German Jordanian University

School of Electrical Engineering and IT

Department of Electrical and Communication Engineering

Communication Circuit Lab Manual

Experiment 3

Crystal Oscillator

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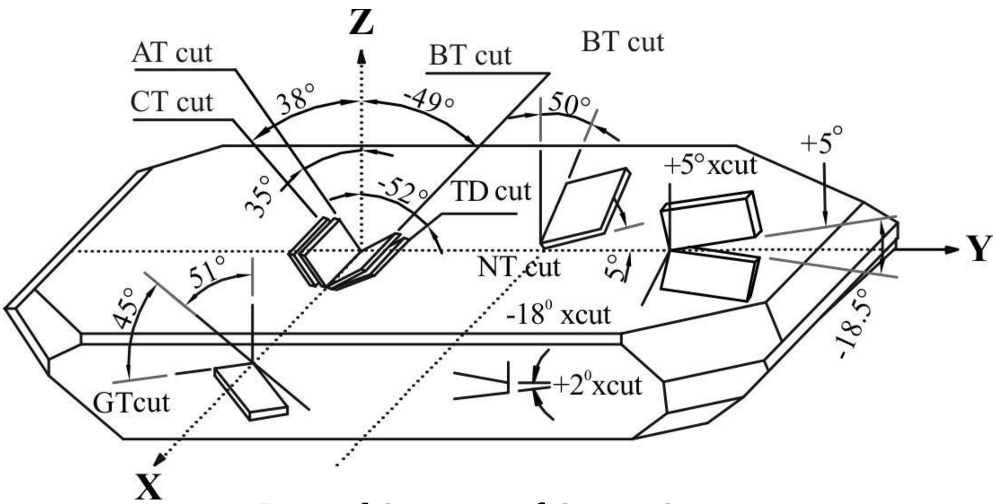
Introduction

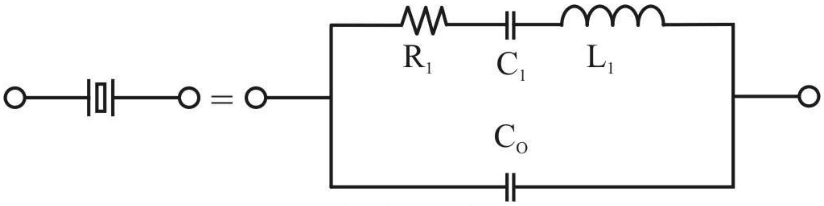
Quartz crystal units serve as the controlling element of oscillator circuits by conversion of mechanical vibrations to electrical current at a specific frequency. This is accomplished by means of the "Piezoelectric" effect. Piezoelectricity is electricity created by pressure. In a piezoelectric material, the application of mechanical pressure along an axis will result in the creation of an electrical charge along an axis at right angles to the first. In some materials, the obverse piezoelectric effect is found, which means that the imposition of an electric field on the ends of an axis will result in a mechanical deflection along an axis at right angles to the first. Quartz is uniquely suited, in terms of mechanical, electrical and chemical properties, for the manufacture of frequency control devices. Quartz crystal units which oscillate within certain frequency and temperature ranges have been developed over the years. Figure 1 shows the location of specific elements within a quartz stone.



Internal Structure of Quartz Stone
Figure 1

Equivalent Circuit:

The equivalent circuit, shown in figure 2, is an electrical depiction of the quartz crystal unit when operating at a frequency of natural resonance. The C_O, or shunt capacitance, represents the capacitance of the crystal electrodes plus the capacitance of the holder and leads. R_1, C_1, and L_1 compose the "motional arm" of the crystal and are referred to as the motional parameters. The motional inductance (L_1), represents the vibrating mass of the crystal unit. The motional capacitance (C_1), represents the elasticity of the quartz and the resistance (R_1), represents bulk losses occurring within the quartz.

