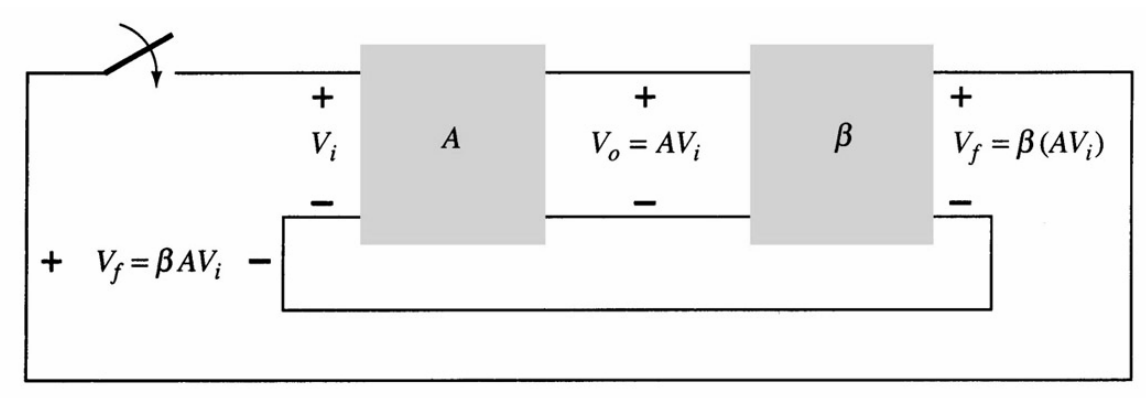
Oscillator Circuits

II. Oscillator Operation

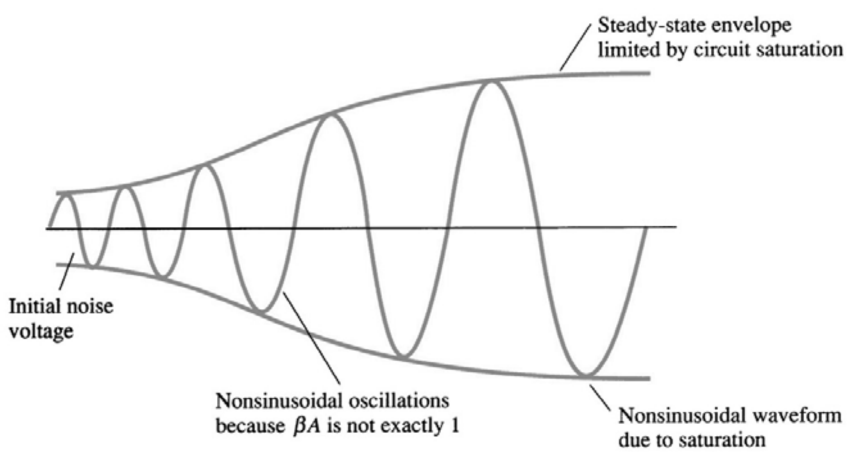
For self-sustaining oscillations:

- the feedback signal must positive
- the overall gain must be equal to one (unity gain)



If the feedback signal is not positive or the gain is less than one, then the oscillations will dampen out.

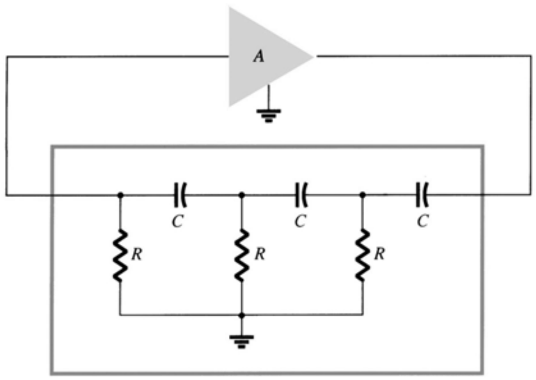
If the overall gain is greater than one, then the oscillator will eventually saturate.



Types of Oscillator Circuits

A. Phase-Shift Oscillator
B. Wien Bridge Oscillator
C. Tuned Oscillator Circuits
D. Crystal Oscillators
E. Unijunction Oscillator

A. Phase-Shift Oscillator



Frequency of the oscillator: $f_0 = \frac{1}{2\pi RC\sqrt{6}}$ (the frequency where the phase shift is 180º)

