ELG4139: Oscillator Circuits

Positive Feedback Amplifiers (Oscillators)

LC and Crystal Oscillators

JBT; FET; and IC Based Oscillators

The Active-Filter-Tuned Oscillator

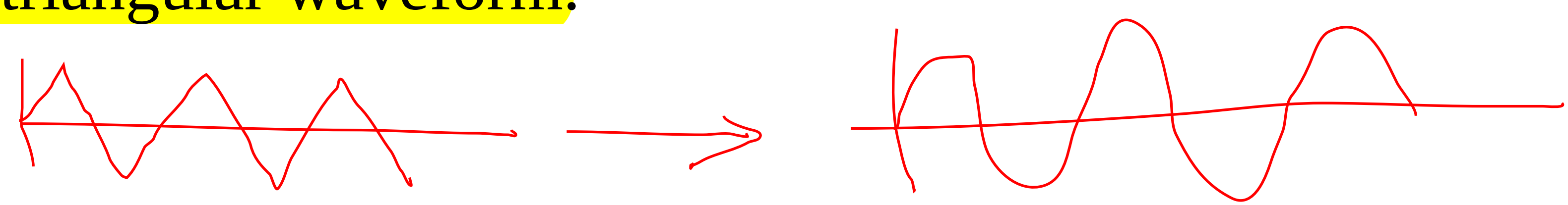
Multivibrators

Introduction

- There are two different approaches for the generation of sinusoids, most commonly used for the standard waveforms:
  - Employing a positive-feedback loop that consists an amplifier and an RC or LC frequency-selective network. It generates sine waves utilizing resonance phenomena, are known as linear oscillators (circuits that generate square, triangular, pulse waveforms are called non-linear oscillators or function generators.)
  - A sine wave is obtained by appropriate shaping a triangular waveform.

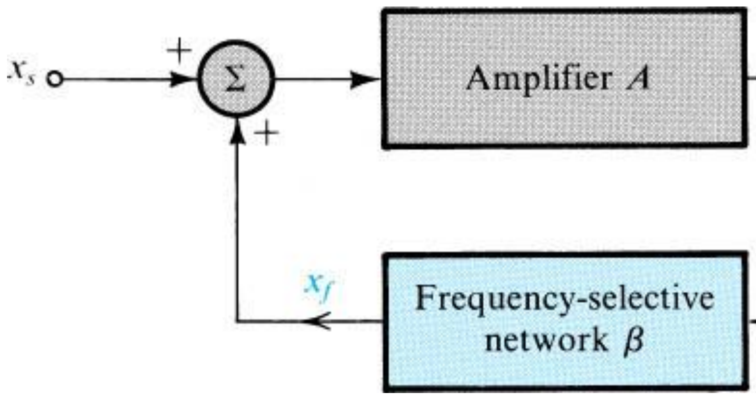
Produces 1 frequency component

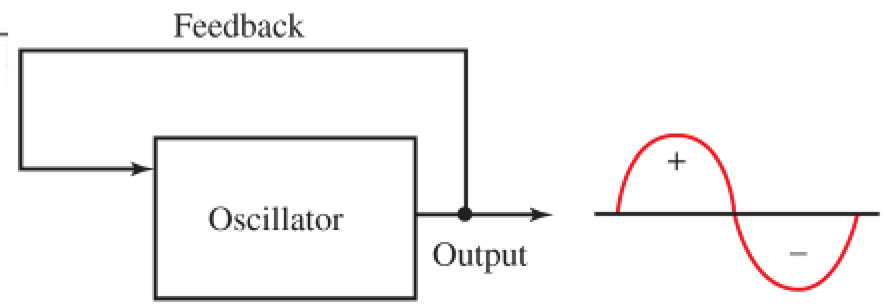
Produces multiple frequency components.



The Oscillator Feedback Loop

A basic structure of a sinusoidal oscillator consists of an amplifier and a frequency-selective network connected in a positive-feedback loop.





$$A_f(s) \equiv \frac{x_o}{x_i} = \frac{A(s)}{1 - A(s)\beta(s)}$$

$$L(s) \equiv A(s)\beta(s)$$

The condition for the feedback loop to provide sinusoidal oscillations of frequency w_o is

$$L(j\omega_0) \equiv A(j\omega_0)\beta(j\omega_0) = 1$$

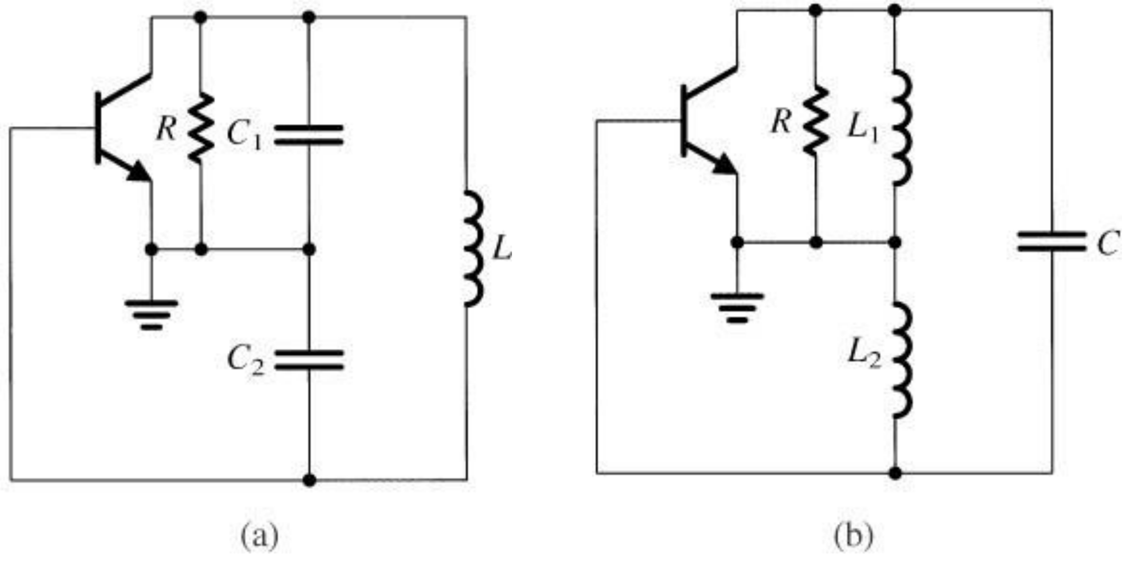
Barkhausen Criterion:

❶ At w_o the phase of the loop gain should be zero.

❷ At w_o the magnitude of the loop gain should be unity.

LC and Crystal Oscillators

For higher frequencies (> 1MHz)



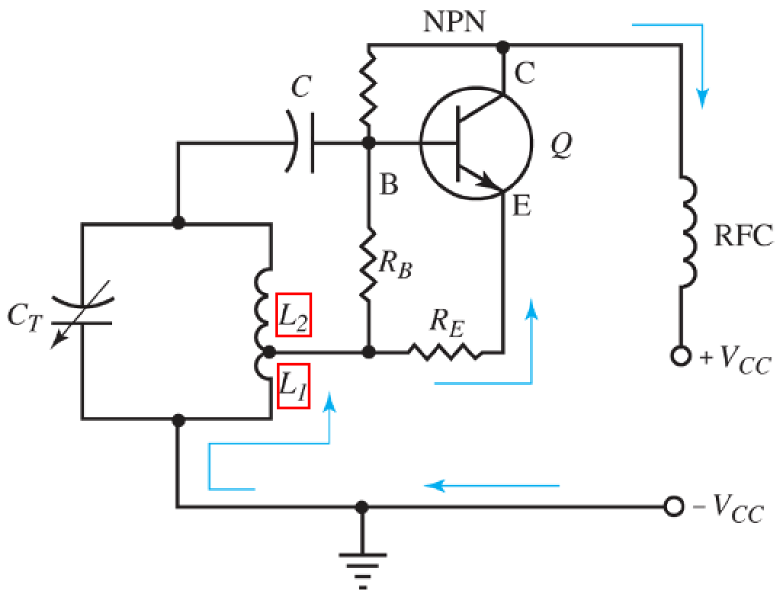
$$wo = \frac{1}{\sqrt{L(\frac{C1C2}{C1+C2})}}$$

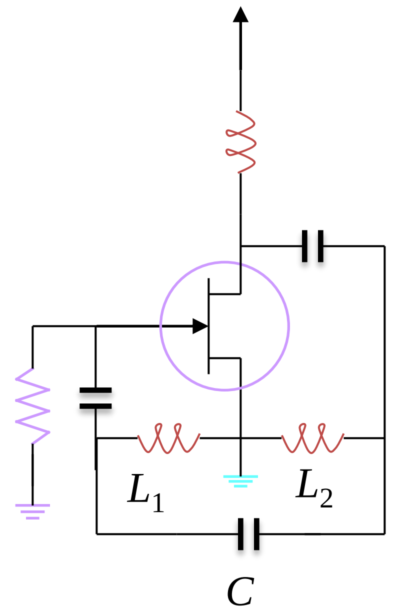
$$wo = \frac{1}{\sqrt{(L1+L2)C}}$$

(a) Colpitts and (b) Hartley.

Hartley Oscillator

Used in radio receivers and transmitters More stable than Armstrong oscillators Radio frequency choke (RFC)



