

## Crystal oscillator

$$Q = \frac{\omega L}{R} \quad Q = \frac{1}{\omega CR}$$

16/4/20

→ Limitations in RC & LC oscillators:-

Oscillator frequency  $f_0$  may change/drift due to:

- 1) change in temperature
- 2) change in power supply voltage
- 3) change in component values

• Crystal oscillator — used in applications where very high level of frequency stability is required.

- have very high Quality factor ( $Q > 10^4$ )
- used for generating stable clock frequencies  
100kHz - 100MHz

→ One difficulty of crystal oscillator is its non-tunable or fixed frequency oscillator.

→ Crystals are naturally available in the forms of:-

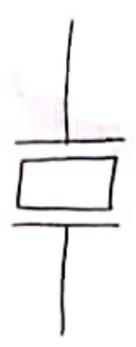
- 1) Rochelle Salt (~ mechanically weak)  
(~ max vibrations)
- 2) Tourmaline (~ mechanically strong)  
(~ least vibration)
- 3) Quartz (~ most preferred)  
(~ easily available)

~ Quartz crystal: Its natural frequency is stable with (1) temperature (2) time

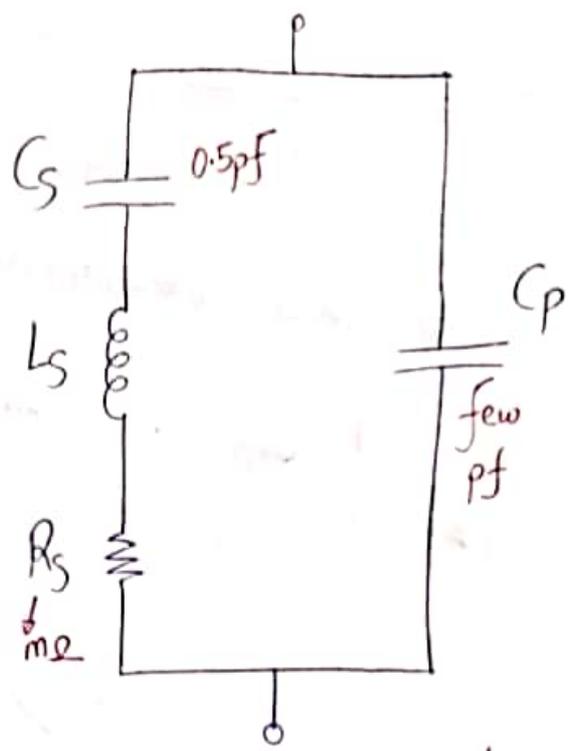
→ Quartz crystal works on the principle of inverse Piezo-electric effect.  
→ It exhibits electro-mechanical resonance.

→ Inverse piezo-electric effect:

When external ac voltage (E-field) is applied to piezo-electric material (Quartz crystal), the crystal starts vibrating at same frequency.



Quartz crystal



Electrical equivalent ckt of crystal

→ Quality factor (Q) is high when R<sub>s</sub> is small

C<sub>s</sub> - motional capacitance

defines

Elasticity, Area of plates, thickness of Quartz

L<sub>s</sub> - motional inductance

defines

mechanical mass of Quartz when it is vibrating

R<sub>s</sub> - Series resistance

defines

Resistive loss

C<sub>p</sub> - shunt capacitance

defines

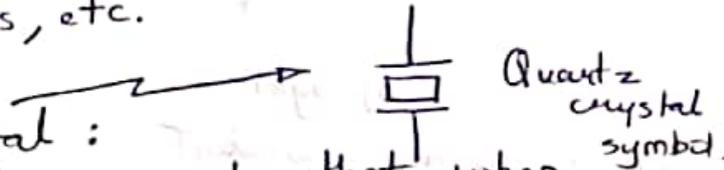
capacitance due to mechanical plates

## \* Crystal oscillator :

- A crystal oscillator is basically a tuned-circuit oscillator using a piezo-electric crystal as a resonant tank circuit.
- The crystal is usually made of quartz material which provides a high degree of frequency stability and accuracy.
- Crystal oscillators are used whenever greater frequency stability is required, such as communication transmitters and receivers, digital watches and clocks, etc.

### • Characteristics of a Quartz crystal :

- A quartz crystal exhibits the property that when mechanical force is applied across one set of its plates, (of quartz crystal), a difference of potential develops across the opposite plate. This property of a crystal is called the "piezo-electric effect". (This property is ever conversely true)
- When ac voltage is applied to a crystal, it starts vibrating. These vibrations have a natural resonant frequency dependent on the crystal.
- The amount of vibration depend upon the frequency of the applied voltage
- By changing the frequency, we can find a frequency at which the crystal vibrations reaches its maximum value. The frequency, at which it happens, is called "resonant frequency of the crystal."
- The quartz crystals are available with resonant frequencies from 15KHz to 10MHz.



