© 2014 IJIRT | Volume 1 Issue 6 | ISSN : 2349-6002

Crystal Oscillator

Kuldeep Yadav,Atul Kumar,Kunal Taneja

Student, Department of ECE, Dronacharya College of Engineering, Gurgaon, India

Abstract: **A semiconductor device capable of generating a signal of known frequency & amplitude is called an oscillator. It is basic element of all ac signal sources. Oscillator is a generator of energy & hence acts as energy converter (electrical to electrical). The input to oscillator is DC supply or noise. In this paper we will discuss about crystal oscillator which is used to generate constant frequency by using a crystal of a particular substance (quartz). It is capable of generating two fix peak frequencies that is series resonant frequency (fs) & parallel resonant frequency (fp).**

I .INTRODUCTION

In crystal oscillators, the electrical resonant circuit is replaced by a mechanical vibrating crystal. The crystal usually quartz has a high degree of stability in holding constant at whatever frequency the crystal is originally cut to operate. The crystal oscillators are used whenever great stability is needed as in communication transmitters & receivers, digital clocks etc. Quartz crystal resonators are widely used in frequency control applications because of their unequaled combination of high *Q*, stability, and small size.

Piezoelectric Effect

A quartz crystal exhibits a very important known as piezoelectric effect. When a potential difference is applied across opposite faces of a quartz crystal, mechanical deformation takes place. If the frequency of the potential is appropriate, the crystal will vibrate and indeed resonate.

Different Parameters of crystal oscillator

The resonant frequency, *Q*, and temperature coefficient depend on the physical size and the orientation of faces relative to the crystal axis. The resonators are classified according to "cut," which is the orientation of the quartz wafer with respect to the crystallographic axes of the material. Examples are AT-, BT-, CT-, DT-, and SC- cuts, but they can also be specified by orientation, for example, a +5° X-cut. Although a large number of different cuts have been developed, some are used only at low frequencies others are used in applications other than frequency control and selection, and still others have been made obsolete by later developments. At frequencies above approximately 1MHz, AT- and SC-cuts are primarily used. For most applications, the two-terminal equivalent circuit consisting of the static capacitance *C*0 in parallel with the dynamic or motional branch, *L*1-*C*1-*R*1, issued as shown in Figure (1), in which fs is called the motional resonance frequency given by:

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

For some applications, harmonics, or overtones, are used, in which case the model has more branches in parallel, one of each harmonic.

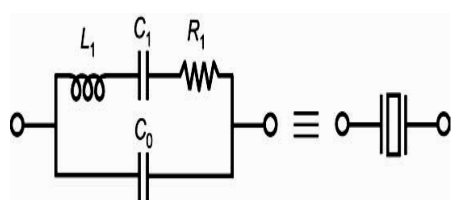

Fig. (1) Two-terminal equivalent circuit of a crystal.

For oscillator applications, the figure of merit, *M*, is a useful indicator that is defined as:

$$M = \frac{1}{2\pi f_s C_0 R_1}$$

For *M* less than 2, the crystal reactance is never inductive at any frequency, and an additional inductor would be required to form an oscillator. In general, a larger *M* results in a more useful resonator. In a crystal resonator, the quality factor of a reactive component is the reactance$X1$ of the motional inductance or capacitance divided by the motional resistance $R1$

$$Q = \frac{|X_1|}{R_1} = \frac{2\pi f_s L_1}{R_1} = \frac{1}{2\pi f_s C_1 R_1}$$

where the time constant $t = C1R1$ depends on the mode of vibration and on the angles of cut. For AT-cut c-mode, t = 10 fs, for SC-cut c-mode, t = 9.9 fs, and for BT-cut b-mode, t = 4.9 fs [33]. Practically, quartz crystal resonators can have an unloaded *Q* up to more than a million and a temperature drift of less than 0.001%over the expected temperature range. The maximum *Q* which can be obtained is determined by several additive loss factors, the first of which is the intrinsic *Q* of quartz, which is approximately 16×106 divided by the frequency in megahertz for the AT-cut and slightly higher for the SC-cut. Other factors that further limit *Q* are mounting loss, atmospheric loading (for non evacuated crystal units), and the surface finish of the blank. Mounting loss depends upon the degree of trapping produced by the electrode and the plate diameter. The highest *Q* is obtained by using mechanically or chemically polished blanks with an adequately large diameter and an evacuated enclosure. In the vicinity of an isolated mode of vibration, the impedance of a crystal resonator is a pure resistance at two frequencies. The lower of these is the *resonance frequency fr* (close to, but not exactly equal to the series self resonance frequency *fs*
due to the presence of *C*0); the greater is the anti resonance frequency *fa*. In the lossless case, the frequency of anti resonance is equal to the parallel resonance frequency *fp* approximately equal to