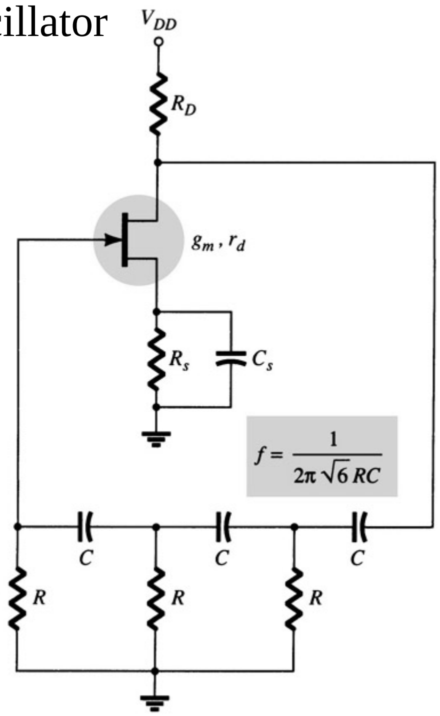
Feedback gain $\beta = 1/[1 - 5\alpha^2 - j\,(6\alpha - \alpha^3)\,]$ where $\alpha = 1\,/\,(2\pi fRC)$
Feedback gain at the frequency of the oscillator $\beta = 1\,/\,29$

The amplifier must supply enough gain to compensate for losses. The overall gain must be unity. Thus the gain of the amplifier stage must be greater than 1/β, i.e. A > 29

The RC networks provide the necessary phase shift for a positive feedback. They also determine the frequency of oscillation.

Example of a Phase-Shift Oscillator

FET Phase-Shift Oscillator



(a)

Example 1

It is desired to design a phase-shift oscillator (as in Fig. 18.21a) using an FET having $g_m = 5000\ \mu S$, $r_d = 40\ k\Omega$, and feedback circuit value of $R = 10\ k\Omega$. Select the value of C for oscillator operation at 1 kHz and R_D for $A > 29$ to ensure oscillator action.

Equation (18.33) is used to solve for the capacitor value. Since $f = 1/2\pi RC\sqrt{6}$, we can solve for C:

$$C = \frac{1}{2\pi Rf\sqrt{6}} = \frac{1}{(6.28)(10 \times 10^3)(1 \times 10^3)(2.45)} = 6.5\ \text{nF}$$

Using Eq. (18.36), we solve for R_L to provide a gain of, say, $A = 40$ (this allows for some loading between R_L and the feedback network input impedance):

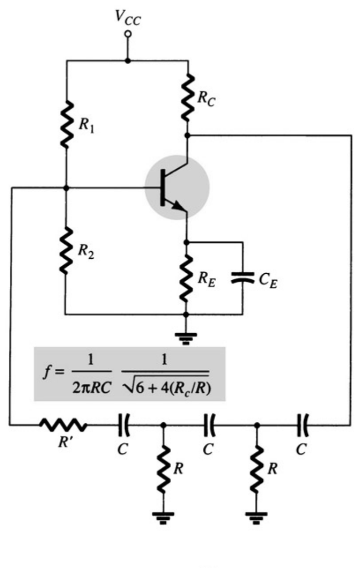
$$|A| = g_m R_L$$

$$R_L = \frac{|A|}{g_m} = \frac{40}{5000 \times 10^{-6}} = 8\ k\Omega$$

Using Eq. (18.37), we solve for $R_D = \mathbf{10\ k\Omega}$.