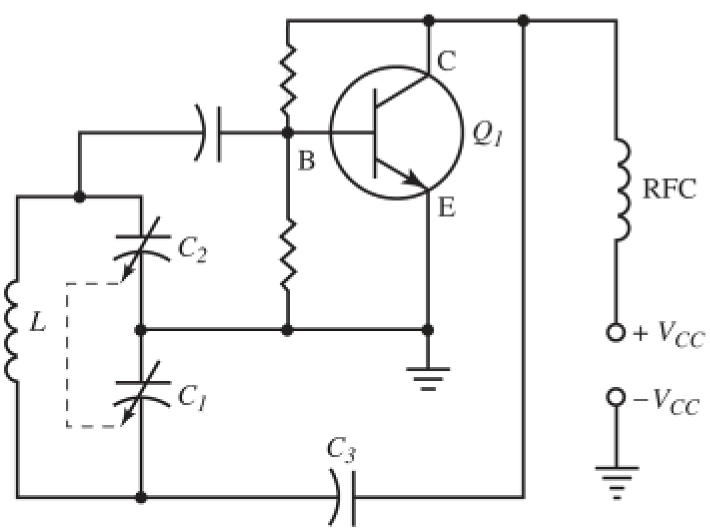


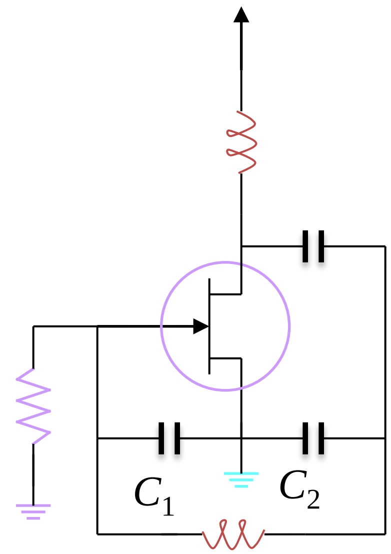
$$f_0 = \frac{1}{2\pi\sqrt{L_{eq}C}} \quad where\ L_{eq} = L_1 + L_2 + 2M$$

$$M = Mutual\ coupling\ between\ L_1\ \&\ L_2$$

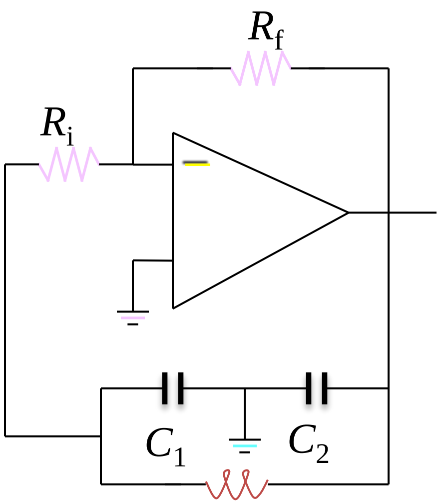
Colpitts Oscillators

BJT; FET; and IC Based





LC network

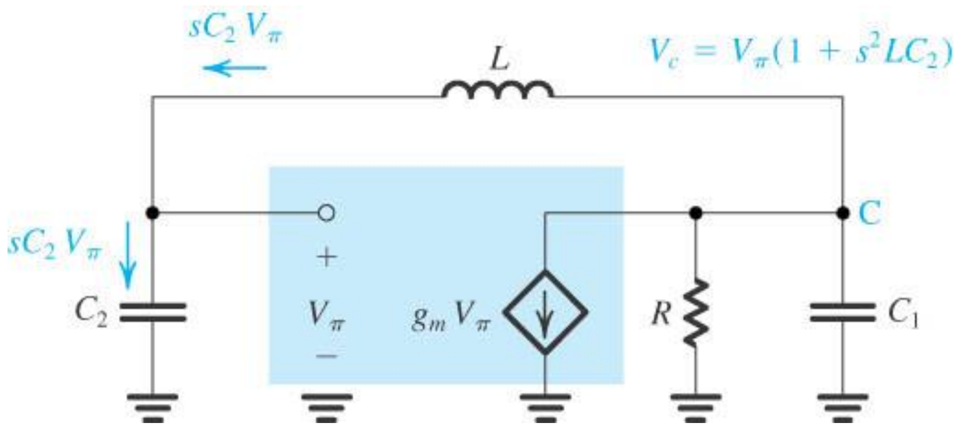


LC network

$$f_0 = \frac{1}{2\pi\sqrt{LC_{eq}}} \quad where\ C_{eq} = \frac{C_1 C_2}{C_1 + C_2}$$

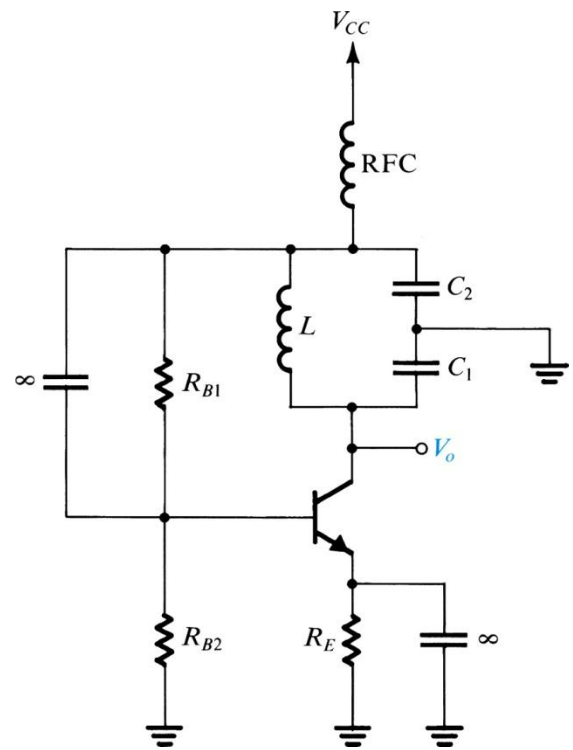
RFC is an impedance which is high (open) at high RF frequencies and low (short) to dc voltages

Equivalent Circuit of the Colpitts Oscillator



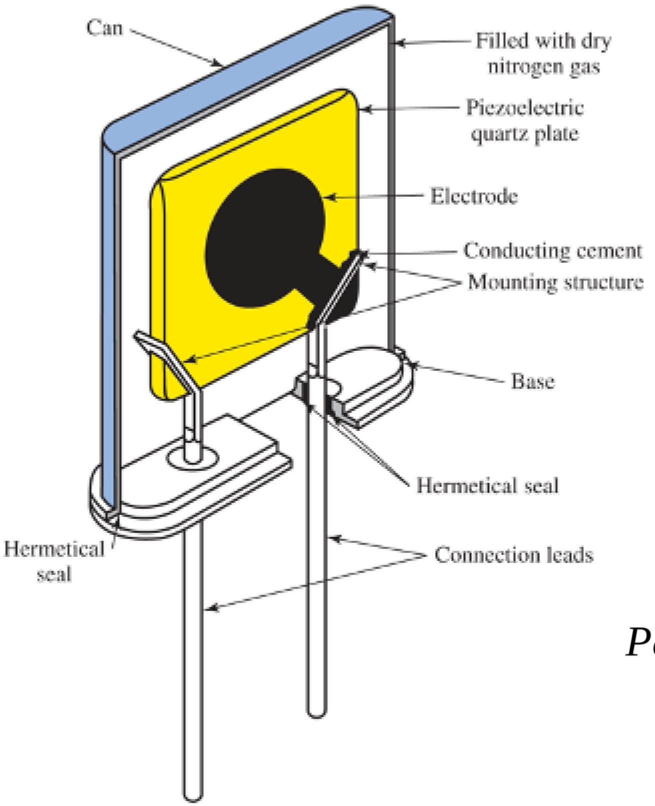
$$wo = \frac{1}{\sqrt{L(\frac{C1C2}{C1+C2})}}$$

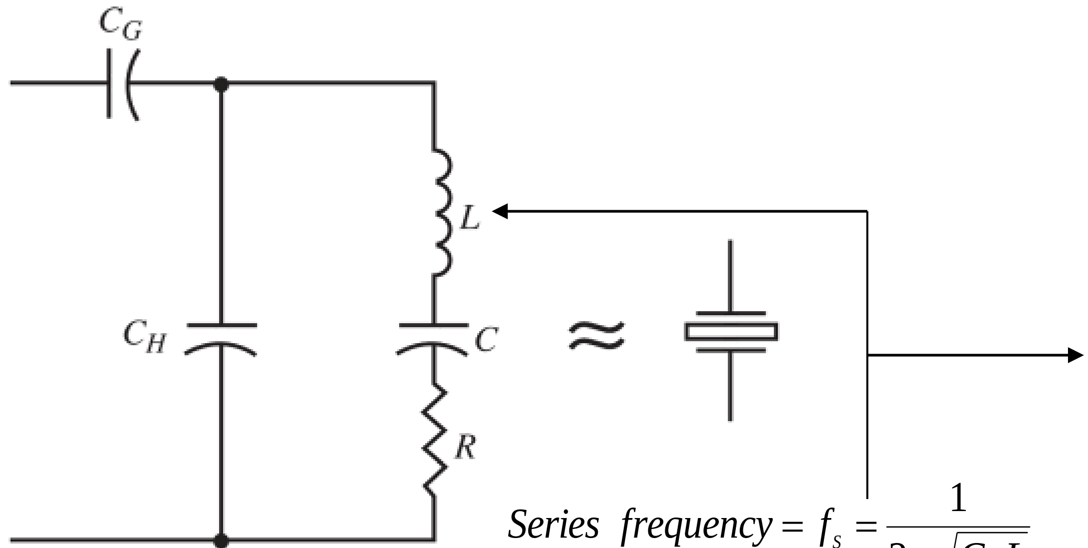
Complete Circuit for a Colpitts Oscillator



Crystal Oscillators

Crystal is a piezo-electric device which converts mechanical pressure to electrical voltage or vice-vasa





$$Series\ \ frequency = f_S = \frac{1}{2\pi\sqrt{C_S L}}$$

$$Parallel\ \ frequency = f_P = \frac{1}{2\pi\sqrt{\left(\frac{C_S C_P}{C_S + C_P}\right)L}}$$

Radio communications, broadcasting stations

Piezoelectric effect

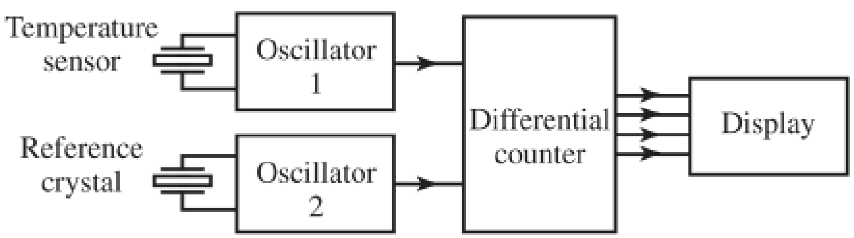
Why are crystal oscillators used in many commercial transmitters?

One reason: A wide range of frequencies that the oscillator can work for.

An Application of Crystal Oscillator

Crystals are fabricated by cutting the crude quartz in a very exacting fashion. The type of cut determines the crystal's natural resonant frequency as well as it's temperature coefficient.

Crystal are available at frequencies about 15kHz and up providing the best frequency stability. However above 100MHz, they become so small that handling becomes a problem.

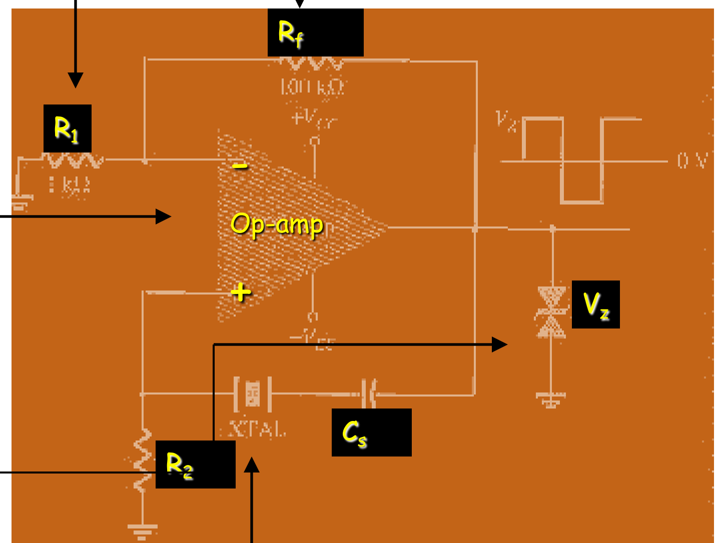


Two crystals producing two different frequencies for measuring temperature Timing devices

Op-Amp Crystal Oscillator

Op-amp voltage gain is controlled by the negative feedback circuit formed by R_f and R_1. More NFB will damp the oscillation, critical NFB will have a sine wave output and less NFB will have a square wave output.