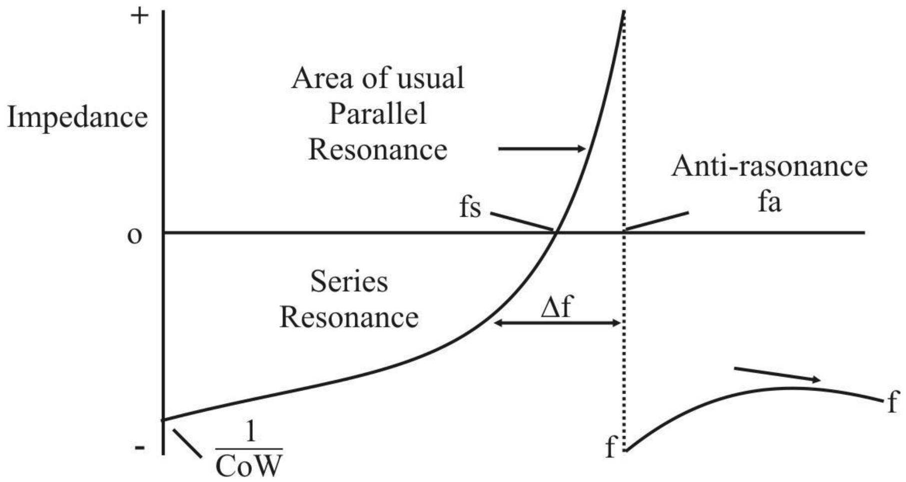


Equivalent Circuit
Figure 2

Impedance/Reactance

Curve:

A crystal has two frequencies of zero phase, as illustrated in figure 2 The first, or lower of the two, is the Series Resonant Frequency, denoted as (f_S). At this point, the crystal appears resistive in the circuit, impedance is at a minimum and current flow is maximum. As the frequency is increased beyond the point of series resonance, the crystal appears inductive in the circuit. When the reactances of the motional inductance and shunt capacitance cancel, the crystal is at the Frequency of Anti-resonance, denoted as (f_a). At this point, impedance is maximized and current flow is minimized.



Impedance / Reactance

Figure 3

Quality Factor (Q):

The ‘Q’ value of a crystal unit is a measure of the unit’s relative quality, or efficiency of oscillation. The maximum attainable stability of a crystal unit is dependent on the ‘Q’ value. In figure above, the separation between the series and parallel frequencies is called the bandwidth. The smaller the bandwidth, the higher the ‘Q’ value, and the steeper the slope of the reactance. Changes in the reactance of external circuit components have less effect (less "pullability") on a high ‘Q’ crystal, therefore such a part is more stable.

Trim Sensitivity:

Trim sensitivity is a measure of the incremental fractional frequency change for an incremental change in the value of the load capacitance. Trim sensitivity (S) is expressed in terms of parts per million (PPM)/pF and is calculated by the following equation:

$$S = \frac{C_1 \times 10^6}{2 \times C_t^2}$$

Where (C_t) is the sum of C_0 and C_L.

Load Capacitance:

This refers to capacitance external to the crystal, contained within the feedback loop of the oscillator circuit. If the application requires a 'parallel' resonant crystal, the value of load capacitance must be specified. If the application requires a 'series' resonant crystal, load capacitance is not a factor and need not be specified. Load capacitance is the amount of capacitance measured or computed across the crystal terminals on the circuit.

Frequency Tolerance:

Frequency tolerance refers to the allowable deviation from nominal, in parts per million (PPM), at a specific temperature, usually +25ƒC.

Frequency Stability:

Frequency stability refers to the allowable deviation, in parts per million (PPM), over a specified temperature range. Deviation is referenced to the measured frequency at +25ƒC.

Aging:

Aging refers to the cumulative change in frequency experienced by a crystal unit over time. Factors affecting aging are excessive drive level, various thermal effects, wire fatigue and frictional wear. Circuit design incorporating low operating ambients and minimum drive level will reduce the aging rate.

Pullability:

Pullability refers to the change in frequency of a crystal unit, either from the natural resonant frequency (F_r) to a load resonant frequency (F_L), or from one load resonant frequency to another. The amount of pullability exhibited by a given crystal unit at a given value of load capacitance is a function of the shunt capacitance (C_o) and the motional capacitance (C_1) of the crystal unit.

