KNUST
Telecomm.
Engineering

TE 364

LECTURE 8:

Introduction to Oscillator Design

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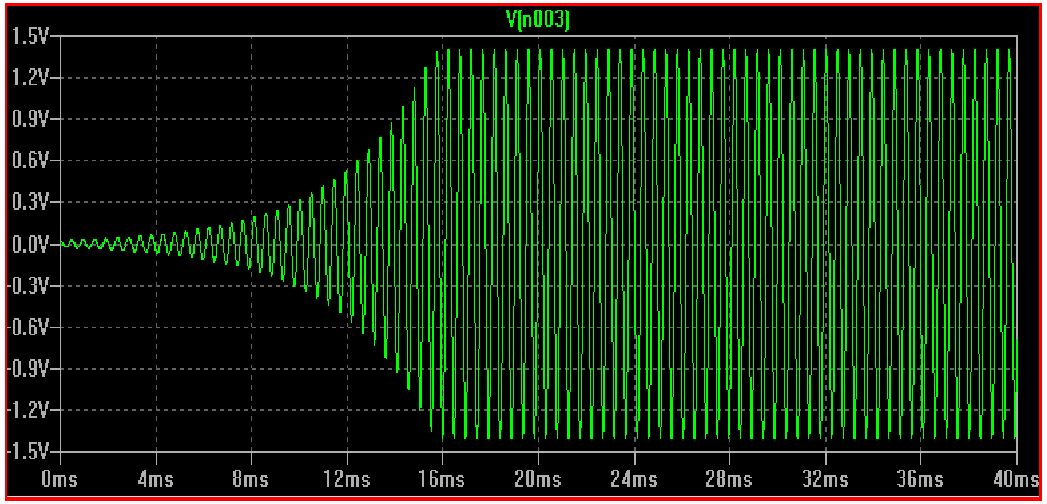
Abdul-Rahman Ahmed

ICnSYS LAB

Introduction

- Oscillator circuits;
  - are used for generating the periodic signals
  - convert a part of dc power into periodic output and do not require a periodic signal as input.



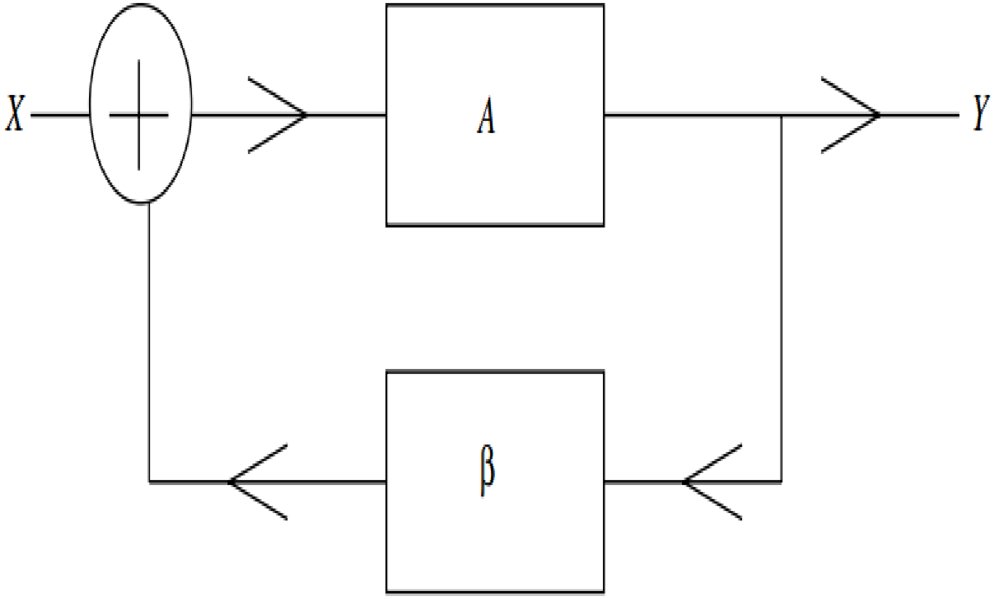
Feedback and Basic Concepts

- Solid-state oscillators use a diode or a transistor
  - in conjunction with the passive circuit to produce sinusoidal steady-state signals.
- Transients or electrical noise triggers oscillations initially.
  - The process requires a nonlinear active device.
  - a negative resistance is necessary to sustain oscillation of RF signal in reactance oscillators.