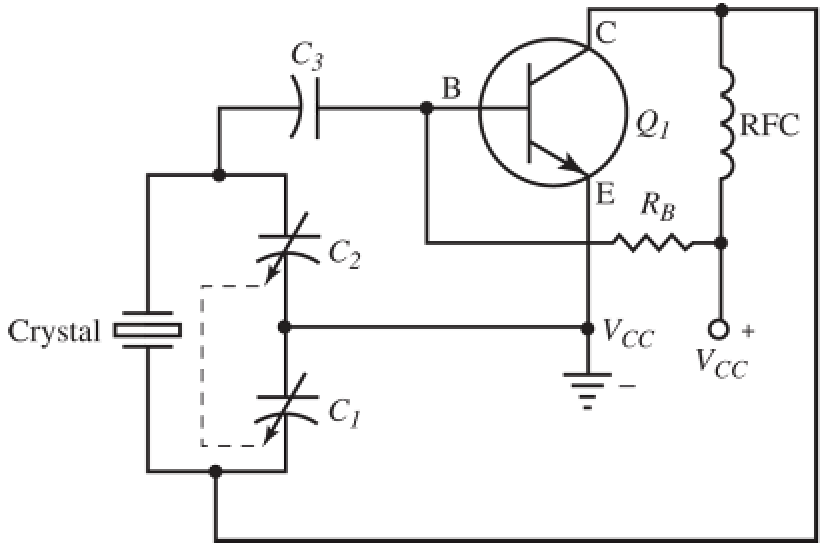
It is very flexible to construct the Op. Amp. crystal oscillator due to high amplifier gain and differential input facility of the Op. Amp.



The two Zener diodes connected face to face is to limit the peak to peak output voltage equal to twice of Zener voltage.

The crystal is fed in series to the positive feedback which is required for oscillation. Therefore the oscillation frequency will be crystal series resonant frequency f_s.

Example



Crystal used instead of inductor in the tank circuit of Colpitts oscillator

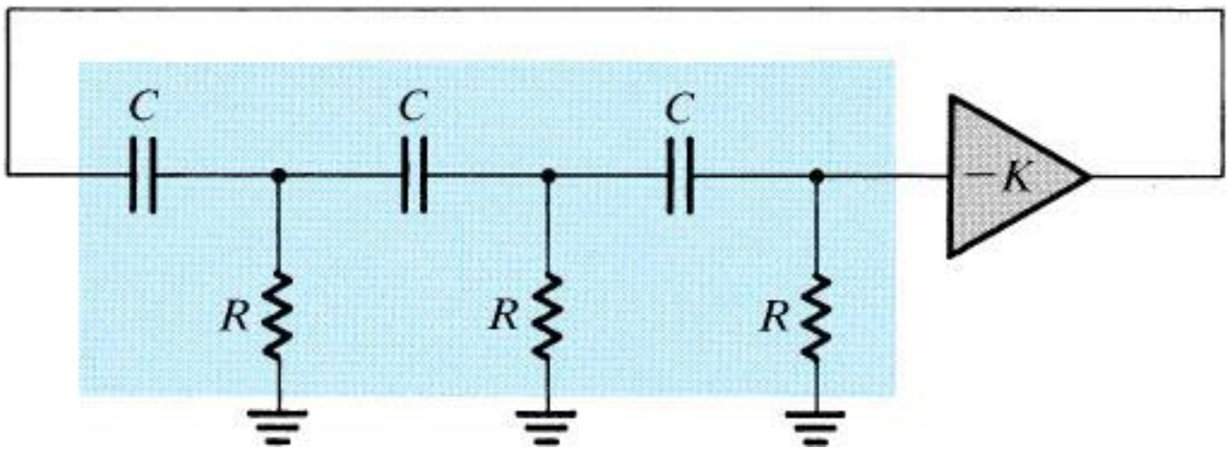
The Phase Shifter Oscillator

The phase-shifter consists of a negative gain amplifier (-K) with a third order RC ladder network in the feedback.

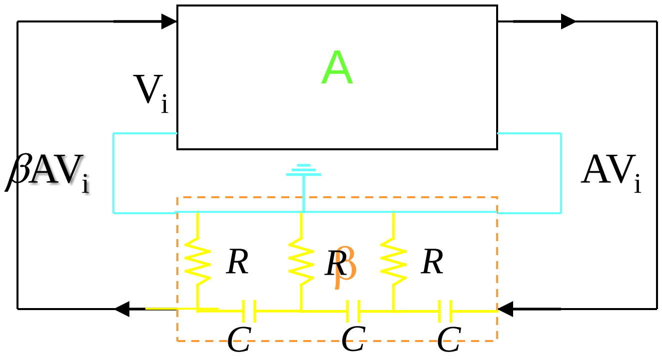
The circuit will oscillate at the frequency for which the phase shift of the RC network is 180°. Only at the frequency will the total phase shift around the loop be 0° or 360°.

The minimum number of RC sections is 3 because it is capable of producing a 180° phase shift at a finite frequency.

Ref: Wikipedia (http://en.wikipedia.org/wiki/Phase-shift_oscillator) "The mathematics for calculating the oscillation frequency and oscillation criterion for this circuit are surprisingly complex, due to each RC stage loading the previous ones. The calculations are greatly simplified by setting all the resistors (except the negative feedback resistor) and all the capacitors to the same values. In the diagram, if R1=R2=R3=R, and C1=C2=C3=C, then:"



Phase-shift Oscillator



$\beta AV_i = V_i$ (or) $A\beta = 1$

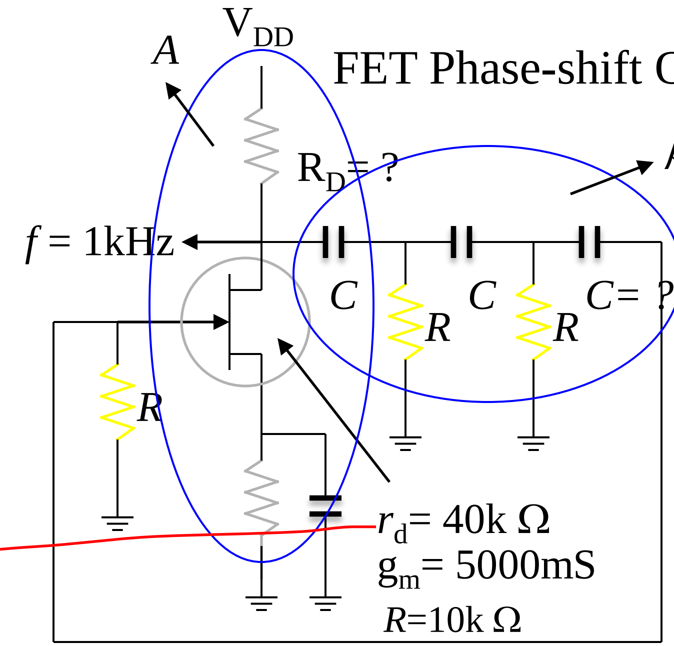
Frequency of oscillation

$$f = \frac{1}{2\pi RC\sqrt{6}}$$

Condition of oscillation

$$\beta \le \frac{1}{29} \qquad A\beta = 1 \qquad \therefore A \ge 29$$

FET Phase-shift Oscillator



Example:

Determine the value of capacitance C and the value of R_D of the Phase-shift oscillator shown, if the output frequency is 1 kHz. Take r_d = 40k and g_m=5000mS, for the FET and R = 10kW.

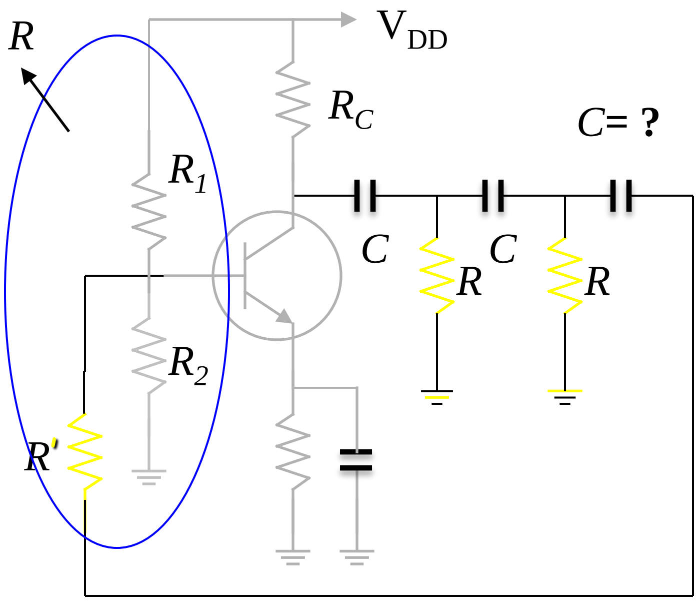
$$f = \frac{1}{2\pi RC\sqrt{6}} \Rightarrow C = \frac{1}{2\pi Rf\sqrt{6}} = \frac{1}{2\pi 10k \times 1k\sqrt{6}} = \underline{\underline{6.5nF}}$$

$$A\beta \ge 1 \;\; Let \;\; A = 40 > 29 \; \therefore |A| = g_m R_L = 40 \Rightarrow R_L = \frac{40}{g_m} = \frac{40}{5000\mu S} = 8k\Omega$$

$$But \;\; R_L = R_D // r_d = R_D // 40k\Omega = 8k\Omega \; \therefore R_D = \frac{8k \times 40k}{40k - 8k} = \underline{\underline{10k\Omega}}$$

8 = (R_D X 40) / (R_D + 40)
=> R_D = 10 kOhm

BJT Phase-Shift Oscillator



Example:
Determine the value of capacitance C and the value of h_{fe} of the Phase-shift oscillator shown, if the output frequency is 1kHz. Take R=10 k. R_C =1 k.

$$f = \frac{1}{2\pi RC\sqrt{6+4R_C/R}} = 1kHz = \frac{1}{2\pi 10kC\sqrt{6+4\times 1k/10k}}$$

$$C = \frac{1}{2\pi 10k \times 1k\sqrt{6+4\times 1k/10k}} = 0.006\mu F = \underline{\underline{6nF}}$$