$$R_L = \frac{R_D r_d}{R_D + r_d}$$

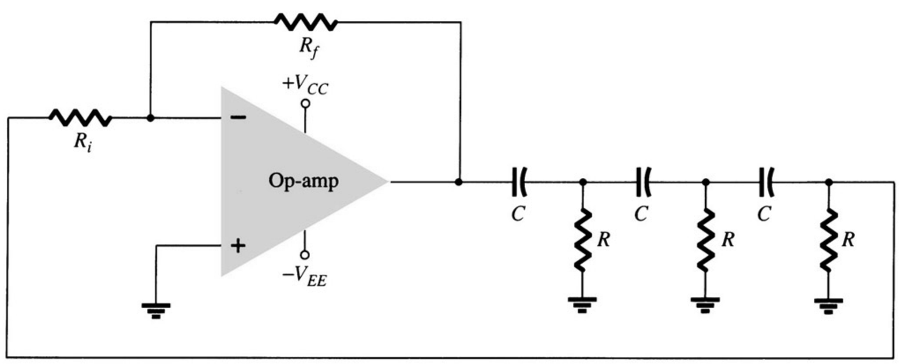
BJT Phase-Shift Oscillator



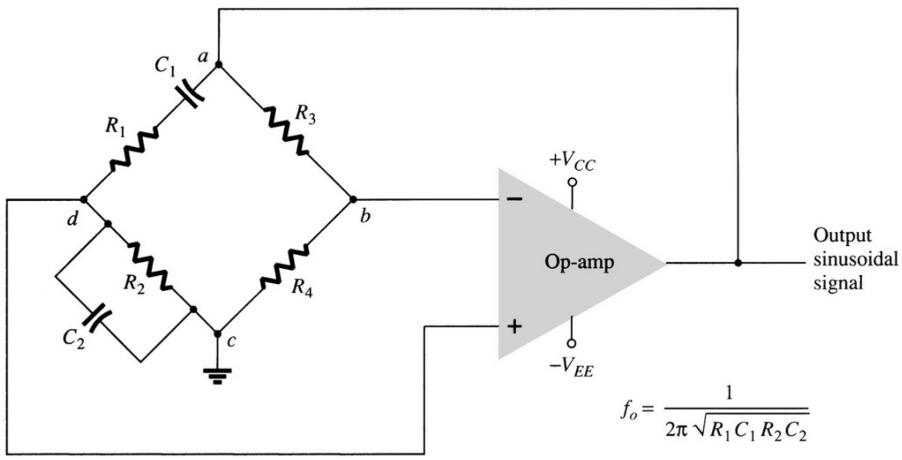
$$R' = R - h_{ie}$$

$$h_{fe} > 23 + 29\frac{R_C}{R} + 4\frac{R}{R_C}$$

Phase-shift oscillator using op-amp



B. Wien Bridge Oscillator



$$\beta = \frac{V_i}{V_o} = \frac{V_d - V_b}{V_a} = \frac{Z_2}{Z_1 + Z_2} - \frac{R_4}{R_3 + R_4} = \frac{1}{\frac{Z_1}{Z_2} + 1} - \frac{1}{\frac{R_3}{R_4} + 1}$$

$$\beta = 0 \quad \Rightarrow \quad \frac{R_3}{R_4} = \frac{R_1}{R_2} + \frac{C_2}{C_1}$$

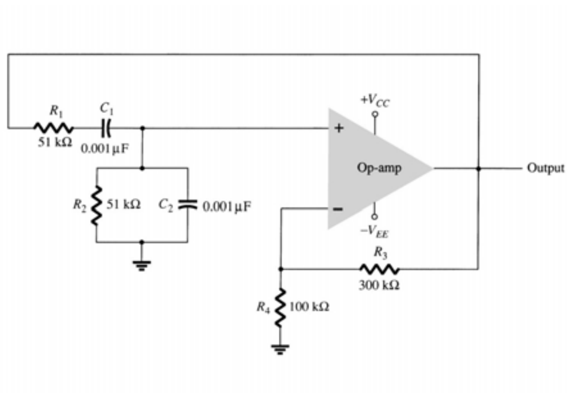
$\frac{Z_2}{Z_1 + Z_2}$, i.e., $\frac{Z_1}{Z_2}$ should have zero phase at the oscillation frequency

So frequency of oscillation is $f_0 = \frac{1}{2\pi\sqrt{(R_1 C_1 R_2 C_2)}}$

When $R_1 = R_2 = R$ and $C_1 = C_2 = C$ then

$$f_0 = \frac{1}{2\pi RC}, \quad \text{and} \quad \frac{R_3}{R_4} \geq 2$$

Example 2



Calculate the resonant frequency of the Wien bridge oscillator shown above

$$f_0 = \frac{1}{2\pi RC} = \frac{1}{2\pi(51\times10^3)(1\times10^{-9})} = 3120.7\,\text{Hz}$$

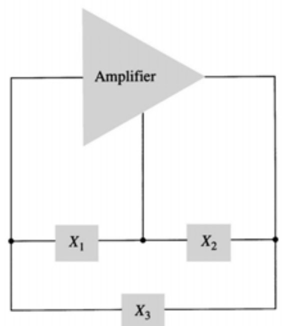
Design the RC elements of a Wien bridge oscillator as in Fig. 18.24 for operation at $f_o = 10$ kHz.

Using equal values of R and C we can select $R = 100$ kΩ and calculate the required value of C using Eq. (18.42):

$$C = \frac{1}{2\pi f_o R} = \frac{1}{6.28(10\times10^3)(100\times10^3)} = \frac{10^{-9}}{6.28} = \mathbf{159\ pF}$$

We can use $R_3 = 300$ kΩ and $R_4 = 100$ kΩ to provide a ratio R_3/R_4 greater than 2 for oscillation to take place.

C. Tuned Oscillator Circuits



Oscillator Type	Reactance Element X_1	X_2	X_3
Colpitts oscillator	C	C	L
Hartley oscillator	L	L	C
Tuned input, tuned output	LC	LC	—

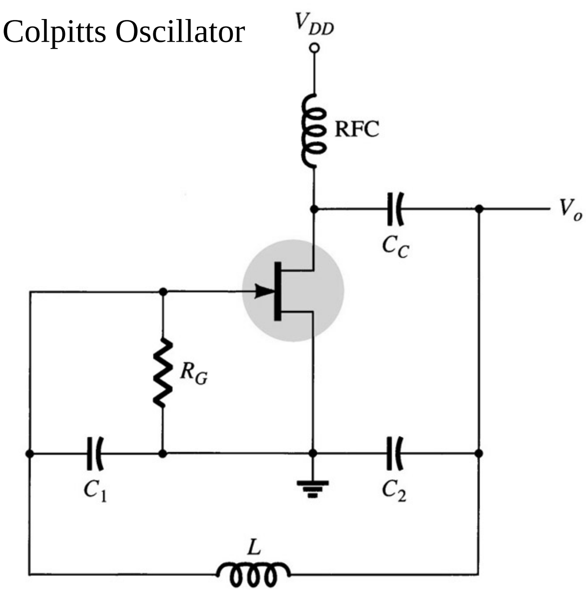
Tuned Oscillators use a parallel LC resonant circuit (LC tank) to provide the oscillations.