Oscillator Theory of Operation:

Oscillator:

Oscillators are circuits that produce periodic waveforms without input other than perhaps a trigger. They generally use some form of active device, lamp, or crystal, surrounded by passive devices such as resistors, capacitors, and inductors, to generate the output.

There are two main classes of oscillator: relaxation and sinusoidal. Relaxation oscillators generate the triangular, saw tooth and other non sinusoidal waveforms. Sinusoidal oscillators consist of amplifiers with external components used to generate oscillation, or crystals that internally generate the oscillation. Sine wave oscillators are used as references or test waveforms by many circuits.

But still the question arises; what is the need of oscillator? And where do we use them? Lets go to the start again .First, what is the oscillator? It is a device that works based on oscillation. Well, what is that? It is the movement of two things that work on the energy flow they receive. An oscillating fan, clock and transmitters work by working on the energy. In the example of a clock, pendulum, the oscillator keeps time for us accurately based on the principles of oscillation. This is a simple type of oscillator.

Oscillators are present in most computers, clocks of all sorts, as well as in watches, metal detectors, radios of all powers and uses, as well as many mechanical devices. The oscillator is one of the most important instruments in our life because it helps us to tell time accurately. The work of oscillator is not stopped here, but they are used in a variety of ways throughout our lives. For example, you will find them located not only in clocks but also in electronic devices of all types. For example, audio frequency equipment has them and wireless receivers and transmitters as well. You will find them in a sensitive amplifier or you will find them in signals that are used and sent out. Their uses are many and far between.

Crystal controlled oscillators may be considered as consisting of an amplifier and a feedback network that selects a part of the amplifier output and returns it to the amplifier input. A generalized depiction of such a circuit is shown below.

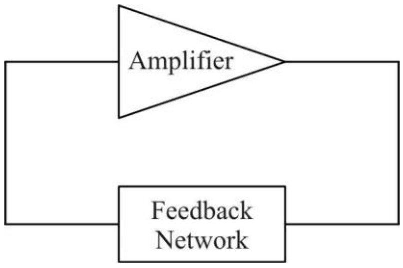


Figure 4

In order for an oscillator circuit to operate, two conditions must be met:

1. The loop power gain must be equal to unity.

2. The loop phase shift must be equal to 0, 2π, 4π, etc. radians.

- AυB 1
- AυB=1/0^0 or 360^0

The type of wave form generated by an oscillator depends on one of the components used in circuits and hence the waveform generated can be any thing from Sine, Square, or triangular. The frequency of the oscillation is also determined by the component in feedback circuit

The power fed back to the input of the amplifier must be adequate to supply the oscillator output, the amplifier input, and to overcome circuit losses.

The exact frequency at which an oscillator will operate is dependent on the loop phase angle shifts within the oscillator circuit. Any net change in phase angle will result in a change in the output frequency. As the usual goal of an oscillator is to provide a frequency that is essentially independent of variables, some means of minimizing the net phase shift must be employed. Perhaps the best, and certainly the most common means of minimizing the net phase shift is to use a quartz crystal unit in the feedback loop.

The impedance of a quartz crystal changes so dramatically with changes in the applied frequency that all other circuit components can be considered as being of essentially constant reactance. Therefore, when a crystal unit is used in the feedback loop of an oscillator, the frequency of the crystal unit will adjust itself so that the crystal unit presents a reactance which satisfies the loop phase requirements. A depiction of the reactance v/s frequency of a quartz crystal unit is shown below.

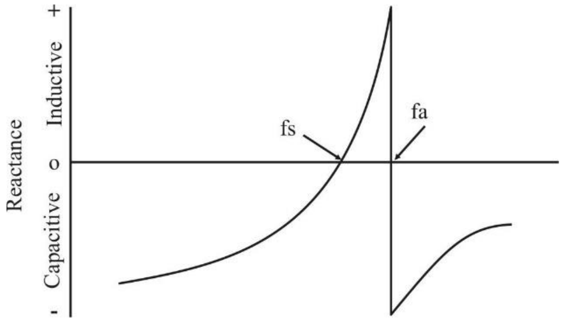


Figure 5

As is apparent from figure 5, a quartz crystal unit has two frequencies of zero phase. The first, or lower of the two, is the series resonant frequency, usually abbreviated as F_S. The second, or higher of the two frequencies of zero phase is the parallel, or anti-resonant frequency, usually abbreviated as F_a. Both the series and parallel resonant frequencies appear resistive in an oscillator circuit. At the series resonant point, the resistance is minimal and the current flow is maximal.