Frequency of oscillation

$$f = \frac{1}{2\pi RC\sqrt{6+4R_C/R}}$$

Condition of oscillation

$$A\beta = 1 \Rightarrow \therefore A \geq 29 \qquad \beta \leq \frac{1}{29}$$

$$for\ BJT \Rightarrow h_{fe} \geq 23 + 29\frac{R}{R_C} + 4\frac{R_C}{R}$$

$$for\ BJT \Rightarrow h_{fe} \geq 23 + 29\frac{R}{R_C} + 4\frac{R_C}{R}$$

$$\geq 23 + 29\frac{10k}{1k} + 4\frac{1k}{10k} \geq 23 + 290 + 0.4 \geq \underline{\underline{313.4}}$$

IC Phase-shift Oscillator

Frequency of oscillation

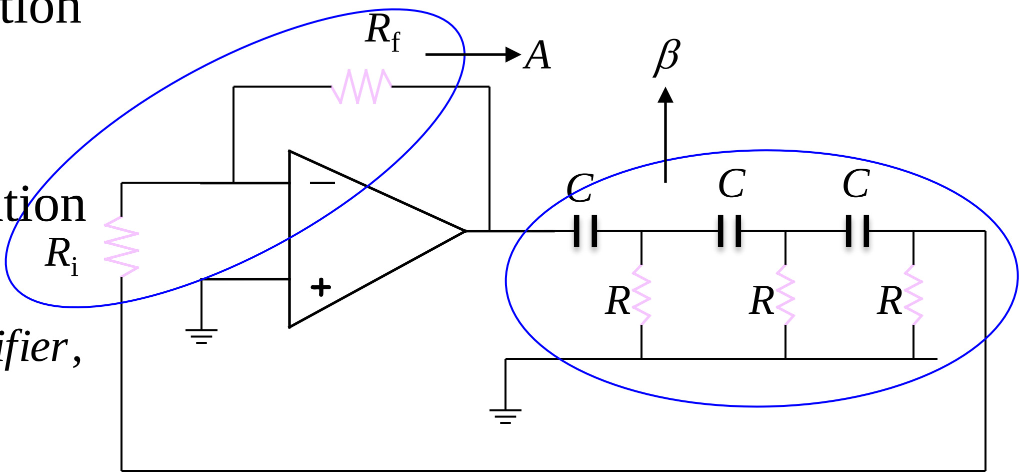
$$f = \frac{1}{2\pi RC\sqrt{6}}$$

Condition of oscillation

$$A\beta = 1 \therefore A \geq 29$$

for IC inverting amplifier,

$$|A| = \frac{R_f}{R_i} \geq 29 \qquad \beta \leq \frac{1}{29}$$



Example:

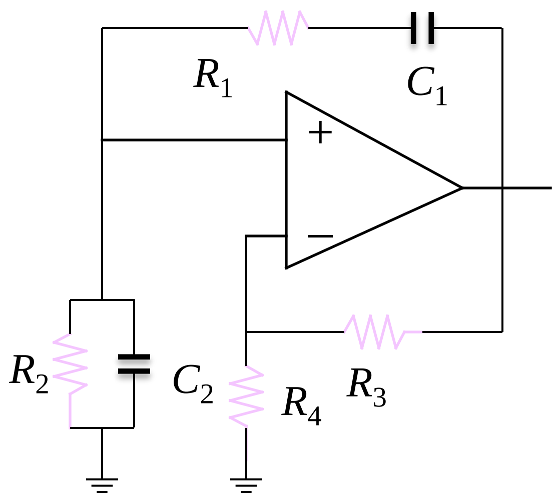
Determine the value of capacitance C and the value of R_f of the IC Phase-shift oscillator shown, if the output frequency is 1kHz. Take R =10kW. R_i =1kW.

$$f = \frac{1}{2\pi RC\sqrt{6}} \Rightarrow C = \frac{1}{2\pi Rf\sqrt{6}} = \frac{1}{2\pi 10k \times 1k\sqrt{6}} = \underline{\underline{6.5nF}}$$

for IC inverting amplifier,

$$|A| = \frac{R_f}{R_i} \geq 29 \Rightarrow R_f \geq 29R_i \geq \underline{\underline{29\text{k}\Omega}}$$

Wien Bridge Oscillator



Frequency of oscillation

$$f = \frac{1}{2\pi\sqrt{R_1C_1R_2C_2}} \qquad f = \frac{1}{2\pi RC}\begin{pmatrix} if \;\; R_1 = R_2 = R \\ C_1 = C_2 = C \end{pmatrix}$$

Condition of oscillation

$$\frac{R_3}{R_4} = \frac{R_1}{R_2} + \frac{C_2}{C_1} \qquad \frac{R_3}{R_4} = 2\begin{pmatrix} if \;\; R_1 = R_2 = R \\ C_1 = C_2 = C \end{pmatrix}$$

Example: Determine the value of capacitance C_1 and R_1 if R_2 =10kW C_2 = 0.1mF R_3 =10kΩ R_4 =1kW in the Wien bridge oscillator shown has an output frequency of 1kHz.

$$f = \frac{1}{2\pi\sqrt{R_1C_1R_2C_2}} \Rightarrow f^2 = \frac{1}{4\pi^2R_1C_1R_2C_2}$$ Frequency of oscillation

$$R_1C_1 = \frac{1}{4\pi^2 f^2 R_2C_2} = \frac{1}{4\pi^2(1k)^2 10k \times 0.1\mu} = 0.025ms \Rightarrow C_1 = \frac{0.025ms}{R_1}$$

$$\frac{R_3}{R_4} = \frac{R_1}{R_2} + \frac{C_2}{C_1} \Rightarrow \frac{10k}{1k} = \frac{R_1}{10k} + \frac{0.1\mu F}{0.025ms} \Rightarrow \frac{R_1}{10k} = 10 - \frac{0.1}{25} = 9.996$$

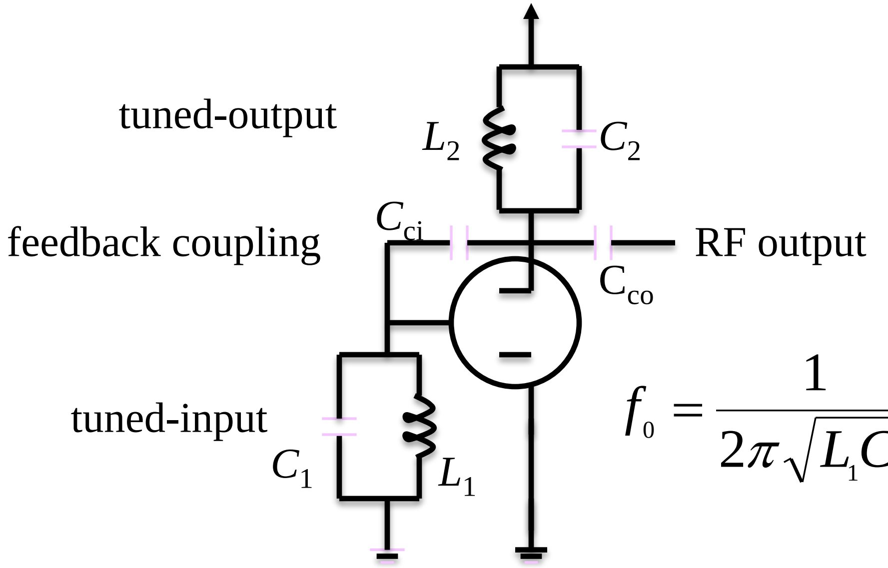
$$R_1 = 9.996 \times 10k = 99.96k \approx \underline{\underline{100k\Omega}}$$

$$C_1 = \frac{0.025ms}{100k} = 0.00025\mu = \underline{\underline{250\,pF}}$$ Condition of oscillation

Tuned Oscillators (Radio Frequency Oscillators)

Tuned oscillator is a circuit that generates a radio frequency output by using LC tuned (resonant) circuit. Because of high frequencies, small inductance can be used for the radio frequency of oscillation.