$$f_p = f_s \left(1 + \frac{C_1}{2C_0}\right) = f_s \left(1 + \frac{1}{2M}\right)$$

Table: Typical Specifications and Parameters for Precision SC-Cut Crystal Resonators:

Parameter	Specifications	Comments
Frequency	5-160Mhz	Harmonic mode for higher frequencies
Frequency load capacitance	About 20 pF	Typically, series capacitor for higher frequencies
Frequency adjustment tolerance	1.5-8 ppm	Generally, higher for higher frequency
Q	80 K -2.5 M	Higher Q for lower frequency
R1	35-120 W	
C1 (fF)	0.13-0.5 fF	
C0 (pF)	3.2-4.7 pF	

For resonators with a large figure of merit (*M* > 5), *fr* can be approximated by

$$f_r = f_s \left(1 + \frac{1}{2QM}\right)$$

.

The impedance of the crystal can be plotted as in Figure 2 . It can be seen that the crystal is inductive in the region between *ws* (very close to *ws*) and *wp* and this will be a very narrow frequency range. If the crystal is used to replace an inductor in an oscillator circuit, for example, as shown in Figure 3(a), then oscillations will only occur in the frequency range where the crystal is actually inductive. While the crystal behaves like an inductor at the oscillating frequency, unlike a real inductor, no dc current flows through the crystal, because at dc, it is like a capacitor. Figure 3(b) can be derived by assuming the positive input in Figure 3(a) is grounded. This is the familiar Pearce amplifier, a subset of the Colpitts oscillator and is a very common way to construct a crystal oscillator. Figure (4) shows two ways to realize this Colpitts based crystal oscillator: one with a bipolar transistor and one with MOS transistors. As to the phase noise, besides the thermal noise with its floor around - 160 dBc/Hz, 1/*f* noise exists in crystal oscillators. The total noise power spectral density of a crystal oscillator can be determined with Leeson's formula

$$PN = \frac{|N_{OUT}(s)|^2}{2P_S} = \left(\frac{|H_1|\omega_0}{(2Q\Delta\omega)}\right)^2 \frac{|N_{IN}(s)|^2}{2P_S}$$

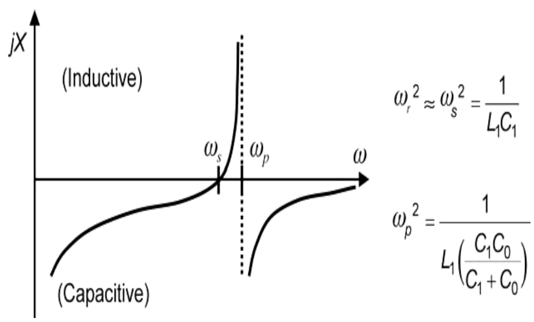

Fig (2) Impedance of crystal circuit model.

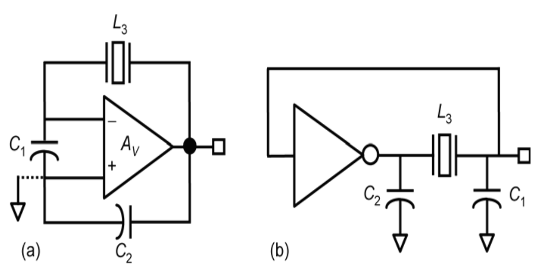

Fig (3) (a, b) Crystal oscillator diagrams using general amplifiers.

