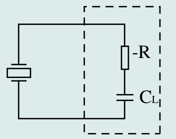
CHARACTERISTICS OF FREQUENCY VS. LOAD CAPACITANCE

In the oscillation circuit allowing a crystal unit to be operated in terms of inductive impedance, the negative resistance and impedance are equivalently given as shown by Fig. 7.

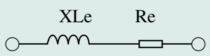


Oscillation Circuit Side

Fig. 7 Relationship between a Crystal Units and the Oscillation Circuit

The capacitance C_1 is an effective value measured from both terminals of a crystal unit to the oscillation circuit. It is generally called load capacitance and indicates the negative resistance on the –R circuit.
In such a circuit, a crystal unit operates in such a way that inductive reactance X_e and resistance R_e are connected in series as shown in Fig. 8. The oscillation frequency is given by the following equation:

$$X_e = \frac{1}{2\pi f_e C_L}$$



Ze = Re + jXe

Fig. 8 Operating State of Crystal Units

The condition for the circuit to oscillate is $|R_e| < |-R|$; where R_e is the series resonance resistance of the crystal unit and load capacitance C_L, which is called load resonance resistance.
We recommend making the circuit load capacitance (–R) large enough against R_e so as to assure oscillation taking into consideration the increase in equivalent resistance at low drive level.
Because oscillation frequencies are determined by electrical equivalent constants of a crystal unit and oscillation-circuit load capacitance (Operating temperature and drive level are to be specified.) irrespective of the composition of an oscillation circuit, please specify the load capacitance of the oscillation circuit prior to the production or use of a crystal unit.

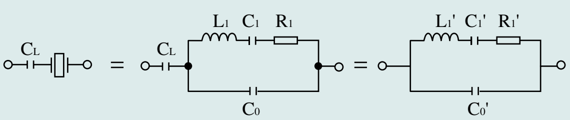


Fig. 9 Electrical Equivalent Circuit with Load Capacitance

Fig. 9 shows an equivalent circuit in the case of connecting C_L (load capacitance) with a crystal unit in series. The equivalent constants are calculated as follows:

$$L_1' = L_1\left(1 + \frac{C_0}{C_L}\right)^2 \qquad R_1' = R_1\left(1 + \frac{C_0}{C_L}\right)^2$$

$$C_1' = \frac{C_1 C_L^2}{(C_0+C_1+C_L)\,(C_0+C_L)} \qquad C_0' = \frac{C_0 C_L}{C_0+C_L}$$

R_e is called load resonance resistance.
The oscillation frequency further increases when C_L is connected, and it approximates the value obtained in the following equation with the amount of change as Δf and the serial resonance frequency as f_0.

$$\frac{\Delta f}{f_0} = \frac{C_1}{2\,(C_0 + C_L)}$$

Using the capacity ratio (C_0/C_1), the above equation is expressed as follows:
If we rearrange the right side, it becomes the following equation:

$$\frac{\Delta f}{f_0} = \frac{1}{2\,\frac{C_0}{C_1}\left(1 + \frac{C_L}{C_0}\right)}$$

C_0/C_1 is called capacitance ratio, which is the barometer of the change in oscillation frequency caused by the change in load capacitance. Fig. 10 shows load capacitance vs. frequency-change rate characteristics for AT-cut fundamental crystal wafers and 3rd overtone crystal wafers.
As shown by Fig. 10, the use of a fundamental-mode crystal wafer at lower load capacitance is required to get wider rate of change with the change of load capacitance.

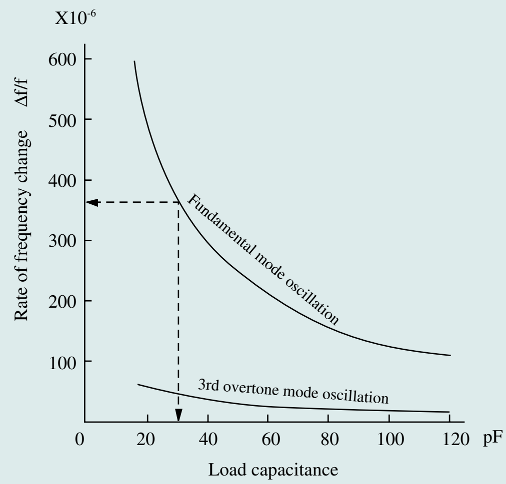


Fig. 10 Load Capacitance vs. Frequency Change