Tuned-input and tuned-output Oscillator

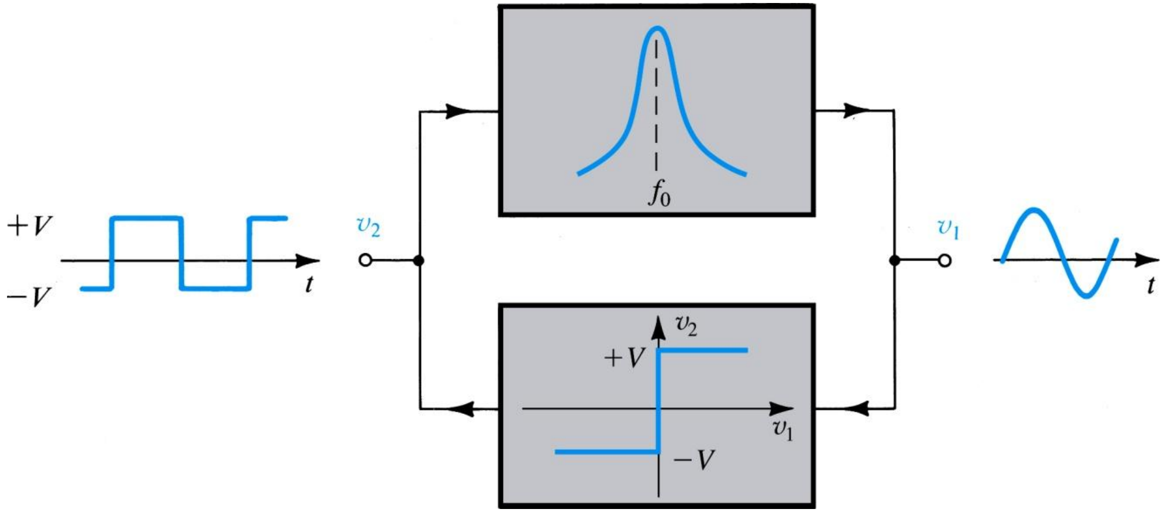


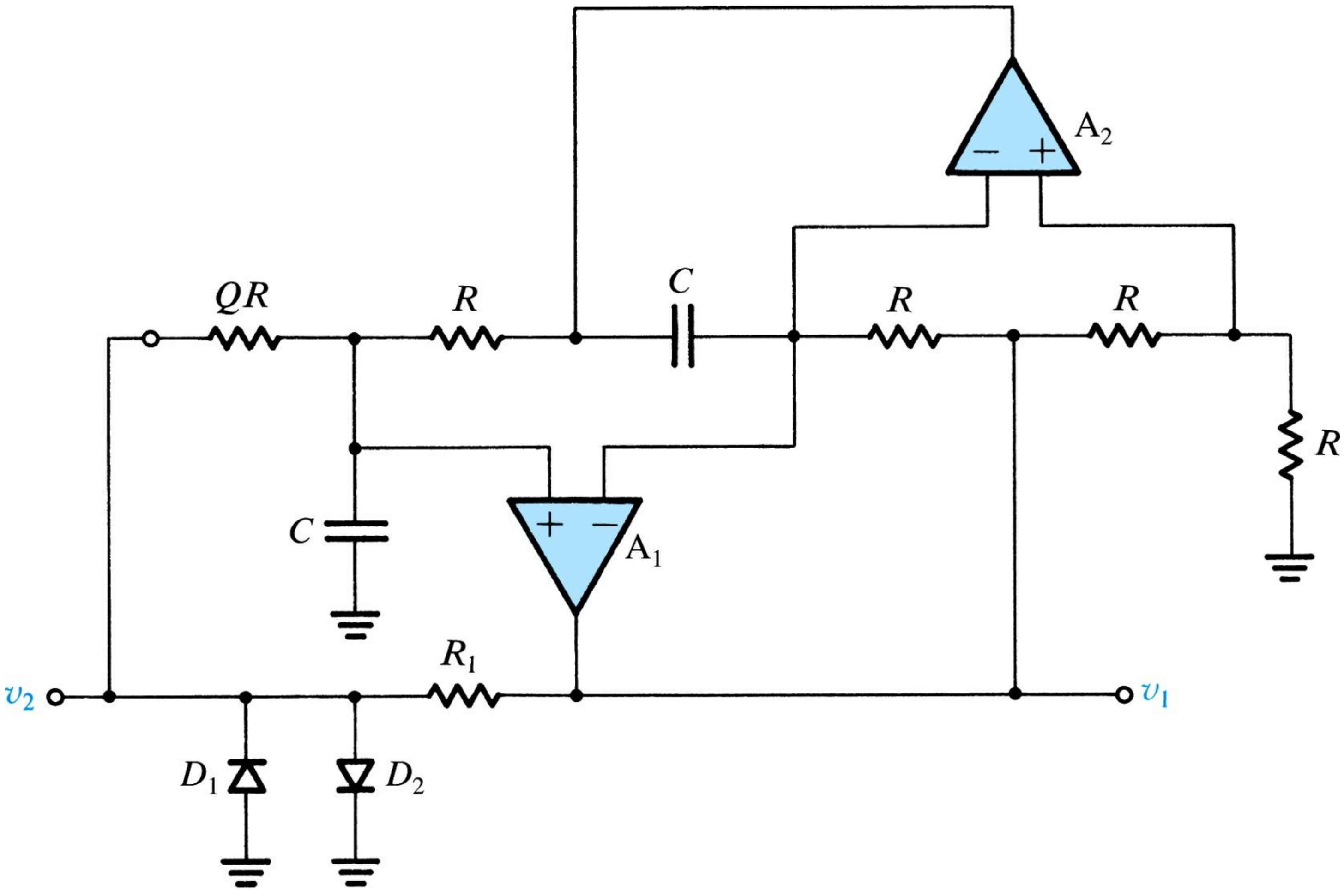
$$f_0 = \frac{1}{2\pi\sqrt{L_1C_1}} = \frac{1}{2\pi\sqrt{L_2C_2}}$$

The Active-Filter-Tuned Oscillator

Assume the oscillations have already started. The output of the band-pass filter will be a sine wave whose frequency is equal to the center frequency of the filter.

The sine-wave signal is fed to the limiter and then produces a square wave.



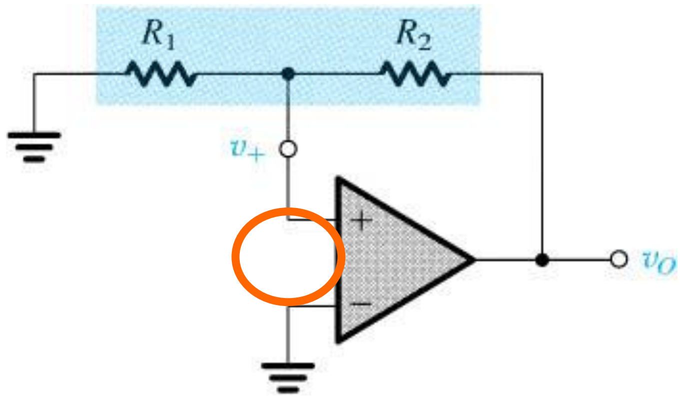


Practical implementation of the active-filter-tuned oscillator

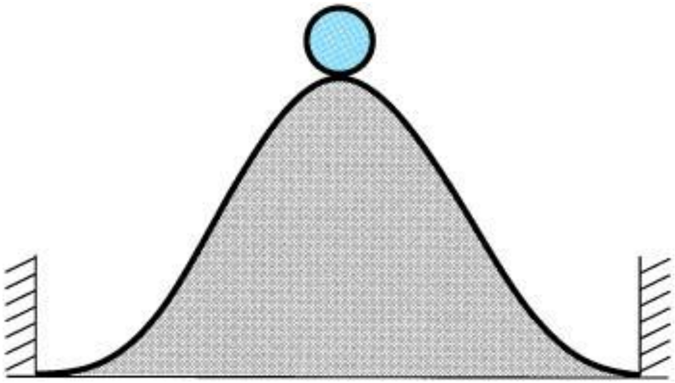
Bistable Multivibrators

Another type of waveform generating circuits is the nonlinear oscillators or function generators which uses multivibrators.

A bistable multivibrator has 2 stable states. The circuit can remain in either state indefinitely and changes to the other one only when triggered.



Metastable state: v_+=0 and v_O=0. The circuit cannot exist in the mestastable state for any length of time since any disturbance causes it to switch to either stable state.



$$v_O = L_+ \text{ and } v_+ = L_+ R_1/(R_1+R_2).$$
$$v_O = L_- \text{ and } v_+ = L_- R_1/(R_1+R_2).$$

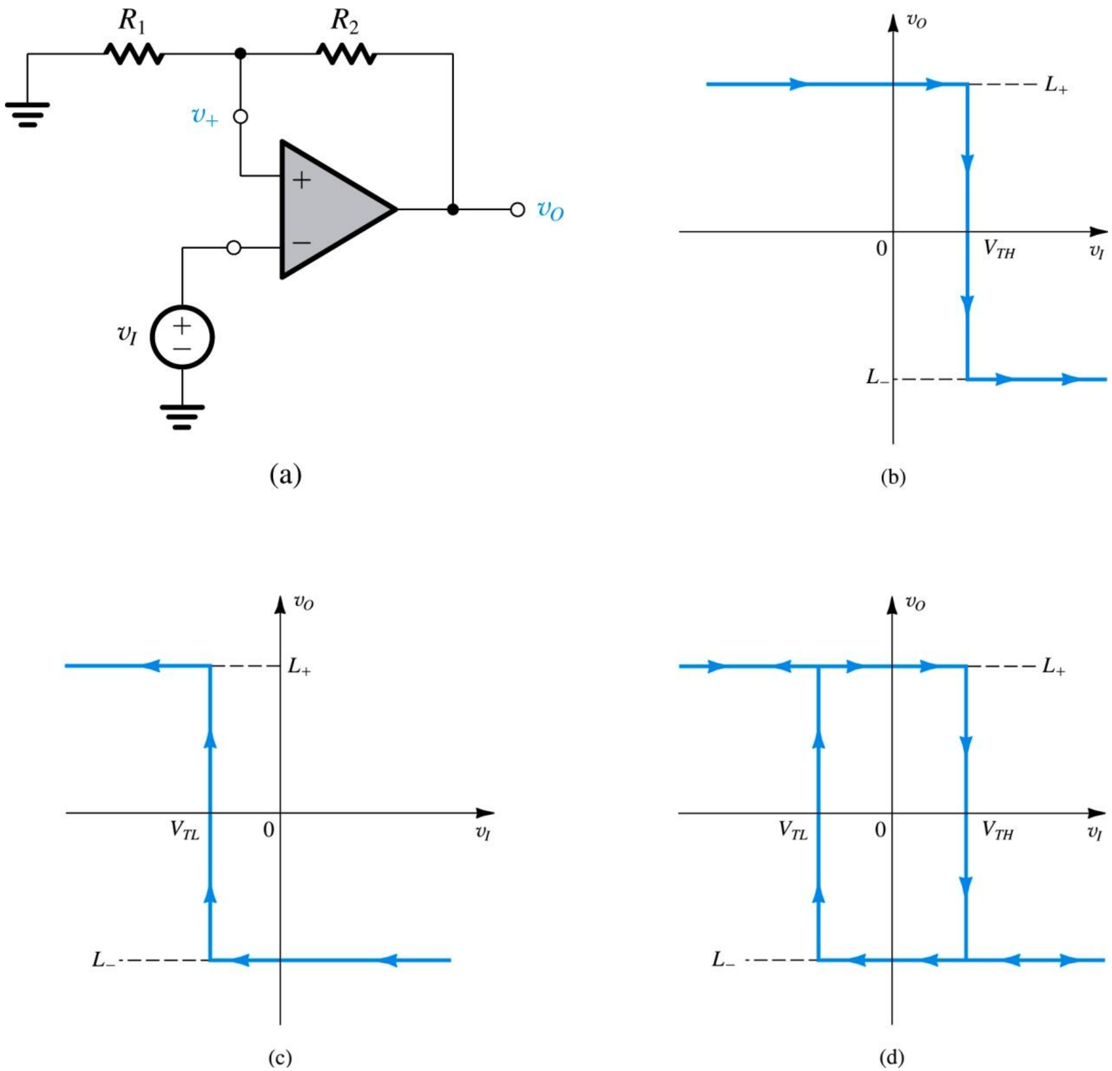


Figure 12.19 (a) The bistable circuit of Fig. 12.17 with the negative input terminal of the op amp disconnected from ground and connected to an input signal v_I. **(b)** The transfer characteristic of the circuit in **(a)** for increasing v_I. **(c)** The transfer characteristic for decreasing v_I. **(d)** The complete transfer characteristics.

Bistable Circuit with Inverting Transfer Characteristics

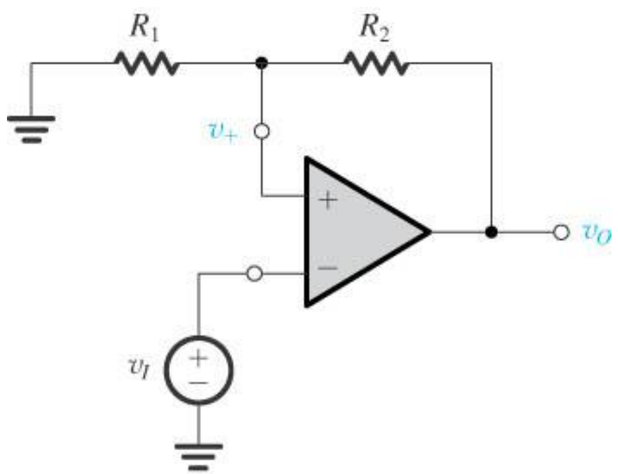
Assume that v_O is at one of its two possible levels, say L_+, and thus $v_+ = \beta L_+$.