Principle of an Oscillator Circuit

- ☐ The basic principle of an oscillator circuit can be explained via a linear feedback system

- ☐ Assume that a part of output *Y* is fed back to the system along with an input signal *X*



Basic Concepts

- ❑Transfer function of the forward-connected subsystem is *A*
- ❑Feedback path has a subsystem with its transfer function as β.
- ❑Therefore,

$$Y = A(X + \beta Y)$$

- ❑The closed-loop gain *T* (generally called the *transfer function*) of this system is found from this equation as

$$T = \frac{Y}{X} = \frac{A}{1 - A\beta}$$

Basic Concepts…

- Product $A\beta$ is known as the *loop gain*.
  - It is a product of the transfer functions of individual units in the loop
- Numerator A is called the *forward path gain*
  - It represents the gain of a signal traveling from input to output
- For a loop gain of unity, T becomes infinite.
  - the circuit has an output signal Y without an input signal X and the system oscillates.
- The condition $A\beta = 1$ is known as the *Barkhausen criterion*

Basic Concepts…

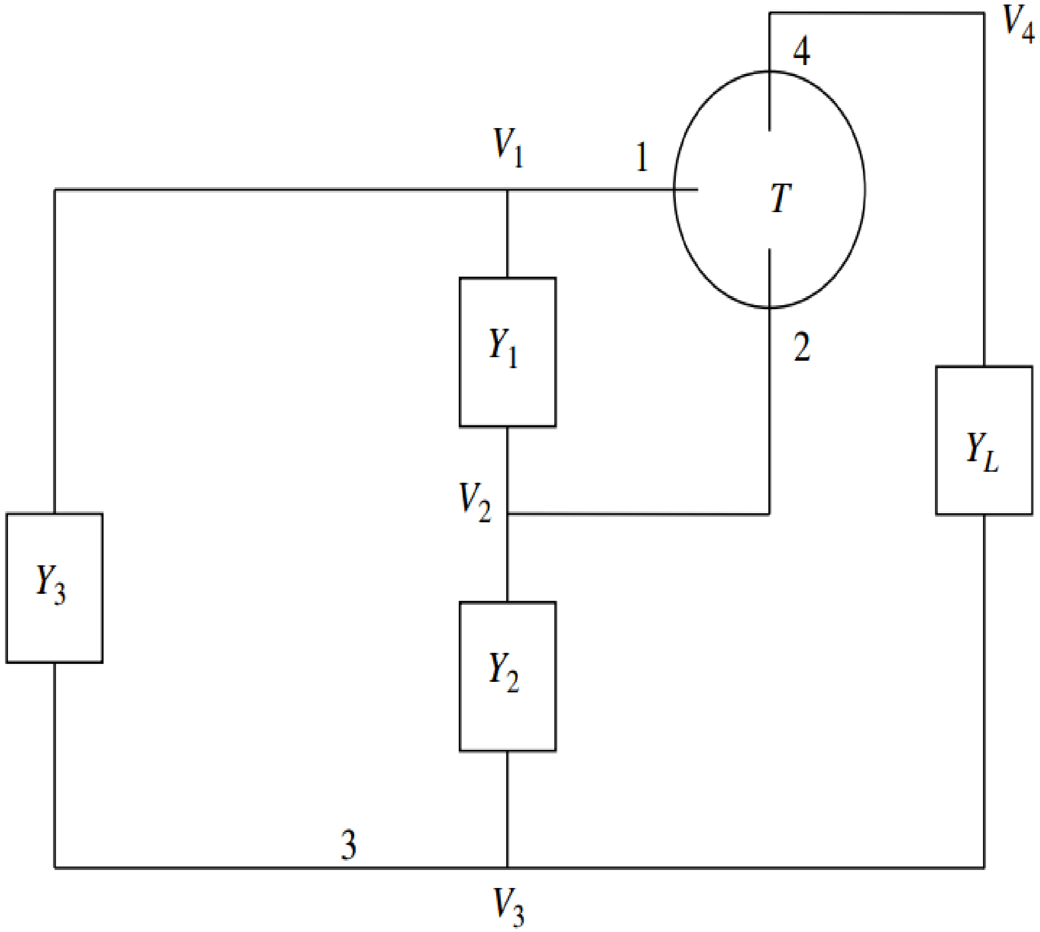
- ❑ If the signal *A*β is subtracted from *X* before it is fed to *A*, the denominator of T changes to;

$$(1 + A\beta)$$

- ❑ In this case, the system oscillates for $A\beta = -1$
- ❑ This is known as the *Nyquist criterion*.
- ❑ Since the output of an amplifier is generally 180° out of phase with its input, it may be a more appropriate description for that case.