There are two common types:

- **Colpitts** – The resonant circuit is an inductor and two capacitors.
- **Hartley** – The resonant circuit is a tapped inductor or two inductors and one capacitor.

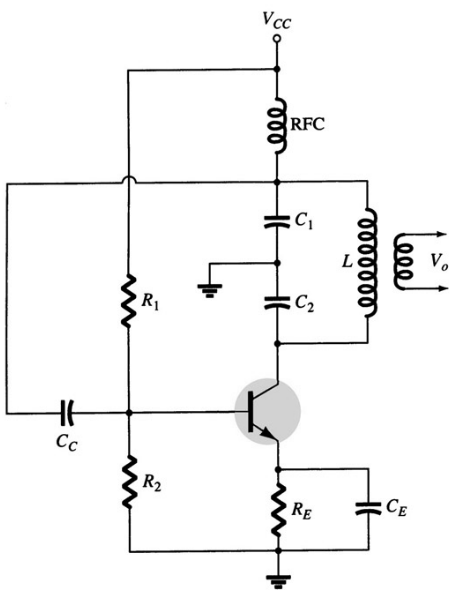
Colpitts Tuned Oscillator Circuit

FET based Colpitts Oscillator

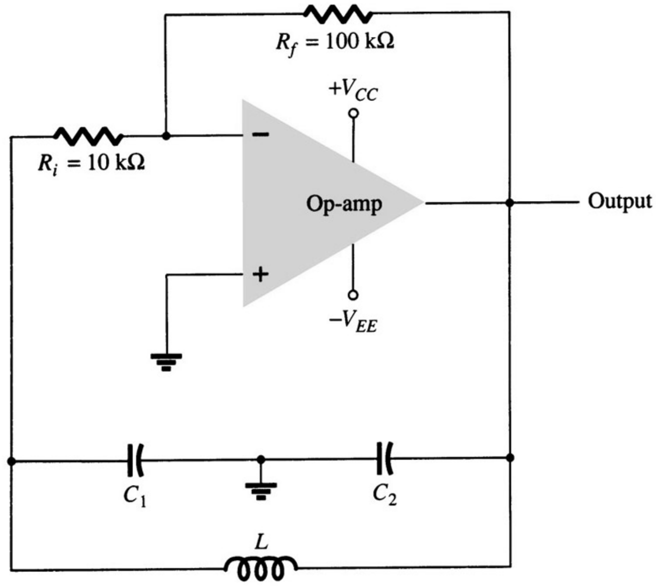


Frequency of oscillations: $$f_0 = \frac{1}{2\pi\sqrt{LC_{eq}}}, \text{ where } C_{eq} = \frac{C_1 C_2}{C_1 + C_2}$$

Transistor Colpitts oscillator.

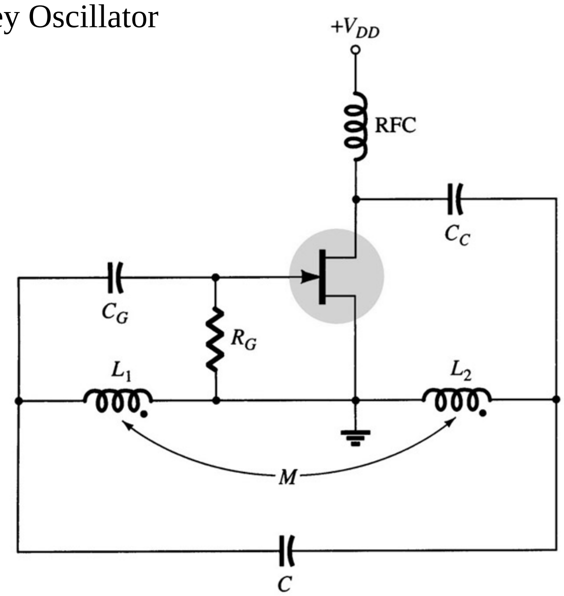


Op-amp Colpitts oscillator.



