Chapter 2
Quartz and MEM Resonators

2.1 The Quartz Resonator

As illustrated by Fig. 2.1(a), a quartz resonator is essentially a capacitor, the dielectric of which is silicon dioxide (SiO₂), the same chemical compound as used in integrated circuits. However, instead of being a glass, it is a monocrystal, a quartz crystal, which exhibits piezoelectric properties. Therefore, a part of the electrical energy stored in the capacitor is converted into mechanical energy.

Figure 2.1 Quartz crystal resonator: (a) Schematic structure; (b) symbol.

Whatever the shape of the piece of quartz, it has some mass and some elasticity; it can therefore oscillate mechanically. Unlike simple LC electrical resonators, mechanical resonators always possess several resonance frequencies, corresponding to different possible modes of oscillation (eigenmodes).
Now, if an AC voltage is applied to the capacitor at a frequency close to that of a possible mode, it can possibly excite this mode and drive the quartz resonator into mechanical oscillation.

In addition to its piezoelectric properties, quartz has the advantage of being an excellent mechanical material, with very small internal friction. It has therefore a very high intrinsic quality factor, of the order of $10^6$.

The resonant frequency depends essentially on the shape and the dimensions of the piece of quartz. Possible frequencies range from 1 kHz for large cantilever resonators to hundreds of MHz for very thin thickness-mode resonators.

The exact frequency and its variation with temperature depend on the orientation with respect to the 3 crystal axes. By choosing the optimum mode with an optimum orientation, the linear and quadratic components of the variation of the frequency with temperature can be cancelled, leaving at best a residual dependency of about $10^{-6}$ from -20 to +80°C.

### 2.2 Equivalent Circuit

The equivalent circuit of a quartz resonator is shown in Fig. 2.2(a). Although the intrinsic device is a dipole, it is very important in some circuits to model it as a 3-point component, in order to separate the electrical capacitor $C_{12}$ from the parasitic capacitances to the packaging case $C_{10}$ and $C_{20}$.

If the device is only considered as a dipole, with node 0 floating, then the lumped electrical capacitance is

$$C_0 \triangleq C_{12} + \frac{C_{10}C_{20}}{C_{10} + C_{20}}. \quad (2.1)$$

Each possible mode of oscillation $i$ of the resonator corresponds to a *motional impedance* $Z_{m,i}$, formed by the series resonant circuit $R_{m,i}L_{m,i}C_{m,i}$. The motional inductance $L_m$ is proportional to the mass of the mechanical resonator. The motional capacitance $C_m$ is proportional to the inverse of its stiffness. The motional resistance $R_m$ represents the mechanical losses.

The resonant angular frequency of mode $i$ is given by

$$\omega_{m,i} = \frac{1}{\sqrt{L_{m,i}C_{m,i}}}, \quad (2.2)$$

and its quality factor by

$$Q_i = \frac{1}{\omega_{m,i}R_{m,i}C_{m,i}} = \frac{\omega_{m,i}L_{m,i}}{R_{m,i}} = \frac{1}{R_{m,i}} \sqrt{\frac{L_{m,i}}{C_{m,i}}}. \quad (2.3)$$