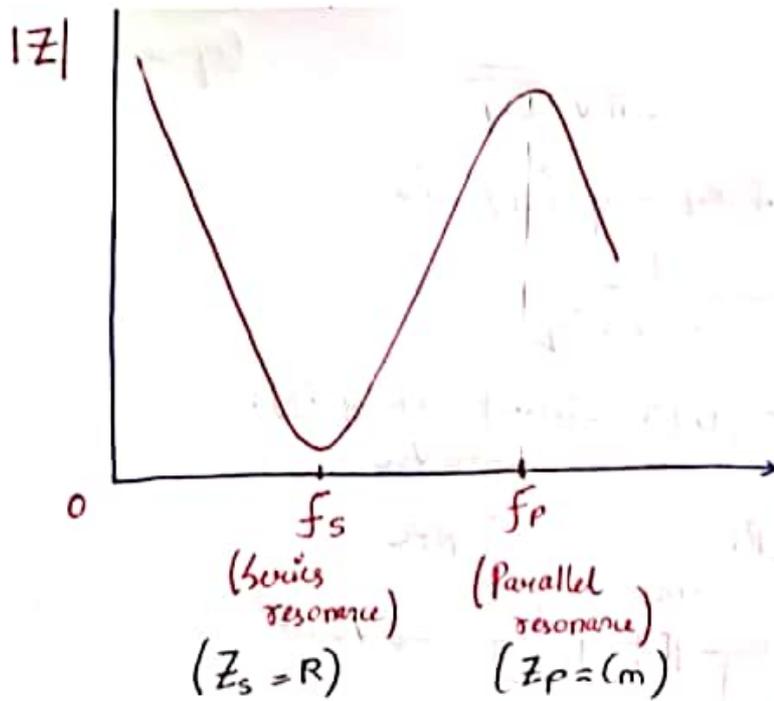


fig 2: Crystal impedance versus frequency.

One resonant condition occurs when the reactances of the series RLC leg are equal and opposite (Refer ch 1. b) (and fig 2) For this condition, series-resonant impedance ( $Z_s$ ) is very low (equal to R) i.e.  $Z_s = R$

Other resonant condition occurs at a higher frequency when the reactance of series (R-L-C) resonant leg equals the reactance of capacitor ( $C_m$ ). This is a parallel resonance condition of the crystal. i.e. ( $Z_p = \infty$ ). At this frequency, the crystal offers a very high impedance to the external circuit.

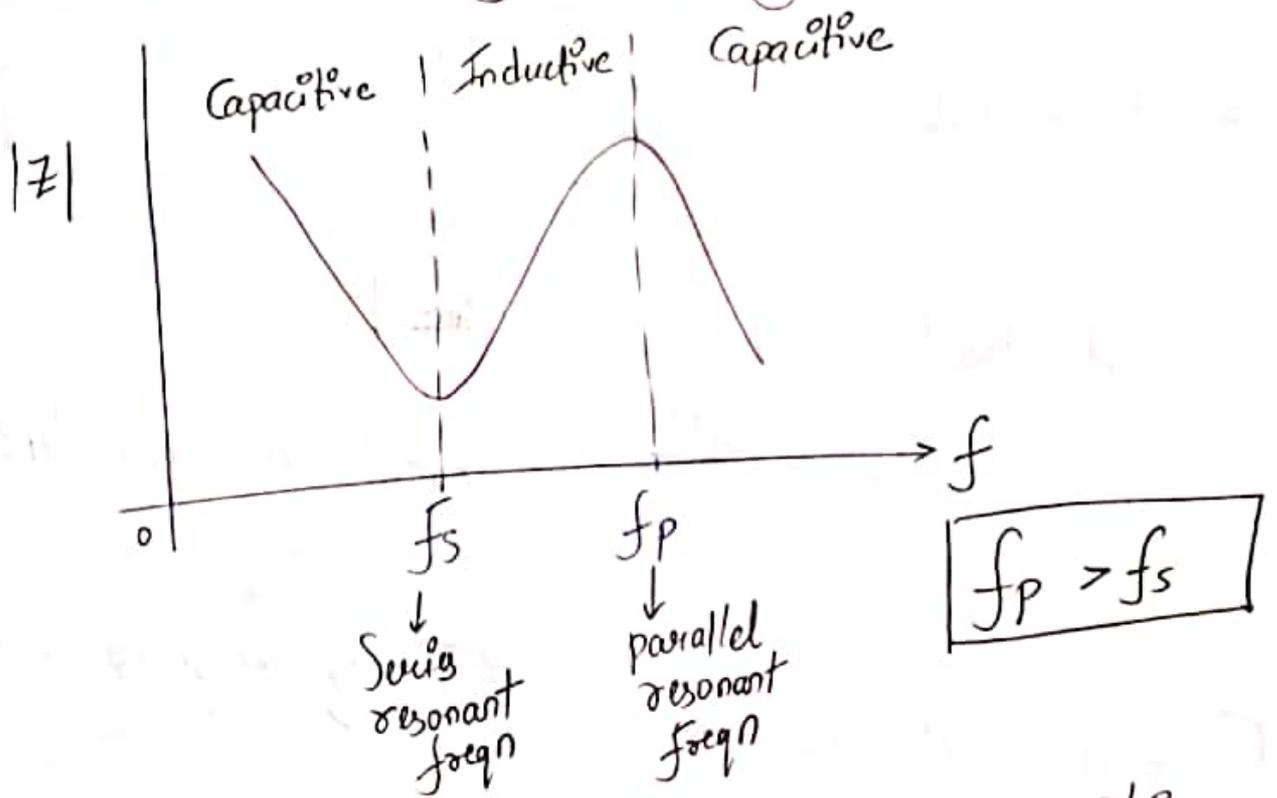
The crystal impedance versus frequency is shown in fig 2.