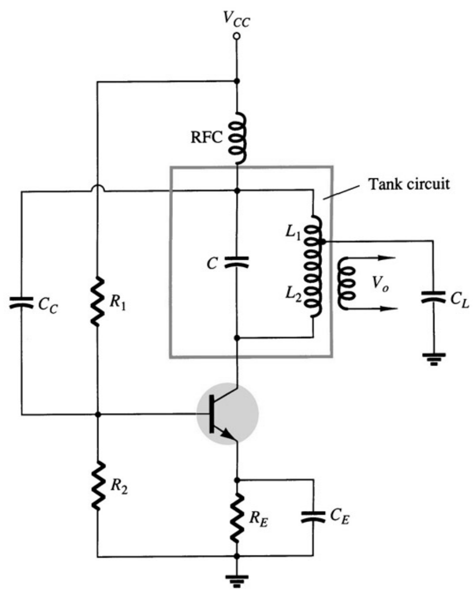
Hartley Tuned Oscillator Circuit

FET Hartley Oscillator



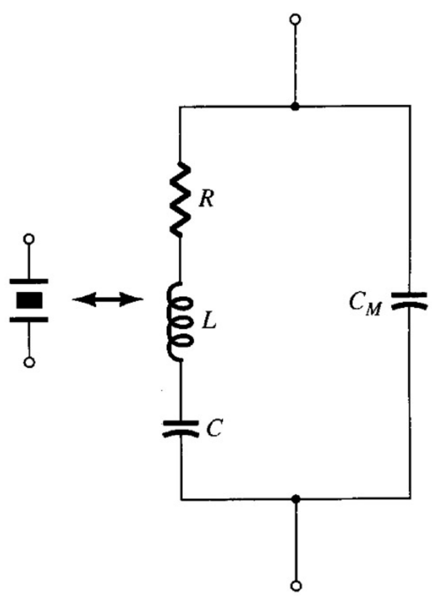
Frequency of oscillations: $f_0 = \frac{1}{2\pi\sqrt{L_{eq}C}}$, where $L_{eq} = L_1 + L_2 + 2L_{12}$

BJT based Hartley Oscillator



D. Crystal Oscillators

The crystal appears to the rest of the circuit as a resonant circuit.

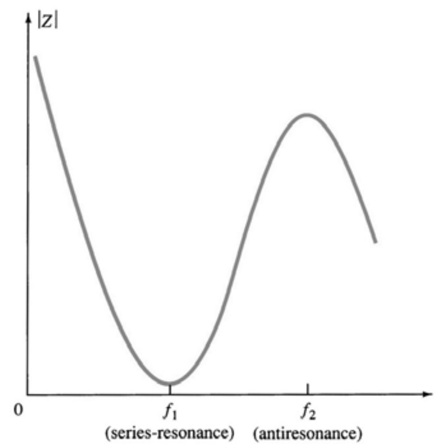


Crystal Resonant Frequencies

The crystal has two resonant frequencies:

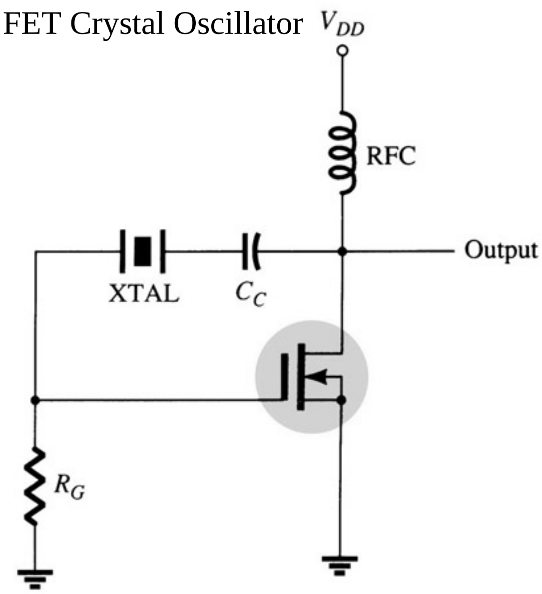
Series resonant: RLC determine the resonant frequency. The crystal has a low impedance.
Parallel resonant: RL and C_M determine the resonant frequency. The crystal has a high impedance.

The series and parallel resonant frequencies are very close, within 1% of each other.