At the parallel point, the resistance is maximal and the current flow is minimal. Therefore, the parallel resonant frequency, F_a, should never be used as the controlling frequency of an oscillator circuit.

A quartz crystal unit can be made to oscillate at any point along the line between the series and parallel resonant points by the inclusion of reactive components (usually capacitors) in the feedback loop of the oscillator circuit. In such a case, the frequency of oscillation will be higher than the series resonant frequency but lower than the parallel resonant frequency. Because of the fact that the frequency resulting from the addition of capacitance is higher than the series resonant frequency, it is usually called the parallel frequency, though it is lower than the true parallel frequency.

Just as there are two frequencies of zero phase associated with a quartz crystal unit, there are two primary oscillator circuits. These circuits are generally described by the type of crystal unit to be used, namely series or parallel.

Series circuit:

A series resonant oscillator circuit uses a crystal which is designed to operate at its natural series resonant frequency. In such a circuit, there will be no capacitors in the feedback loop. Series resonant oscillator circuits are used primarily because of their minimal component count. These circuits may, however, provide feedback paths other than through the crystal unit. Therefore, in the event of crystal failure, such a circuit may continue to oscillate at some arbitrary frequency.

Parallel Circuit:

A parallel resonant oscillator circuit uses a crystal unit which is designed to operate with a specified value of load capacitance. This will result in a crystal frequency which is higher than the series resonant frequency but lower than the true parallel resonant frequency. These circuits do not provide paths other than crystal unit to complete the feedback loop. In the event of crystal unit failure, the circuit will not continue to oscillate.

A variety of crystal oscillator circuits are possible. If in the basic configuration of a feedback oscillator a tuned LC combination at output, a quartz crystal in feedback network and a FET as amplifier are used the circuit becomes crystal version of the tuned-drain tuned-gate oscillator. The crystal used here has the oscillation frequency of 1 MHz. From the theory given in preceding sections, the crystal reactance, as well as that of LC Tank circuit must be inductive in order the loop gain to be greater than unity and hence to start the oscillations in circuit. The resonance frequency of LC Tank circuit must match with that of the quartz crystal for sinusoidal oscillations at output.

Resonance Frequency of Tank circuit is given by

$$f_r = \frac{1}{2\pi\sqrt{LC}}$$

$$A_{min} = \frac{C_2}{C_1}$$

$$B = \frac{C_1}{C_2}$$

When accuracy and stability of the oscillation frequency are important, a quartz crystal oscillator is used. A Typical crystal oscillator is shown in figure 6.

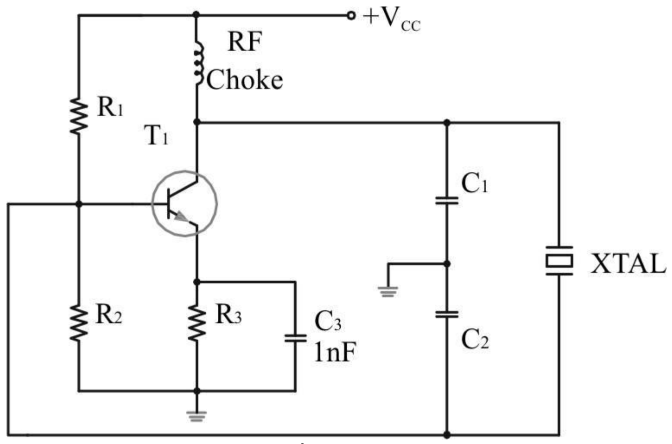


Figure 6

The feed back signal comes from a capacitive tap; as we know, a crystal acts like a large inductor in series with a small capacitor. Due to this, the resonant frequency is almost totally unaffected by transistor and stray capacitance.