To use the crystal properly, it must be connected in a circuit so that its low impedance in the series-resonant operating mode or high impedance in the parallel-resonant operating mode is selected

**INDERJIT SINGH**

→ Quartz crystal acts a LC tank circuit 04.  
hence can generate oscillations at specified freq.

→ It has two resonating frequency.



→ While selecting Quartz crystal for specific application, decide at which resonant frequency it is going to be operated.

$$f_s = \frac{1}{2\pi \sqrt{L_s C_s}}$$

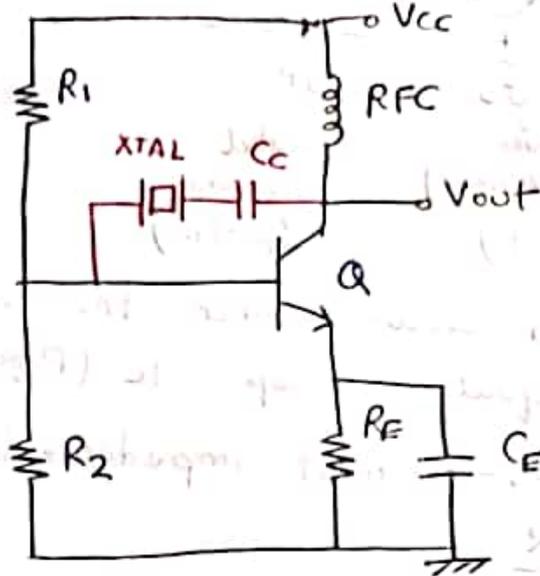
--- series resonant freqn

$$f_p = \frac{1}{2\pi \sqrt{L_s C_{eq}}}$$

$$C_{eq} = \frac{C_p C_s}{C_p + C_s}$$

Parallel resonant freqn

→ Crystal oscillator (BJT circuit analysis):



ckt (2): Crystal-controlled oscillator using a crystal ( $XTAL$ ) in a series-feedback path.

- Above ckt (2) is a Series-Resonant circuit.
- In this circuit, the crystal ( $XTAL$ ) is connected in as a series element in the feedback path from collector to base. This is done to excite the crystal for operating in series-resonant mode.
- At the series-resonant frequency of the crystal, its impedance is smallest and the amount of (positive) feedback is largest.

- Resistor's  $R_1, R_2$  and  $R_E$  provide a voltage-divider stabilized dc bias to Q.
- Capacitor  $C_E$  provides ac bypass of the emitter resistor  $R_E$ .
- RFC coil establishes dc bias while decoupling any ac signal on the power lines from affecting the op signal.
- Coupling capacitor  $C$  has negligible impedance at circuit operating frequency. But it blocks any dc signal between collector and base.

The circuit frequency of oscillations is set by series-resonant frequency of the crystal and its value is given by,

$$f_s = f_o = \frac{1}{2\pi\sqrt{LC}}$$

Series resonant frequency

→ At  $f_s$ , min impedance → the flb will be max.

→ By setting gain at  $f_s$  → we can use this ckt to generate sustained oscillations.

