crystal mounts.

5.11. VIBRATION, SHOCK, AND ACCELERATION

Crystal units are available which will meet most environmental specifications. In general, vibration and shock do not cause catastrophic failures but, rather, frequency shifts and resistance changes. Frequency shifts on the order of 0.0001 percent are common, and resistance changes of 10 percent may occur. Figure 5-9 shows several ruggedized crystal mounts. The wire-mounted crystal is generally not satisfactory for severe environmental conditions, and one of the ruggedized versions must be used. (A) and (C) in Figure 5-9 generally are satisfactory for vibration up to 2000 Hz. Large crystal blanks are difficult to ruggedize and, consequently, low-frequency crystals should be avoided if severe environmental conditions will be encountered. For more specific information on environmental conditions, the reader may consult vibration specifications in MIL-C-3098.*

5.12. STANDARD MILITARY CRYSTALS

It is possible to specify a crystal to fit the needs of a particular oscillator circuit. Where possible, however, it is more desirable to use standard crystals. Table 5-2 presents a summary of selected MIL crystals, while Table 5-3 gives the maximum resistance for these units.

*AT-cut resonators generally show an acceleration sensitivity of about 1 ppb/*g*. Research is presently being conducted, however, to develop a stress-compensated crystal cut (SC) which shows promise of reducing the sensitivity by more than an order of magnitude. This also results in a reduction of the frequency overshoot during warm up due to thermal stress in the crystal blank.

TABLE 5-3. Maximum Crystal Resistance. (Compiled from MIL-C-3098F, 24 July 1973)

CR-18A/U

MHz	(Ω)
0.8 to 0.85	625
0.85+ to 0.9	600
0.9+ to 1	575
1+ to 1.12	540
1.12+ to 1.25	490
1.25+ to 1.37	450
1.37+ to 1.5	410
1.5+ to 1.62	375
1.62+ to 1.75	330
1.75+ to 1.87	300
1.87+ to 2	290
2+ to 2.12	270
2.12+ to 2.25	245
2.25+ to 2.6	195
2.6+ to 3	150
3+ to 3.4	110
3.4+ to 3.75	90
3.75+ to 4	75
4+ to 5	60
5+ to 7	35
7+ to 10	24
10+ to 15	22
15+ to 20	20

CR-19A/U

MHz	(Ω)
0.8 to 0.85	520
0.85+ to 0.9	480
0.9+ to 1	440
1+ to 1.12	400
1.12+ to 1.25	380
1.25+ to 1.37	340
1.37+ to 1.5	300
1.5+ to 1.62	275
1.62+ to 1.75	250
1.75+ to 1.87	220
1.87+ to 2	185
2+ to 2.12	165
2.12+ to 2.25	150
2.25+ to 2.6	125

CR-19A/U

MHz	(Ω)
2.6+ to 3	90
3+ to 3.4	70
3.4+ to 3.75	52
3.75+ to 4	45
4+ to 5	37
5+ to 7	25
7+ to 10	20
10+ to 15	18
15+ to 20	15

CR-25A/U

kHz	(Ω)
200 to 225	2,500
225+ to 265	3,000
265+ to 290	3,500
290+ to 330	4,000
330+ to 370	4,500
370+ to 410	5,000
410+ to 425	5,500
425+ to 460	6,500
460+ to 500	7,500

CR-26A/U
Same as CR-25A/U

CR-27A/U

MHz	(Ω)
0.8 to 0.85	620
0.85+ to 0.9	600
0.9+ to 1	570
1+ to 1.12	540
1.12+ to 1.25	490
1.25+ to 1.37	450
1.37+ to 1.5	410
1.5+ to 1.62	370
1.62+ to 1.75	330
1.75+ to 1.87	300
1.87+ to 2	290
2+ to 2.12	270
2.12+ to 2.25	240
2.25+ to 2.6	190

TABLE 5-3. (Continued)

CR-27A/U

MHz	(Ω)
2.6+ to 3	150
3+ to 3.4	110
3.4+ to 3.75	90
3.75 to 4	75
4+ to 5	60
5+ to 7	35

Same as CR-19A/U

CR-36A/U
Same as CR-27A/U

CR-37A/U

kHz	(Ω)
90 to 170	5,000
170+ to 250	5,500

CR-38A/U

MHz	(Ω)
16 to 50	110,000
50+ to 80	100,000
80+ to 100	90,000

CR-42A/U

kHz	(Ω)
190 to 225	3,700
225+ to 275	4,200
275+ to 325	4,600
325+ to 375	4,900
375+ to 425	5,300
425+ to 475	5,600
475+ to 500	6,000