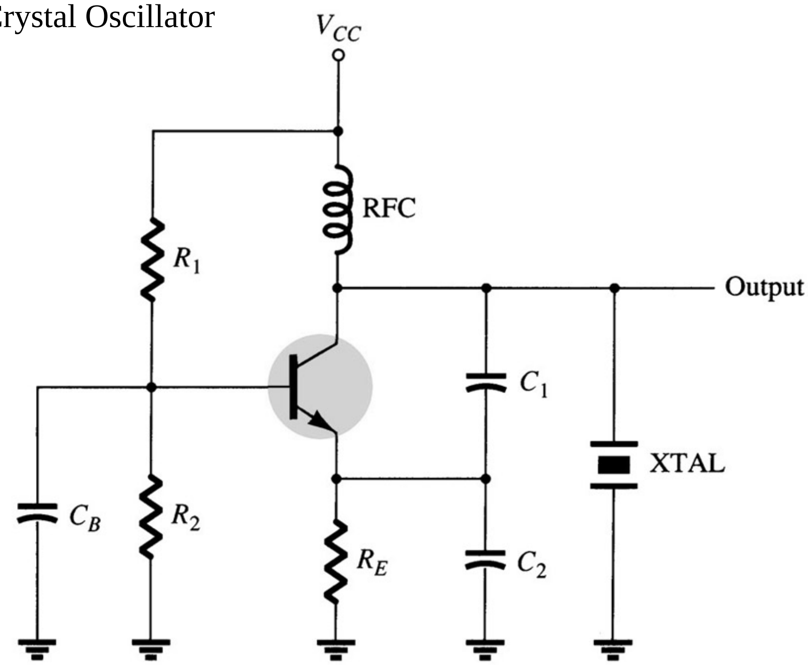
Series Resonant Crystal Oscillator

FET Crystal Oscillator

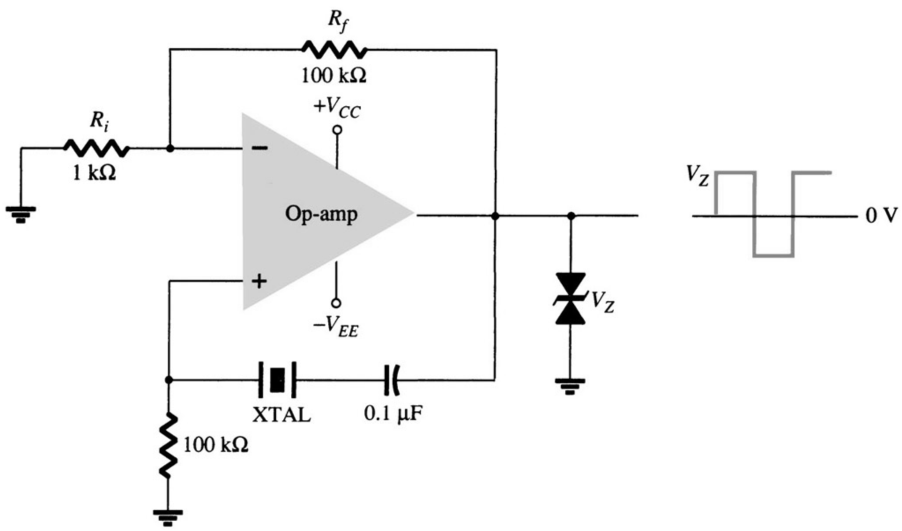


Parallel Resonant Crystal Oscillator

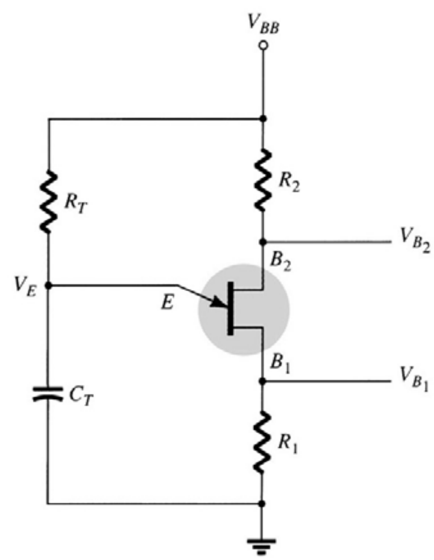
BJT Crystal Oscillator



Crystal Oscillator using Op-amp



E. Unijunction Oscillator

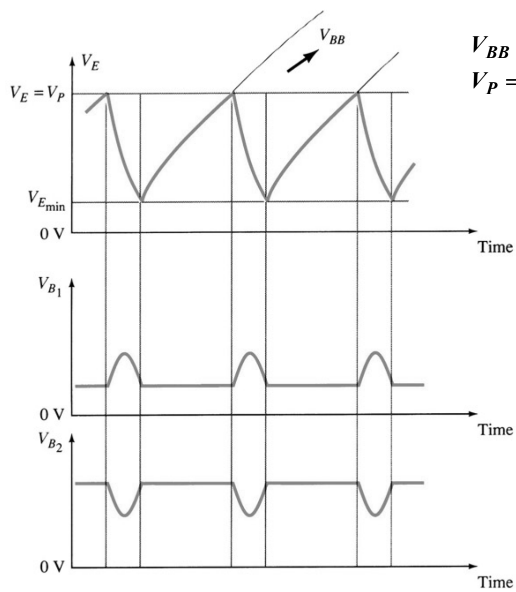