❶ As v_I increases from 0 and then exceeds βL_+, a negative voltage developes between input terminals of the op amp.

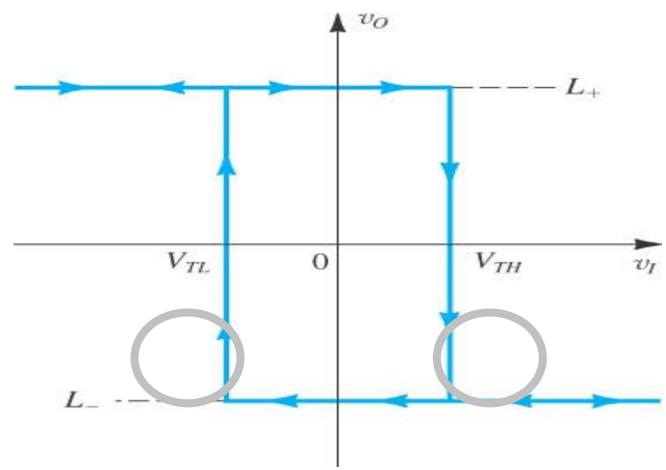
❷ This voltage is amplified and v_O goes negative.

❸ The voltage divider causes v_+ to go negative, increasing the net negative input and keeping the regenerative process going.

❹ This process culminates in the op amp saturating, that is, $v_O = L_-$.

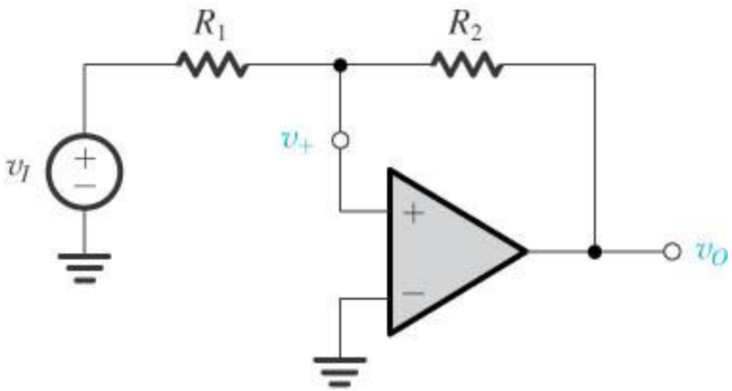


The circuit is said to be inverting

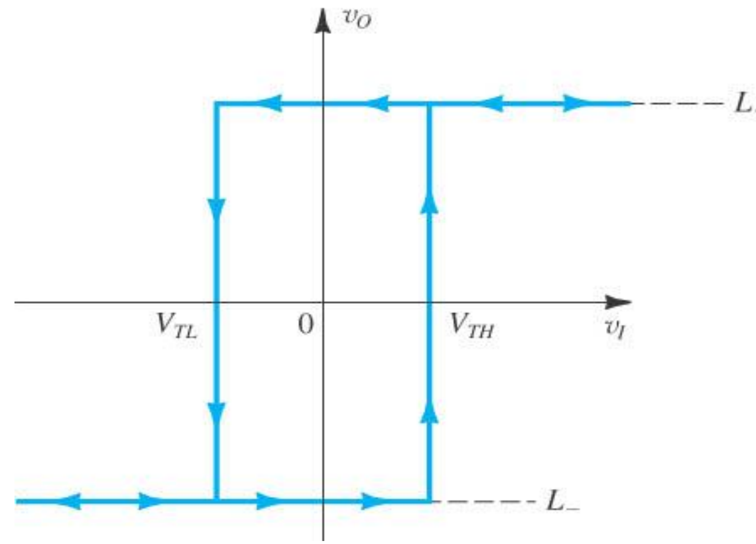


Trigger signal

Bistable Circuit with Noninverting Transfer Characteristics

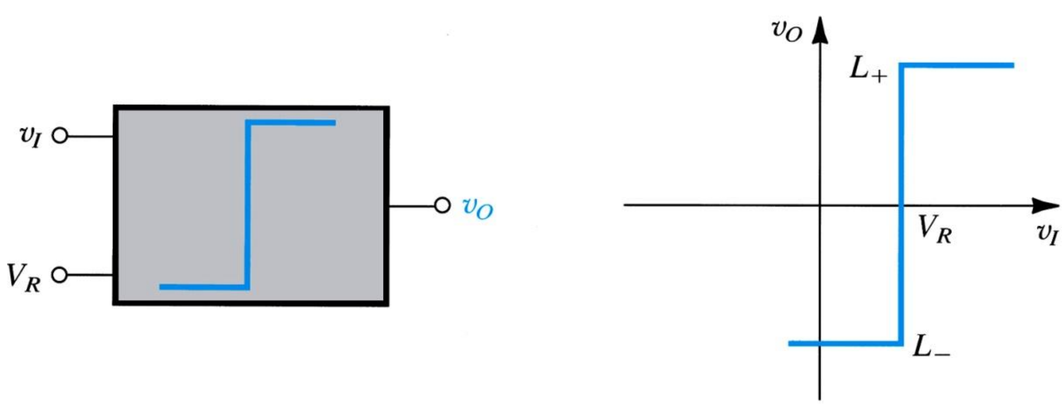


$$v_+ = v_I R_2/(R_1+R_2) + v_O R_1/(R_1+R_2)$$

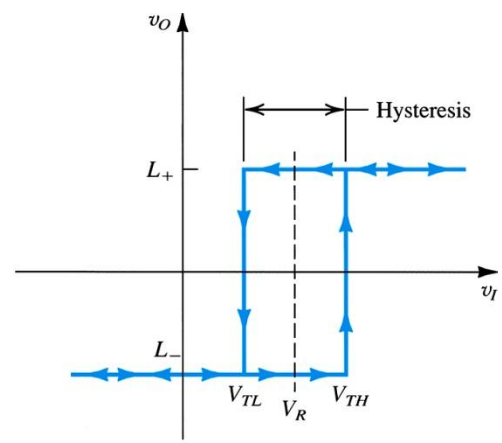


$$V_{TL} = -L_+(R_1/R_2)$$

$$V_{TH} = -L_-(R_1/R_2)$$



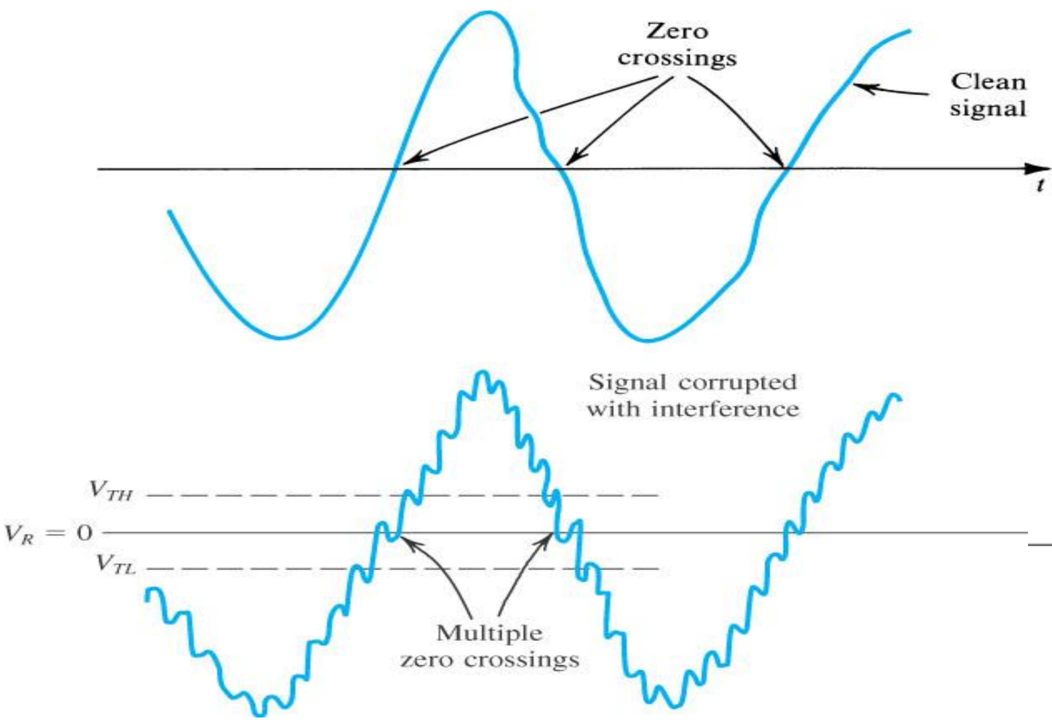
(a)

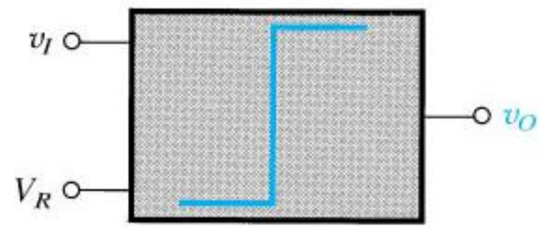


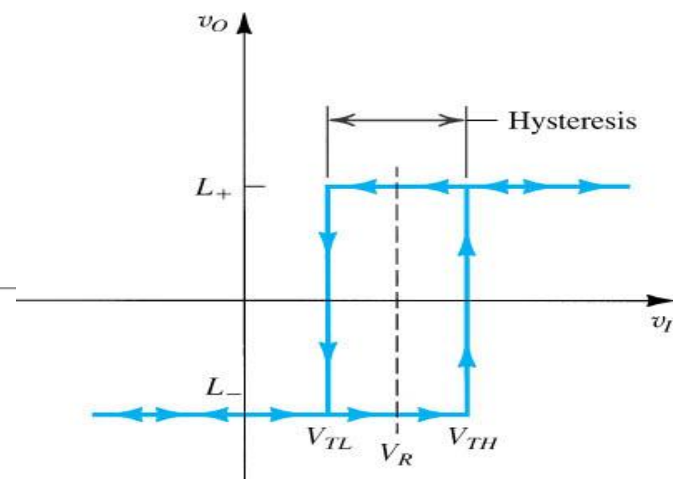
(b)

Application of the Bistable Circuit as a Comparator

To design a circuit that detects and counts the zero crossings of an arbitrary waveform, a comparator whose threshold is set to 0 can be used. The comparator provides a step change at its output every time zero crossing occurs.