An empirical formula to describe crystal oscillator phase noise is given by

$$PN(\Delta f) = 10^{-16\pm1} \times \left(1 + \left(\frac{f_0}{2\Delta f \times Q_L}\right)^2\right)\left(1 + \frac{f_c}{|\Delta f|}\right)$$

where f0 is the oscillator output frequency, Df is the offset frequency, and fc is the corner frequency between 1/f and thermal noise regions, which is normally in the range 1 to 10 kHz. QL is the loaded Q of the resonator. Since the Q for a crystal resonator is very large .The reference noise contributes only to the very close-in noise and it quickly reaches the thermal noise floor at an offset frequency around fc. Figure (5) demonstrates an example of a phase noise spectral density of a crystal reference source. In summary, because of its effective high Q (up to hundreds of thousands) and relatively low frequency (less than a few hundred megahertz), crystal oscillators will have significantly lower phase noise and lower power dissipation than LC or ring oscillators.

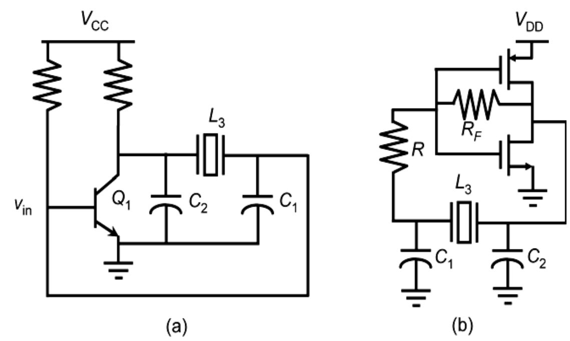

Fig (4) (a, b) Two implementations of crystal oscillators

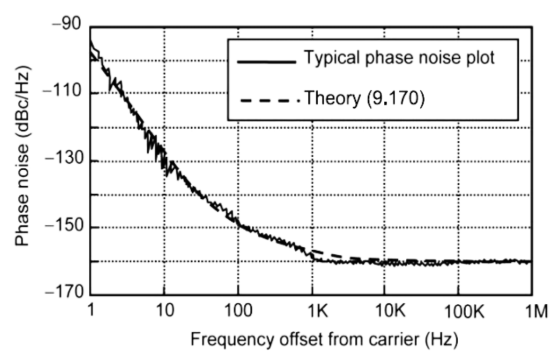

Fig (5) Phase noise of a crystal reference source. Theory with *f0*= 10 MHz, *QL* = 120k, *fc* = 1Khz

However, typically the purpose of a crystal oscillator is to achieve ultra-high stability, of the order of parts per million. To accomplish this, a complete commercial crystal oscillator will also have the means to do temperature compensation and amplitude control, and this is where a lot of the design effort would be directed.

References

1) Kurokawa, K., “Some Basic Characteristics of Broadband Negative Resistance Oscillator Circuits,” The Bell System Technical Journal, July 1969.
2) Gonzalez, G., Microwave Transistor Amplifiers Analysis and Design, 2nd ed., Upper Saddle River, NJ: Prentice-Hall, 1997.
3) Voinigescu, S. P., D. Marchesan, and M. A. Copeland, “A Family of Monolithic Inductor-Varactor SiGe-HBT VCOs for 20 GHz to 30 GHz LMDS and Fiber-Optic Receiver Applications,” Proc. RFIC Symposium, June 2000, pp. 173–176.
4) Dauphinee, L., M. Copeland, and P. Schvan, “A Balanced 1.5 GHz Voltage Controlled Oscillator with an Integrated LC Resonator,” International Solid-State Circuits Conference, 1997, pp. 390–391.
5) Zannoth, M., et al., “A Fully Integrated VCO at 2 GHz,” IEEE J. Solid-State Circuits, Vol. 33, December 1998, pp. 1987–1991.
6) Hegazi, E., H. Sjoland, and A. Abidi, “A Filtering Technique to Lower LC Oscillator Phase Noise,” IEEE J. Solid-State Circuits, Vol. 36, December 2001, pp. 1921–1930.
7) Razavi, B., “A Study of Phase Noise in CMOS Oscillators,” IEEE J. Solid-State Circuits, Vol. 31, March 1996, pp. 331–343.
8) Leeson, D. B., “A Simple Model of Feedback Oscillator Noise Spectrum,” Proc. of the February 1966, pp. 329–330.