Generalized Oscillator Circuit

- Schematic of oscillator circuit
  - Device T in this circuit may be a bipolar transistor or a FET. If it is a BJT, terminals 1, 2, and 4 represent the base, emitter, and collector, respectively. On the other hand, these may be the gate, source, and drain terminals if it is a FET



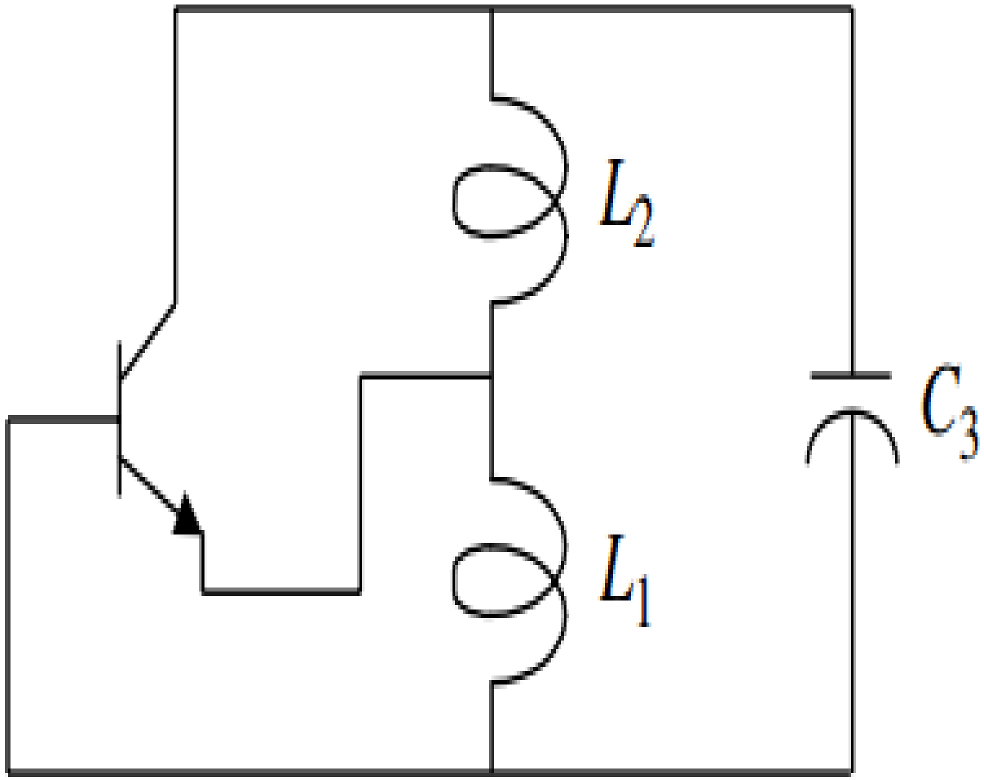
Hartley Oscillator

- ❑Resonant frequency is obtained via