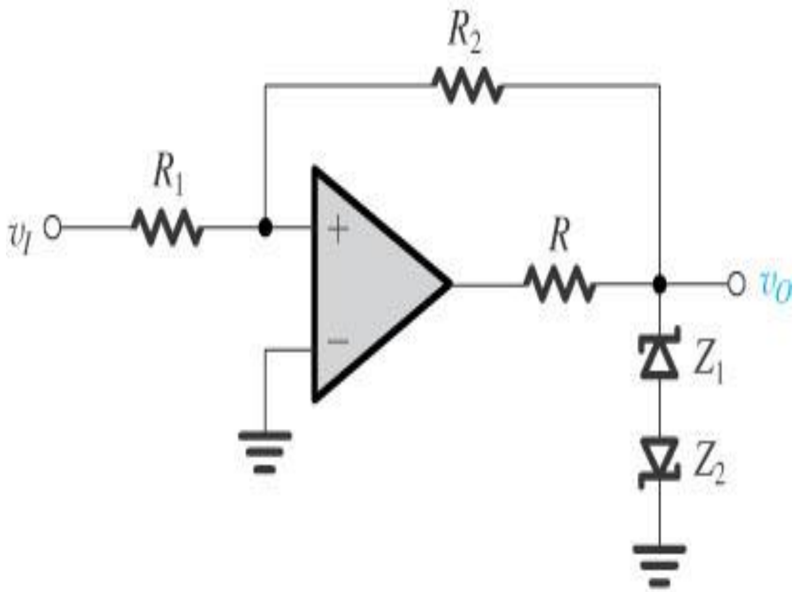


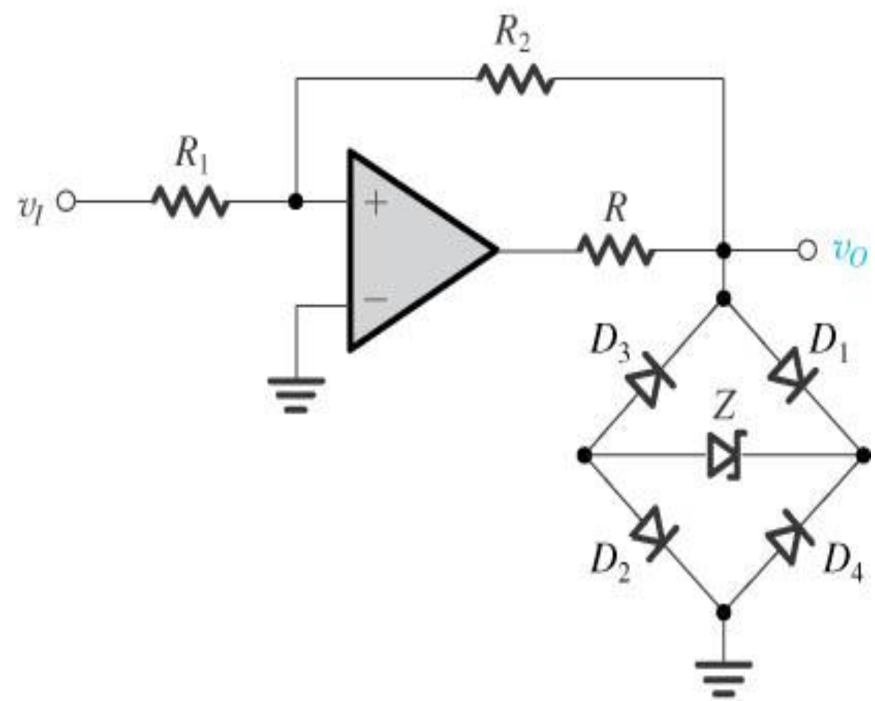




Bistable Circuit with More Precise Output Level

Limiter circuits are used to obtain more precise output levels for the bistable circuit.



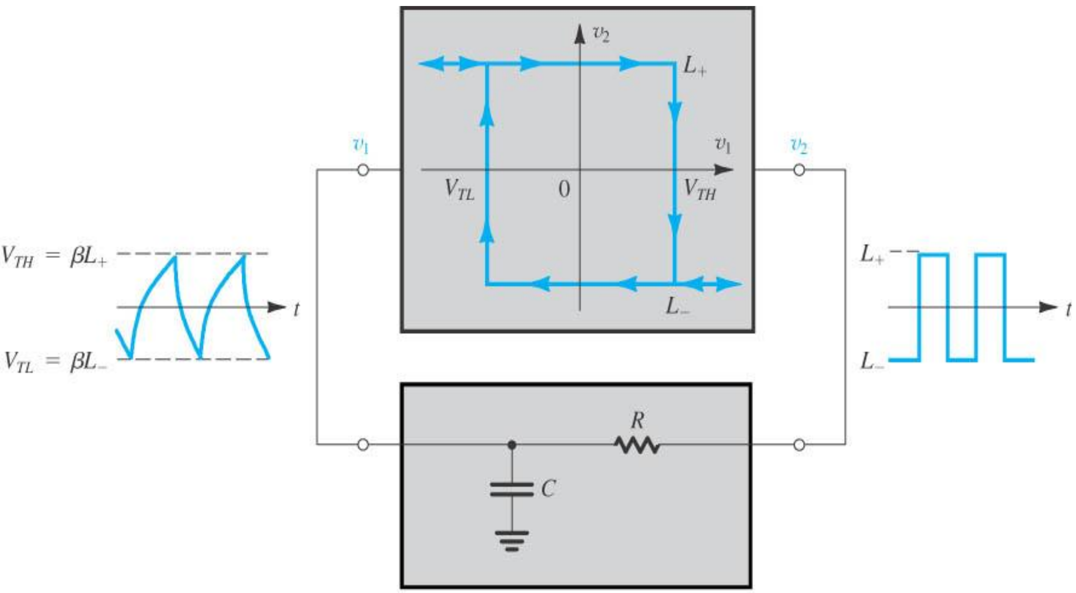


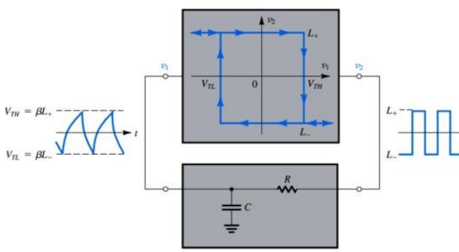
$L+ = V_{Z1} + V_D$ and $L- = -(V_{Z2} + V_D)$, where V_D is the forward diode drop.

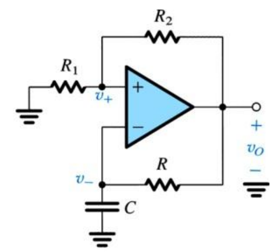
$L+ = V_Z + V_{D1} + V_{D2}$ and $L- = -(V_Z + V_{D3} + V_{D4})$.

Operation of the Astable Multivibrator

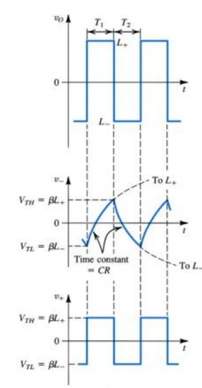
Connecting a bistable multivibrator with inverting transfer characteristics in a feedback loop with an RC circuit results in a square-wave generator.




(a)

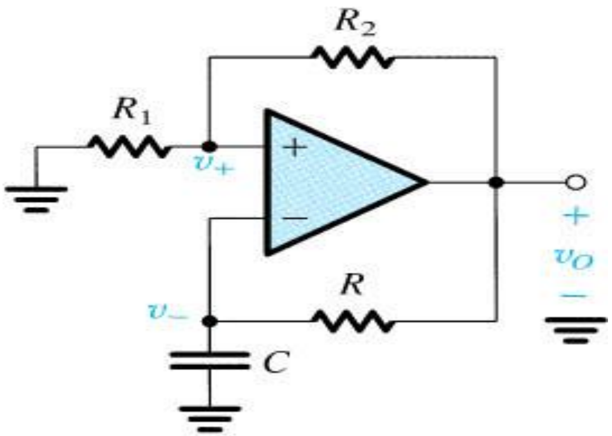


(b)



(c)

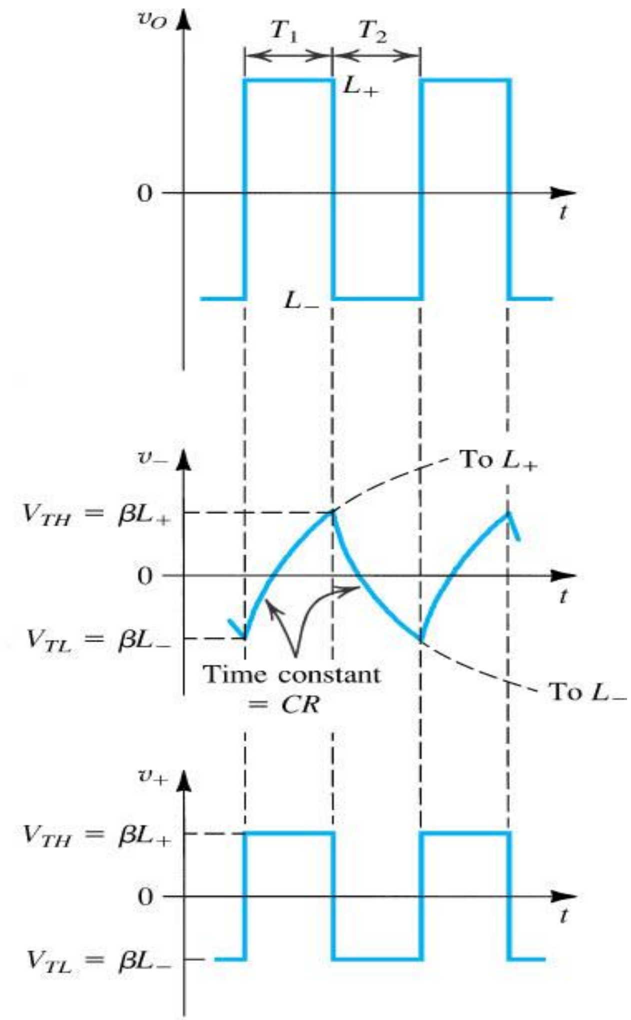
Operation of the Astable Multivibrator



$$v_- = L_+ - (L_+ - \beta \cdot L_-)e^{-T_1/RC} = \beta \cdot L_+ \quad \rightarrow T_1 = \tau \ln \frac{1-\beta(L_-/L_+)}{1-\beta}$$

