Oscillators

Oscillators

Role of oscillators:

*oscillators are used to generate signal

*it converts power from the dc power supply into an ac power

Harmonic oscillators → sinusoidal wave form

Relaxation oscillators →produce non sinusoidal

They are used in :

1.Electronic Communication Devices .

2. Lab.

Oscillators

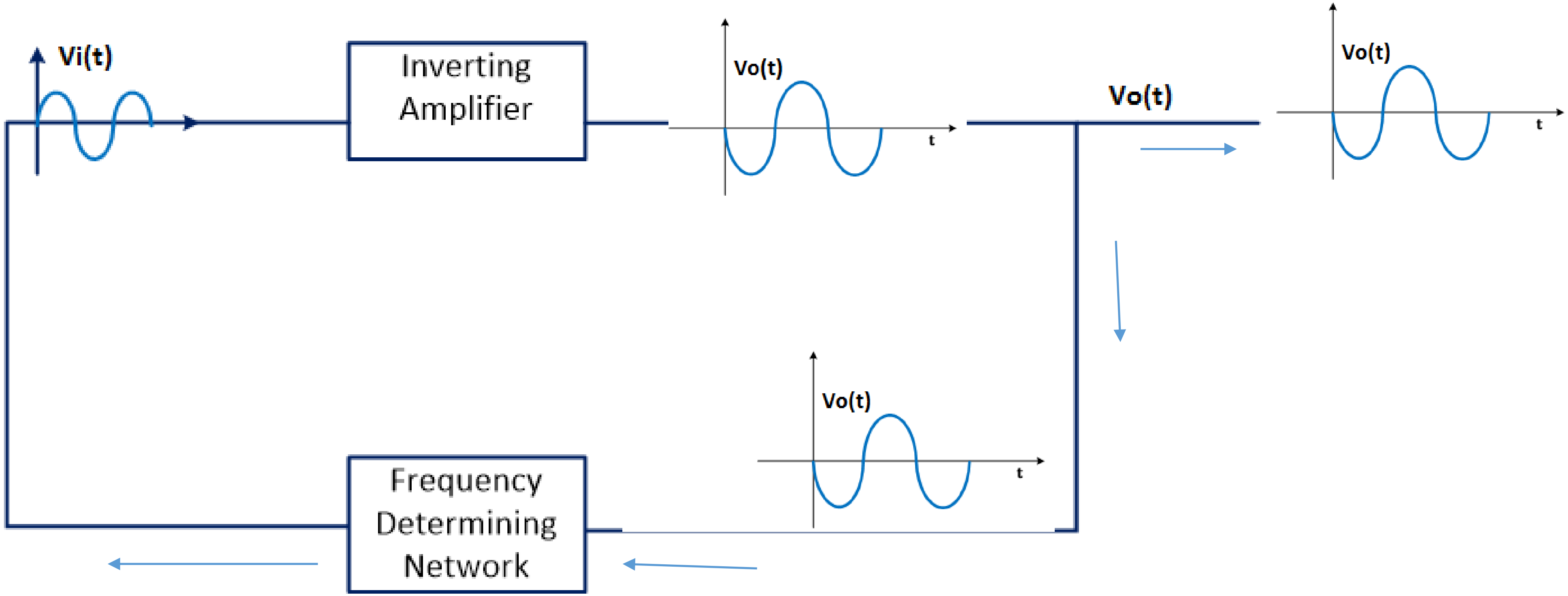
For the circuit to operate as an oscillator it must satisfy the Barkhausen criterial for sustained oscillation.

#1-The feedback must be positive ,this means that the feedback signal must be phased so that it adds to the amplifiers input signal .

#2-The loop gain (AB) must be greater than unity to allow oscillation to build up and equal to unity to sustain the oscillation .