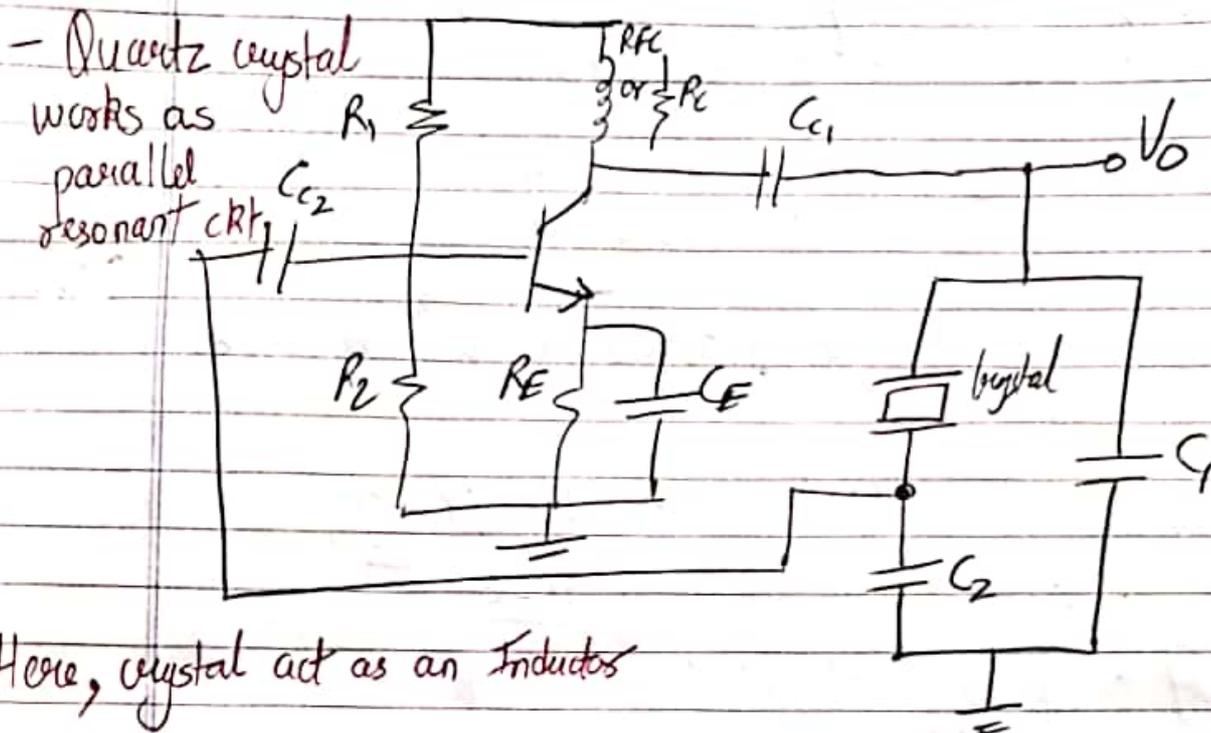
The voltage feedback from collector to base is a maximum when the crystal impedance is minimum (in series-resonant mode)

The resulting circuit frequency of oscillation is set, then by the series-resonant frequency of the crystal.

Advantage Changes in supply voltage, transistor device parameters, have no effect on the circuit operating frequency, which is held stabilized by the crystal.

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# # Pierce Crystal oscillator - Colpitt's crystal oscillator:



Here, crystal act as an Inductor

- Here,  $L_3$  is replaced by a crystal.
- Piezo-electric crystal is used as a resonant CRT replacing an LC CRT.

oscillating freq<sup>n</sup>  $f_0 = \frac{1}{2\pi \sqrt{C_{eq} L}}$

(L)  $\rightarrow$  reactance of crystal is inductive.

$\rightarrow$  crystal is made to operate as an inductance

$\rightarrow$  This is possible if freq<sup>n</sup> of oscillation is adjusted between  $\omega_s$  &  $\omega_p$  i.e. ( $f_s$  &  $f_p$ )

$\rightarrow$  Basic operat<sup>n</sup> - same as that of Colpitt's oscillator.

$\rightarrow$  RFC is a Radio freq<sup>n</sup> choke which connects DC supply to the CRT but isolates the DC supply from high-freq<sup>n</sup> oscillat<sup>n</sup> generated in the tank CRT.

Adv: - crystal has very high Q as a resonant CRT  $\rightarrow$  results in good freq<sup>n</sup> stability. for the oscillator.

Adv:-

1) v. high freq<sup>n</sup> stability

(ie changes in supply v<sub>t</sub>, & device parameters, have no effect on ckt f<sub>o</sub>, which is held stable by crystal)

2)  $Q \rightarrow$  quality factor  
 $Q$  is v. high

$$Q = \frac{X}{R}$$

$X = X_C \text{ or } X_L$

Applications of Crystal oscillator: - <sup>quartz</sup> only <sup>crystal</sup>

1) As a crystal clock in microprocessors.

2) In freq<sup>n</sup> synthesizers

3) In the radio & TV transmitters

4) Digital watches. <sup>quartz crystal.</sup>