Frequency of oscillations: $$f_0 = \frac{1}{R_T\, C_T\, \ln[1/(1-\eta)]}$$

where η = 0.4 to 0.6

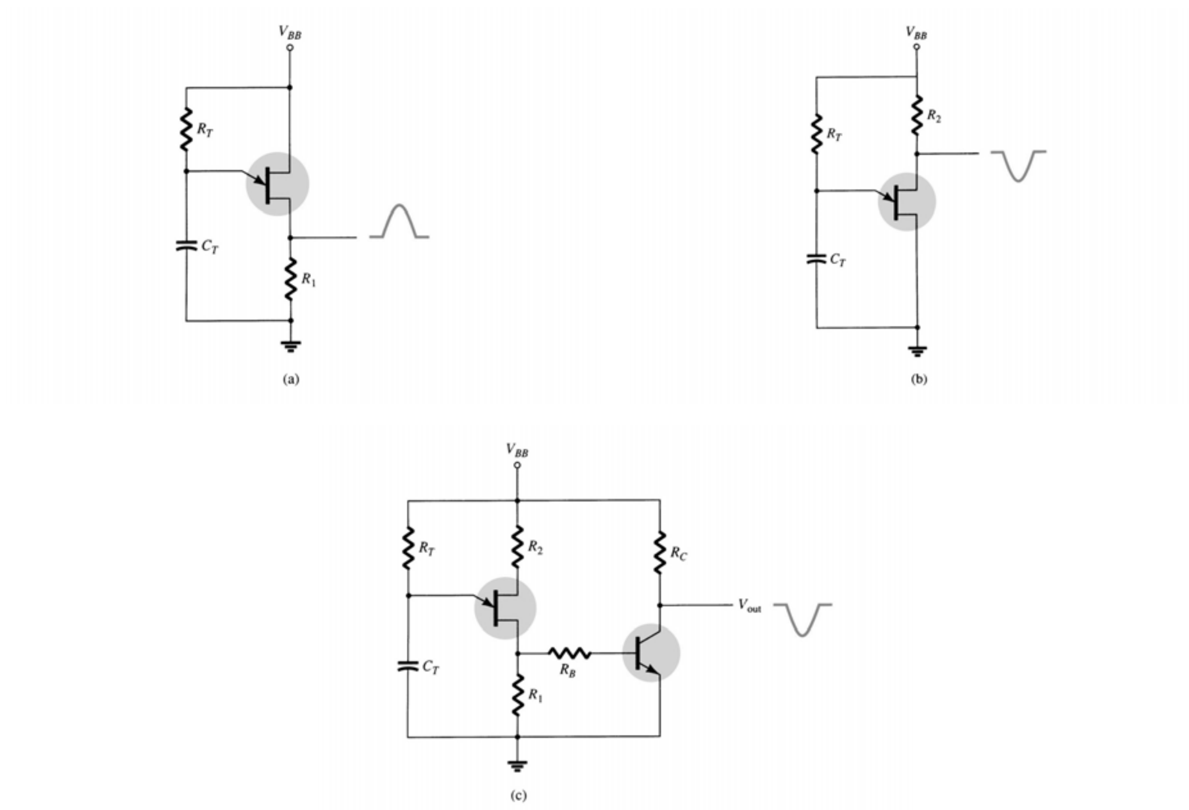
η is a rating of the unijunction transistor.

Unijunction Oscillator Waveforms



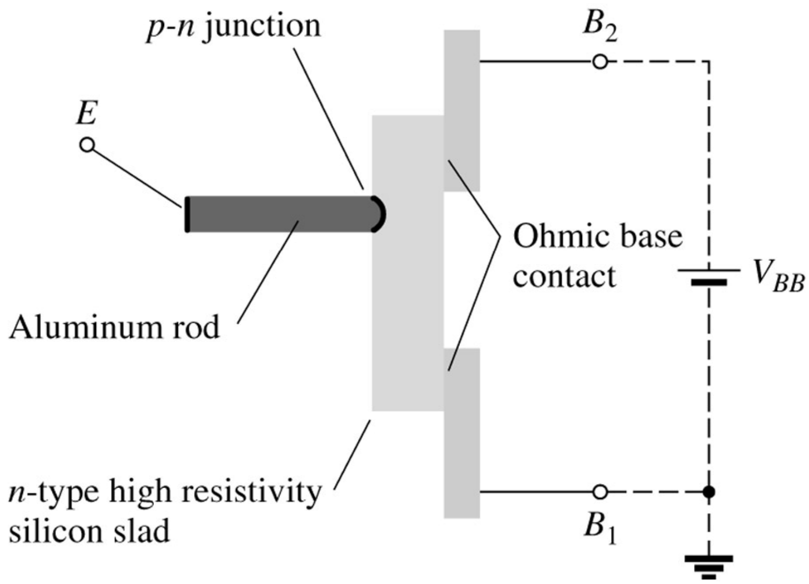
$$V_{BB} = V_{B2} - V_{B1}$$
$$V_P = \eta V_{BB} + V_{B1} + V_D$$

The unijunction oscillator (or relaxation oscillator) produces a sawtooth waveform.