AB114

Experiment

Objective:

Study of the Transistorized Crystal Oscillator (1MHz)

Equipments Needed:

- Analog board, **AB114**
- DC Power Supply 12V from external source.
- Oscilloscope.
- 2mm patch cords.

Circuit diagram:

The circuit to study the Crystal Oscillator is shown below:

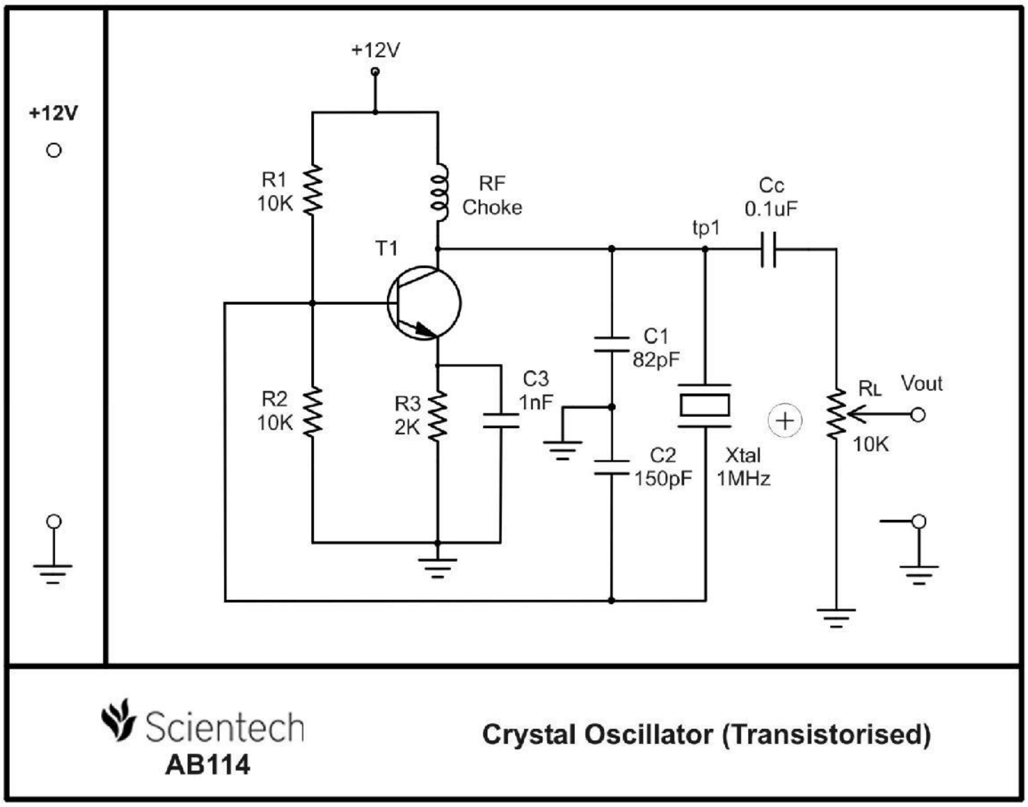


Figure 7

Procedure:

1. Connect +12V variable DC power supplies at the indicated position from external source or **Scientech 2612 Analog Lab.**

· Connect Oscilloscope CHI at the output socket 'V_{out} '.

· Switch 'On' the Power Supply.

· Observe output on Oscilloscope, if there is a sinusoidal wave present than note down amplitude and frequency of the same in table given below.

· If the output is not the proper sine wave rotate the pot given for Load resistance.

· Compare the output frequency with that of quartz crystal 'XTAL' which is 1 MHz.

· Also observe the output at test point TP1 and DC output occurring at the test point.

Observation Table:

Amplitude of Output V_{OUT}	**Frequency of Output V_{OUT}**	**Resonance Frequency of Tank circuit (Measured)**	**S. No.**

Table 1

Calculation

$$f_r = \frac{1}{2\pi\sqrt{LC}}$$

Oscillations at output present only when the resonance frequency of Tank circuit matches the fundamental frequency of crystal 'XTAL' which is 1 MHz