$$\omega L_1 + \omega L_2 - \frac{1}{\omega C_3} = 0$$

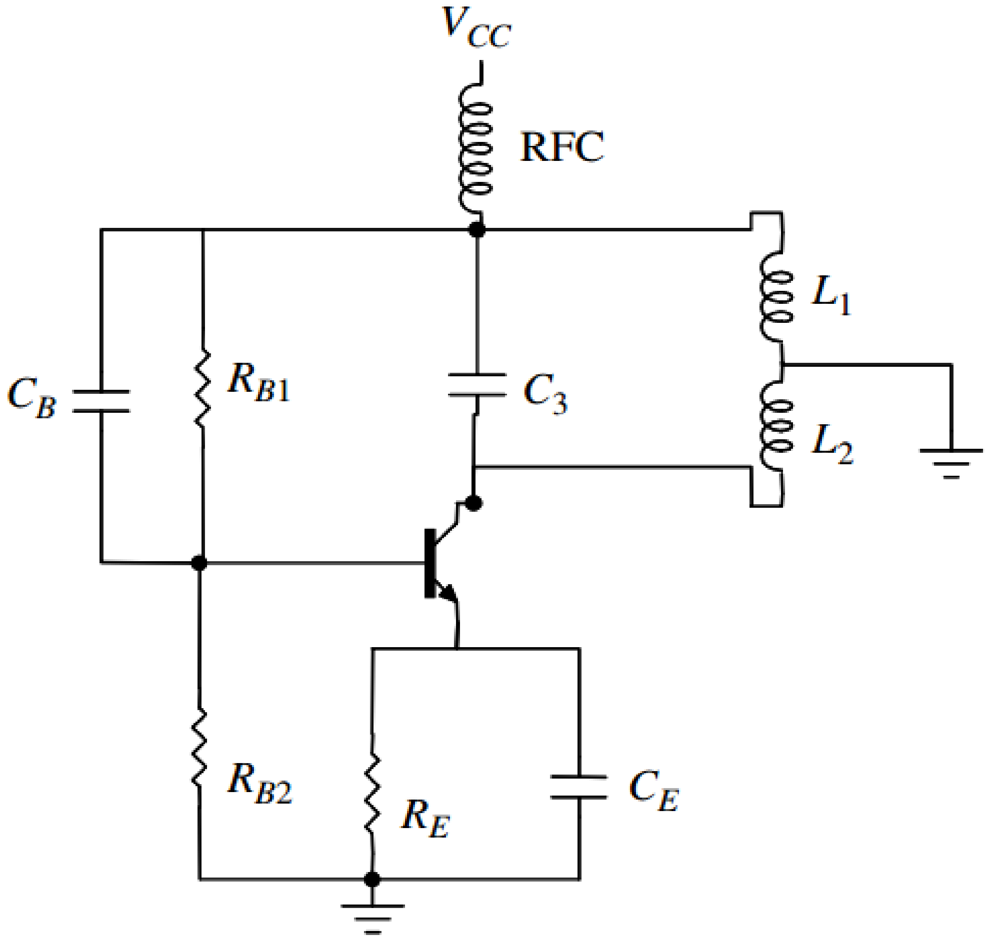
or

$$\omega^2 = \frac{1}{C_3(L_1 + L_2)}$$



Biased BJT Hartley Oscillator Circuit

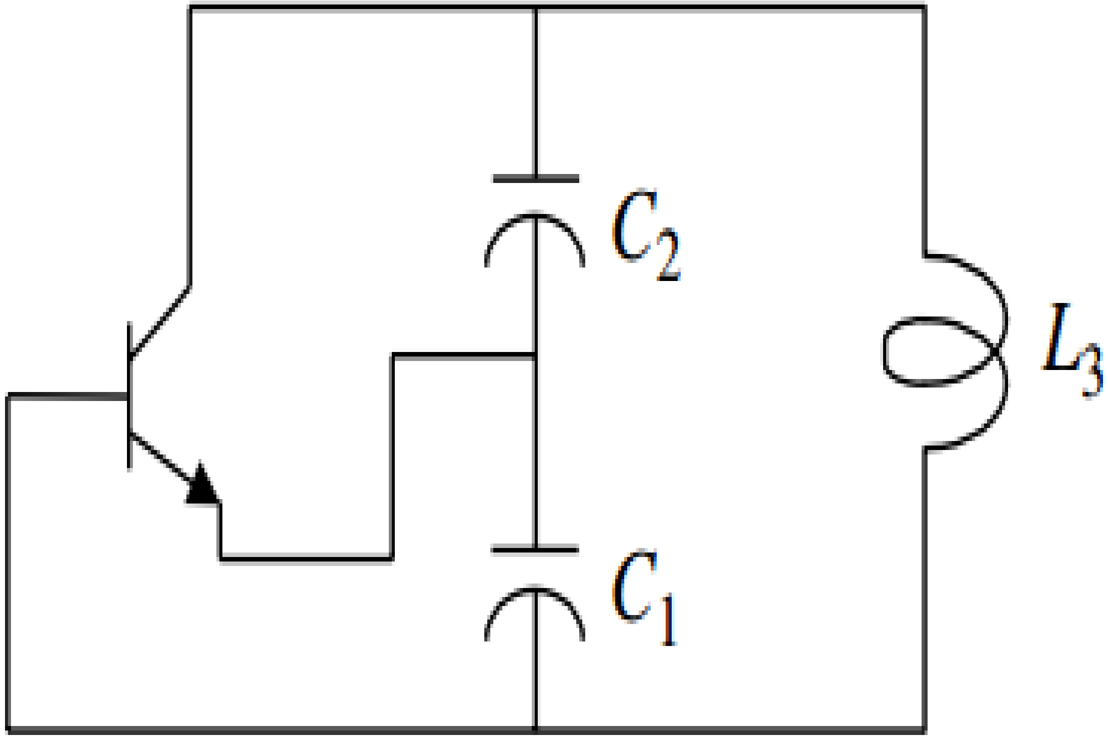
- ❑Note that this relation assumes that there is no mutual coupling between L_1 and L_2.
- ❑If the coupling factor is *k*, the correction term is $2k(L_1 L_2)^{0.5}$ that should be added to L_1+L_2