V_{BB}
R_T
C_T
R_1
(a)
V_{BB}
R_T
R_2
C_T
(b)
V_{BB}
R_T
R_2
R_C
V_{out}
C_T
R_B
R_1
(c)

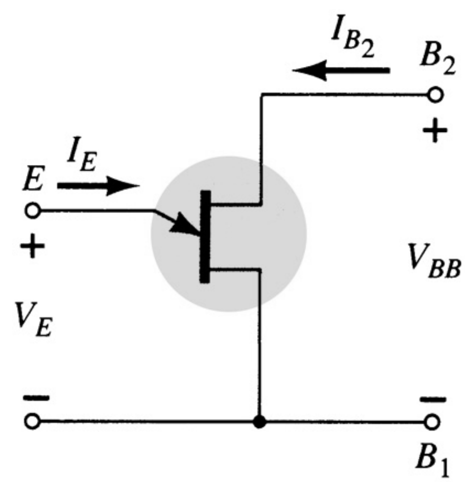
Unijunction transistor (UJT): basic construction.



UJT – Unijunction Transistor

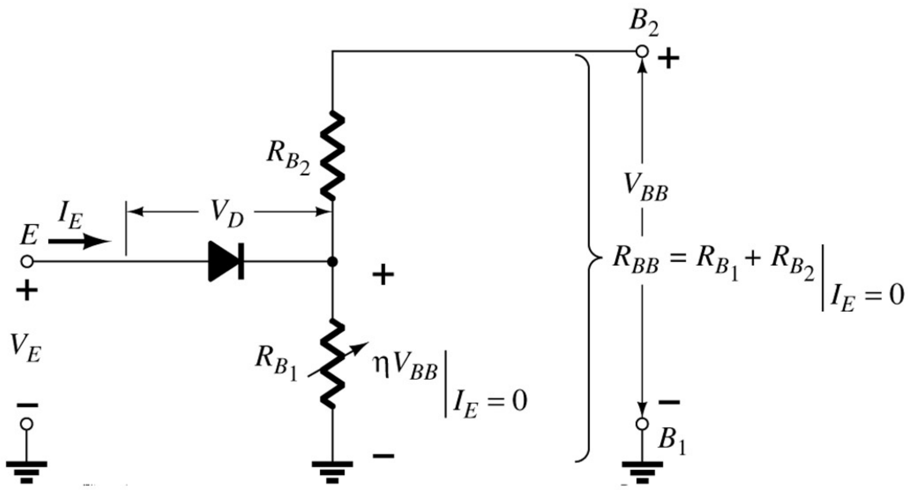
The UJT is also basically a switching device.

Schematic Symbol:



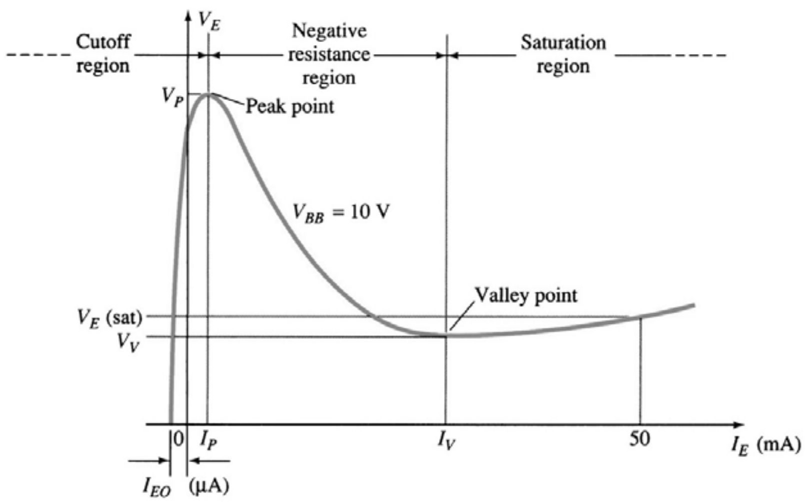
UJT Basic Operation

Even though the UJT is a switching device it works very differently from the SCR variety of devices.



The equivalent circuit indicates that the UJT is like a diode and a resistive voltage divider circuit. The resistance exhibited by R_{B1} is variable; it is dependent on the value of current I_E.

UJT Characteristic Curve



A voltage is applied across the UJT (V_{BB}) and to the Emitter input (V_E). Once V_E reaches a peak value (V_p) the UJT begins to conduct. At the point where $V_E = V_p$, the current I_E is at minimum. This is the threshold value of V_E that puts the UJT into conduction. Once conducting, I_E increases and V_E decreases. This phenomenon occurs because the internal resistance labeled R_{B1} in the equivalent circuit decreases as the UJT conducts more and more. This is called negative resistance.