CR-50A/U

kHz	(Ω)
16 to 30	100,000
30+ to 50	90,000
50+ to 70	80,000
70+ to 90	70,000
90+ to 100	60,000

CR-52A/U	40 Ω
CR-55/U	40 Ω
CR-56A/U	60 Ω

CR-59A/U

MHz	(Ω)
50 to 500	50
100+ to 125	60

CR-60A/U

MHz	(Ω)
5 to 7	50
7+ to 10	30
10+ to 15	25
15+ to 20	20

CR-61/U	40 Ω

225+ to 275	6,000
275+ to 325	6,500
325+ to 375	7,000
375+ to 425	7,500
425+ to 475	8,000
475+ to 500	8,500
500+ to 555	5,000

TABLE 5-3. (Continued)

CR-64/U

MHz	(Ω)
2.9 to 3.75	180
3.75+ to 4.75	120
4.75+ to 6	75
6+ to 7	50
7+ to 10	30
10+ to 20	25

CR-65/U 40 Ω

CR-66/U

MHz	(Ω)
3 to 4	60
4+ to 5	50
5+ to 7	45
7+ to 10	35
10+ to 20	25

CR-67/U 40 Ω

CR-68/U

MHz	(Ω)
3 to 4	40
4+ to 5	35
5+ to 6	30
6+ to 7	28

CR-74/U 50 Ω

CR-75/U 40 Ω

2.2 to 3.00	360
3.0+ to 3.75	180
3.75+ to 4.75	120
4.75+ to 6	75
6+ to 7	50
7+ to 10	30
10+ to 20	25

CR-79/U

MHz	(Ω)
2.9 to 7.0	50
7+ to 10	30
10+ to 15	25
15+ to 20	20

CR-80/U
Same as CR-54A/U

CR-103/U 40 Ω

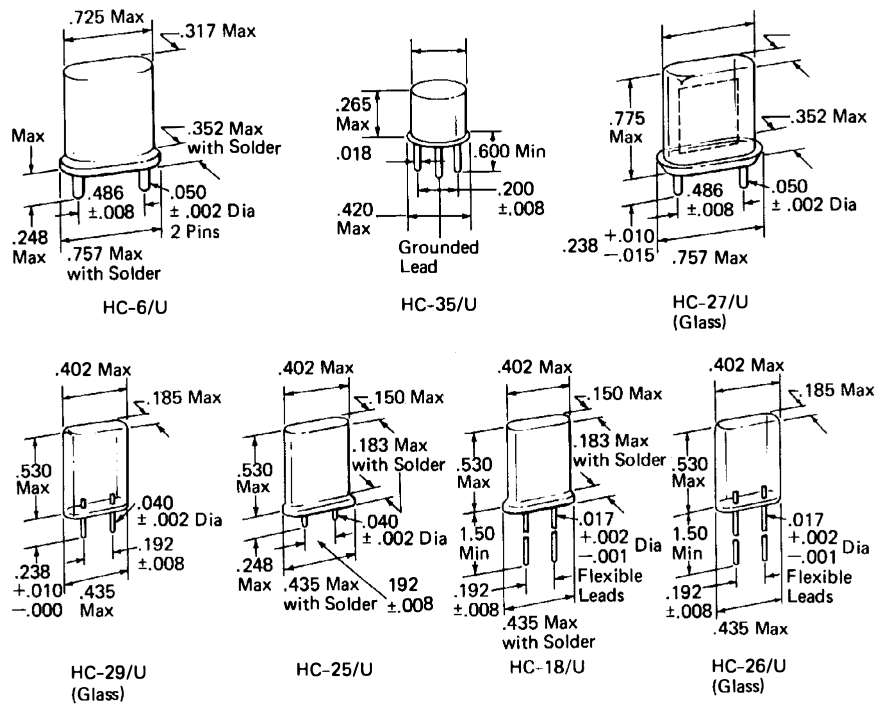


Figure 5-10. Crystal holder dimensions.

The dimensions of the more commonly used crystal holders are given in Figure 5-10. For additional information the reader may consult the latest version of MIL-C-3098. In some applications only a few parameters will be different from a standard crystal, and here the military specifications are a good basic guideline to use in writing the specification. An example of a crystal specification which refers to several MIL standards is given in Appendix L.

5.13. SPECIFICATIONS AND STANDARDS

A large number of specifications and standards are available which present very useful information on crystals and methods of measurement. Among these are IEEE Standards, EIA Standards, IEC Standards, and MIL Standards. A good listing of these is presented in reference 50, p. 494 along with information on where they may be obtained.