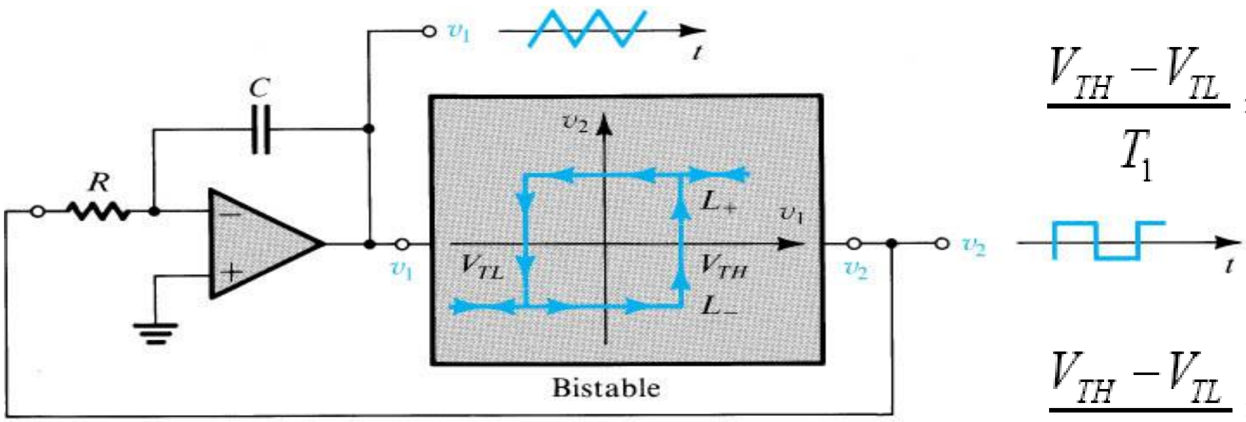
$$v_- = L_- - (L_- - \beta \cdot L_+)e^{-T_2/RC} = \beta L_- \quad \rightarrow T_2 = \tau \ln \frac{1-\beta(L_+/L_-)}{1-\beta}$$

$$T \approx 2\tau \ln \frac{1+\beta}{1-\beta}$$



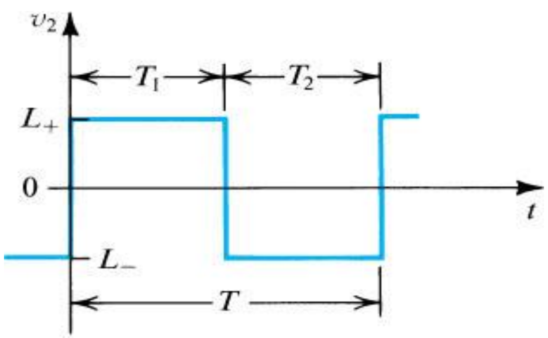
Generation of Triangular Waveforms

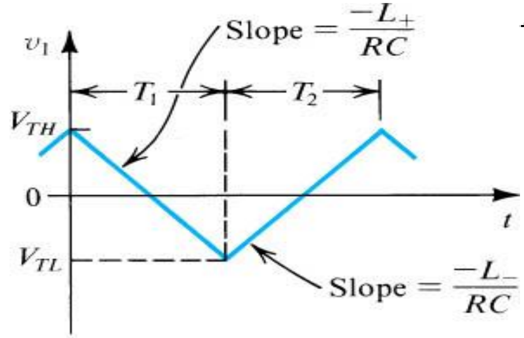
Triangular waveforms can be obtained by replacing the low-pass RC circuit with an integrator. Since the integrator is inverting, the inverting characteristics of the bistable circuit is required.



$$\frac{V_{TH}-V_{TL}}{T_1}=\frac{L_+}{RC}\rightarrow T_1=RC\frac{V_{TH}-V_{TL}}{L_+}$$

$$\frac{V_{TH}-V_{TL}}{T_2}=\frac{-L_-}{RC}\rightarrow T_2=RC\frac{V_{TH}-V_{TL}}{-L_-}$$





Generation of a Standard Pulse

In the stable state, V_A=L+ (why?), V_B=V_{D1}, V_C=βL+ (D2: ON and R4>>R1). When a negative-going step applies at the trigger input:

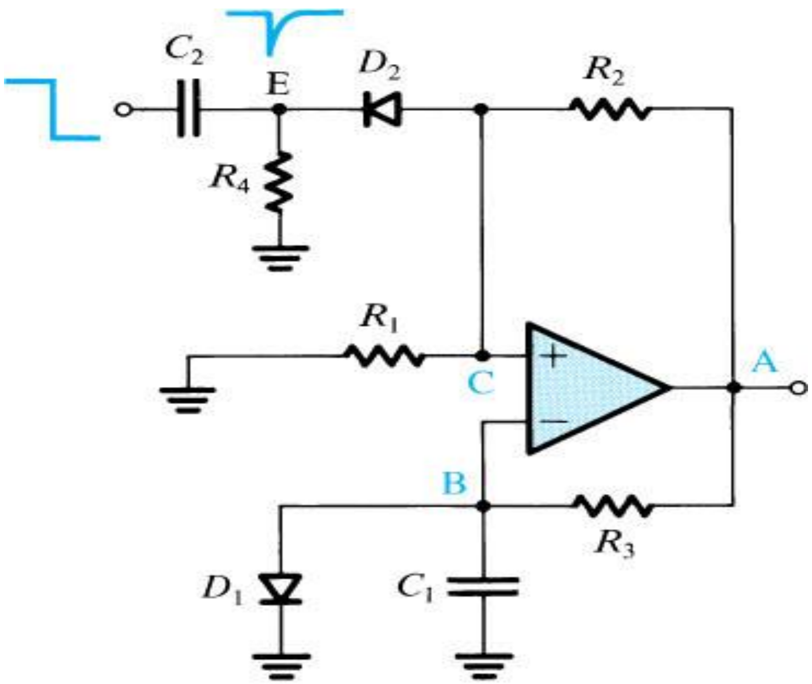
❶ D2 conducts heavily and pulls node C down (lower than V_B).

❷ The output of the op amp switch to L- and cause V_C to go toward βL-.

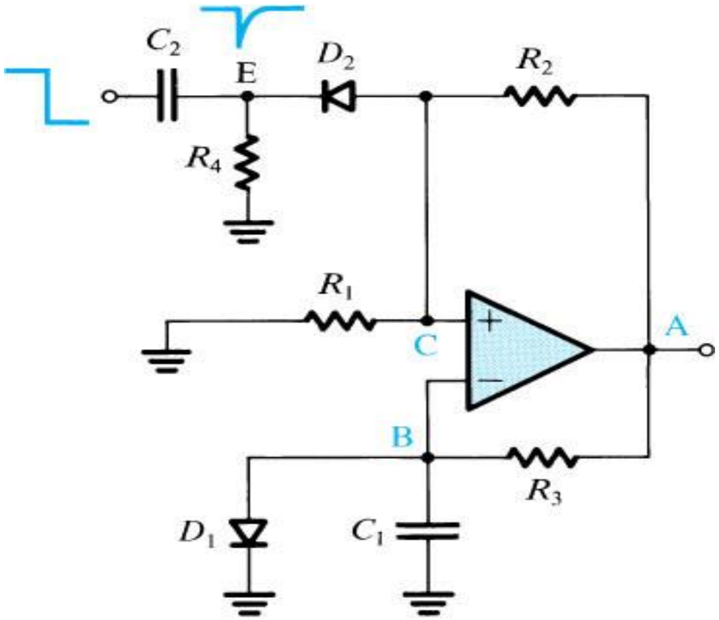
❸ D2 OFF and isolates the circuit from changes at the trigger input.

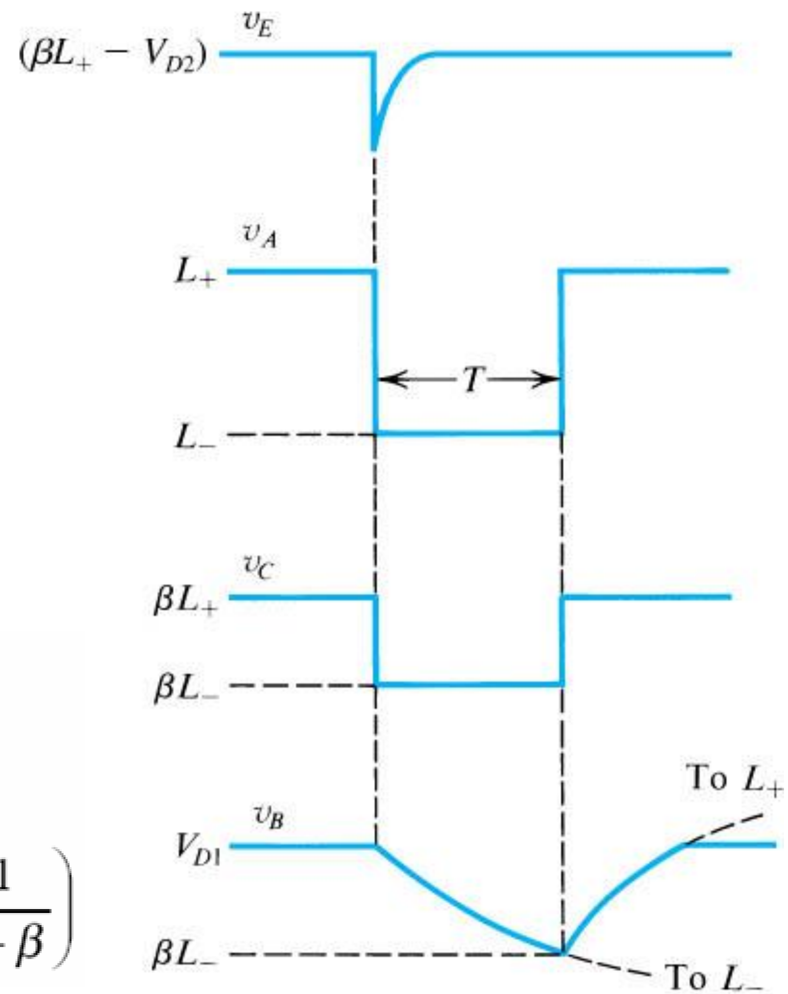
❹ D1 OFF and C1 begins to discharge toward L-.

❺ When $V_B < V_C$, the output of the op amp switch to L+.



Generation of a Standard Pulse





$$v_B(t) = L_- - (L_- - V_{D1})e^{-t/R_3C_1}$$

$$v_B(T) = L_- - (L_- - V_{D1})e^{-T/R_3C_1} = \beta \cdot L_-$$

$$\rightarrow T \approx C_1R_3 \ln\left(\frac{V_{D1} - L_-}{\beta \cdot L_- - L_-}\right) \approx C_1R_3 \ln\left(\frac{1}{1-\beta}\right)$$

The 555 Circuit

Commercially available integrated-circuit package such as 555 timer exists that contain the bulk of the circuitry needed to implement monostable and astable multivibrator.