Colpitt's Oscillators

- The resonant frequency of a Colpitt's oscillator is as follows:

$$-\frac{1}{\omega C_1}-\frac{1}{\omega C_2}+\omega L_3=0$$

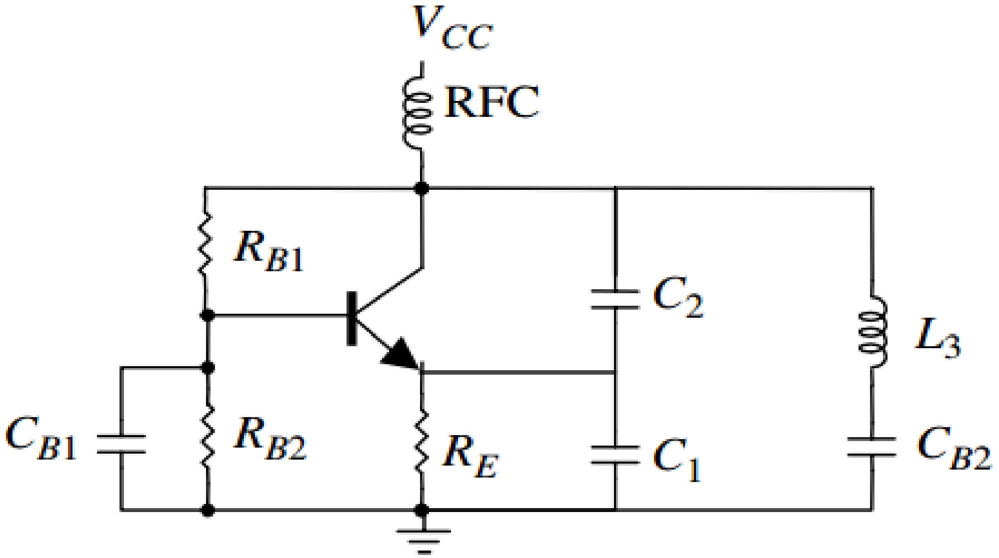


- or

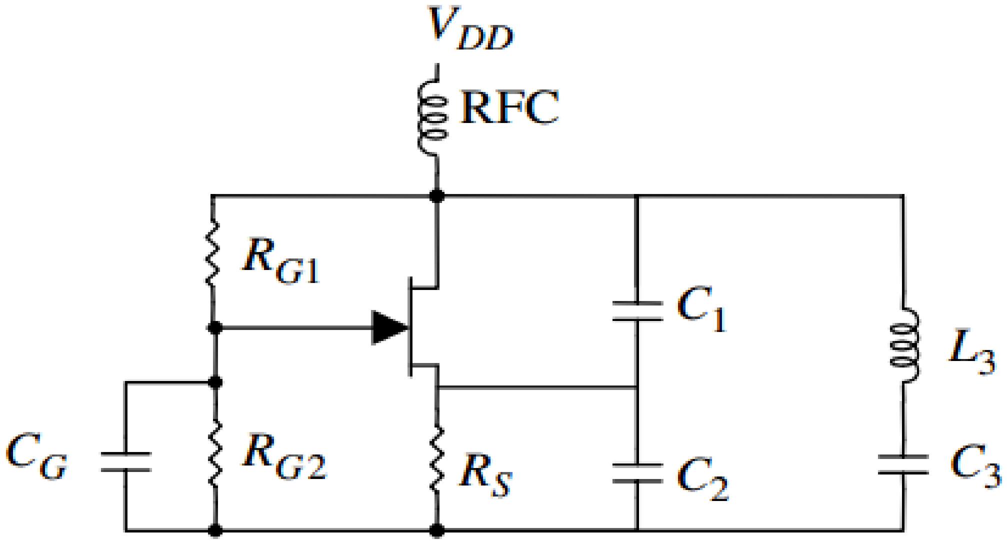
$$\omega^2=\frac{C_1+C_2}{C_1C_2L_3}$$

Biased BJT Colpitts Oscillator Circuit

- Biased BJT Colpitts oscillator circuit



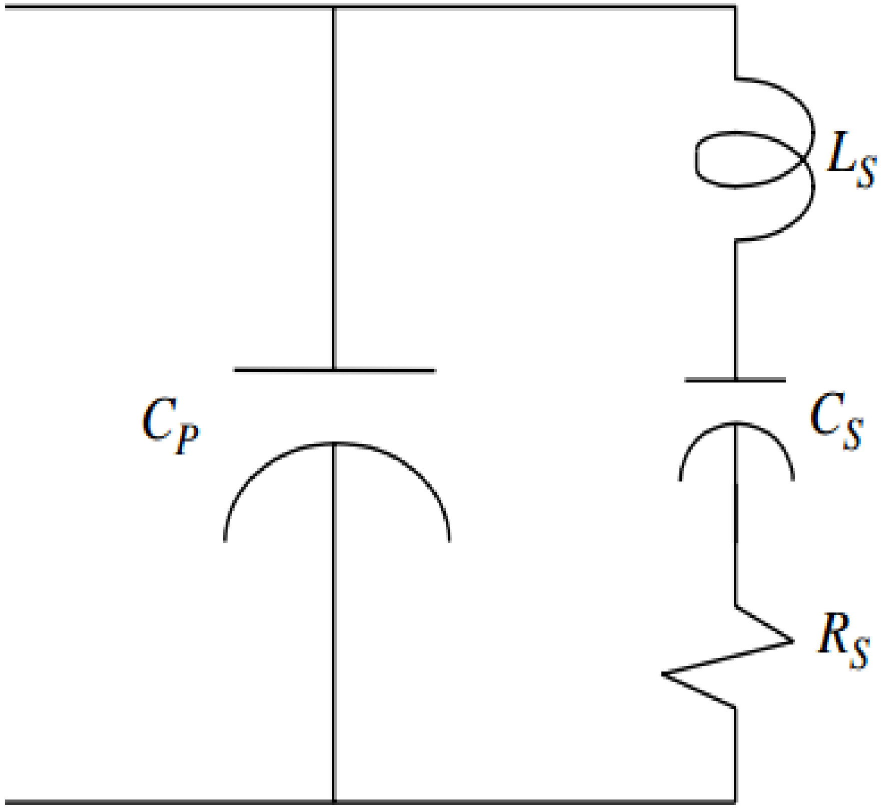
FET-based Clapp oscillator circuit



- Resonant circuits for Colpitts and Clapp oscillators

Crystal Oscillators

- ☐ Quartz and ceramic crystals are used in oscillator circuits for additional stability of frequency.
- ☐ They provide a fairly high *Q* value (on the order of 100,000) that shows a small drift with temperature (on the order of 0.001% per °C)
- ☐ The crystal exhibits both series and parallel resonant modes



Crystal Oscillators…

- Series resonant frequency ω_S and parallel resonant frequency ω_P of the crystal can be found from its equivalent circuit.
- These are as follows:

$$\omega_S = \frac{1}{\sqrt{L_S C_S}}$$

$$\omega_P = \omega_S \sqrt{1 + \frac{C_S}{C_P}}$$

- Hence, the frequency range $\Delta\omega$ over which the crystal behaves as an inductor can be determined as follows:

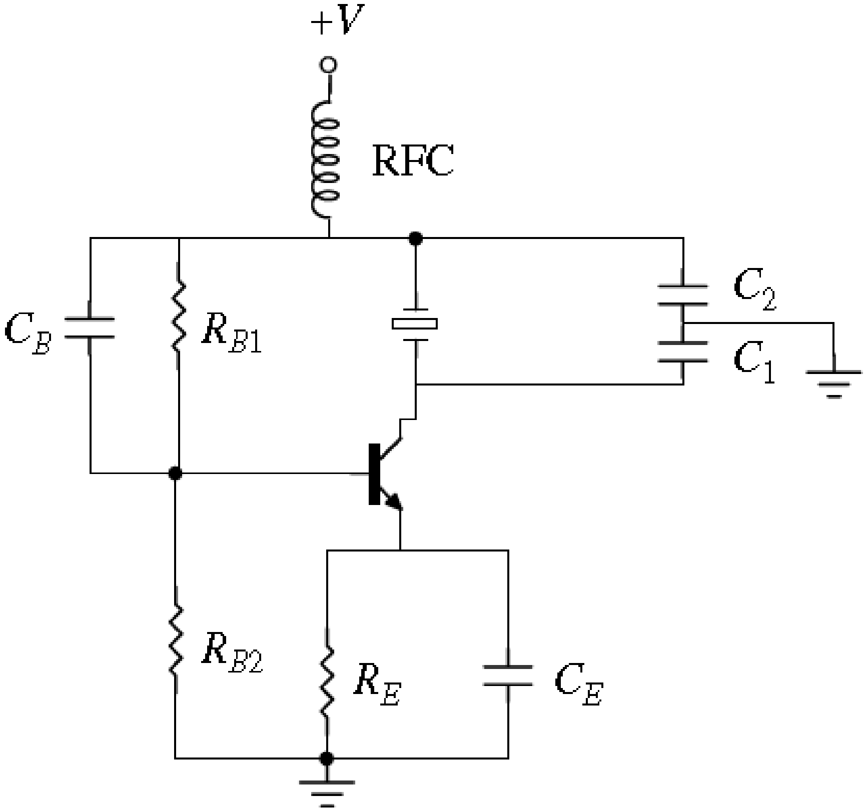
$$\omega_P - \omega_S = \Delta\omega = \omega_S \left[\sqrt{\left(1 + \frac{C_S}{C_P}\right)} - 1 \right] \approx \frac{C_S}{2C_P}\omega_S$$

Crystal Oscillators…

- ❑ $\Delta\omega$ is known as the *pulling figure* of the crystal.
- ❑ Typically, ω_P is less than 1% higher than ω_S.
- ❑ For an oscillator design, a crystal is selected such that the frequency of oscillation falls between ω_S and ω_P .
  - ❖ Therefore, the crystal operates basically as an inductor in the oscillator circuit

Pierce Oscillator

- A BJT oscillator circuit using crystal as the resonant circuit.



Pierce Oscillator

- A BJT oscillator circuit using crystal as the resonant circuit.
  - The crystal provides very stable frequency of oscillation over a wide range of temperature.
  - The main drawback of a crystal oscillator circuit is that its tuning range is relatively small.
  - It is achieved by adding a capacitor in parallel with the crystal.
  - In this way, the parallel resonant frequency ω_P can be decreased up to the series resonant frequency ω_S

Electronic Tuning of Oscillators

- The capacitance of the tuned circuit can be varied to change the frequency of oscillation
- It can be done electronically by using a varactor diode and controlling its bias voltage. Two main type of veractor diode:
  - Abrupt and
  - hyperabrupt junctions
- *Abrupt junction diodes* provide very high *Q* values and also operate over a very wide tuning voltage range (typically, 0 to 60 V). These diodes provide an excellent phase noise performance because of their high *Q* value

Electronic Tuning of Oscillators…

- *Hyperabrupt-type diodes* exhibit a quadratic characteristic of the capacitance with applied voltage.
  - Therefore, these varactors provide a much more linear tuning characteristic than does the abrupt type.
  - These diodes are preferred for tuning over a wide frequency band. An octave tuning range can be covered in less than 20 V.
- The main disadvantage of these diodes is that they have a much lower *Q* value, and therefore the phase noise is higher than that obtained from the abrupt junction diodes.

Electronic Tuning of Oscillators…

- ❑ The capacitance of a varactor diode is related to its bias voltage as follows:
- ❑

$$C = \frac{A}{(V_R + V_B)^n}$$

→ $C=A/V^n$

- ❖ A is a constant,
- ❖ V_R the applied reverse bias voltage, and
- ❖ V_B the built-in potential
- ❖ n is a number between 0.3 and 0.6 for a hyperabrupt junction

Electronic Tuning of Oscillators…

- The resonant circuit of a typical voltage-controlled oscillator (VCO) has a parallel tuned circuit consisting of
  - inductor *L*,
  - fixed capacitor *Cf*, and
  - The varactor diode with capacitance *C*
- Its frequency of oscillation can be written as

$$\omega = \frac{1}{\sqrt{L(C_f + C)}} = \frac{1}{\sqrt{L\left(C_f + \frac{A}{V^n}\right)}}$$