Audio frequency Oscillators

1) Phase-shift Oscillator

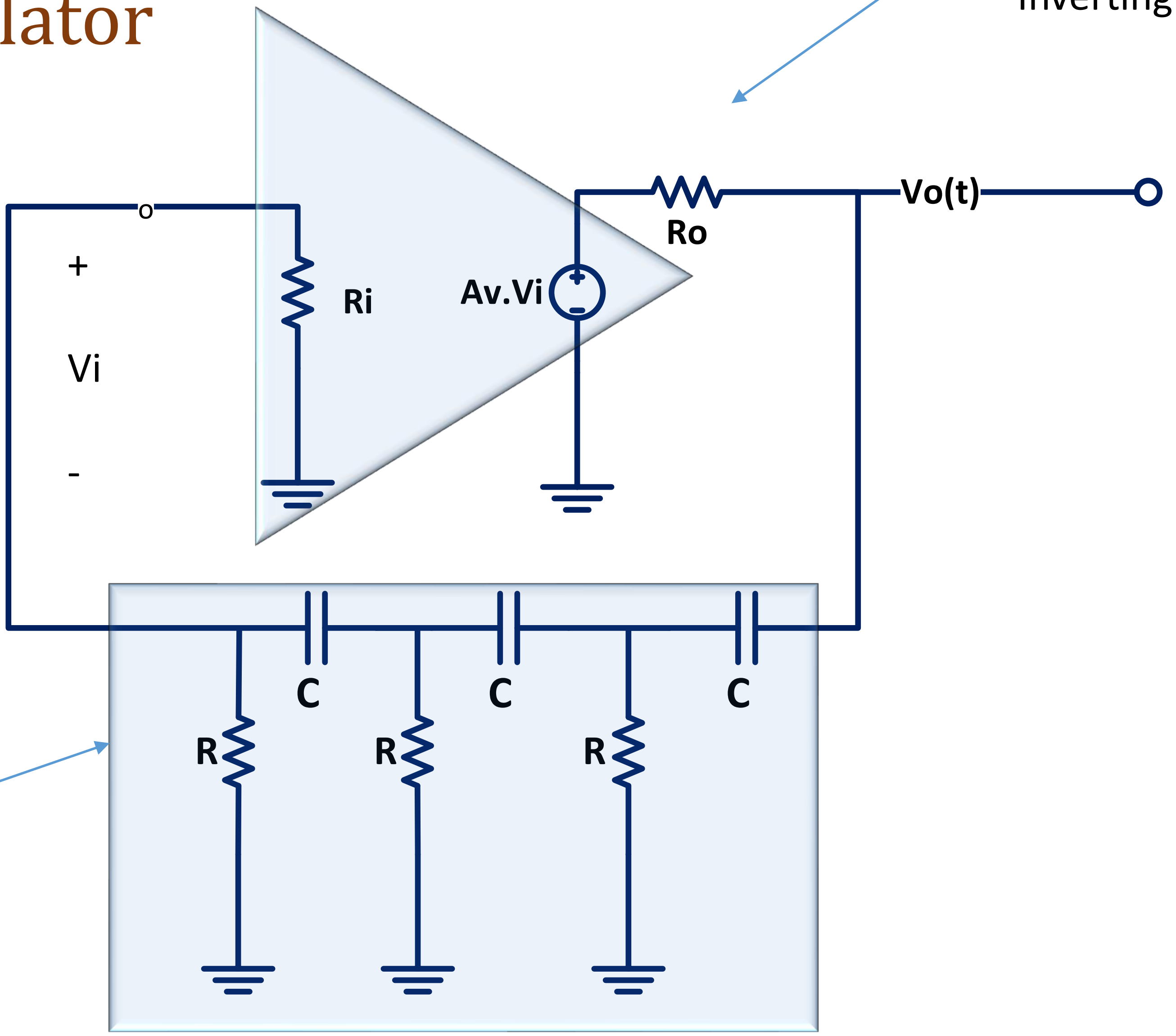


180 phase shift at wo

Audio frequency Oscillators

1) Phase-shift Oscillator

Inverting amplifier

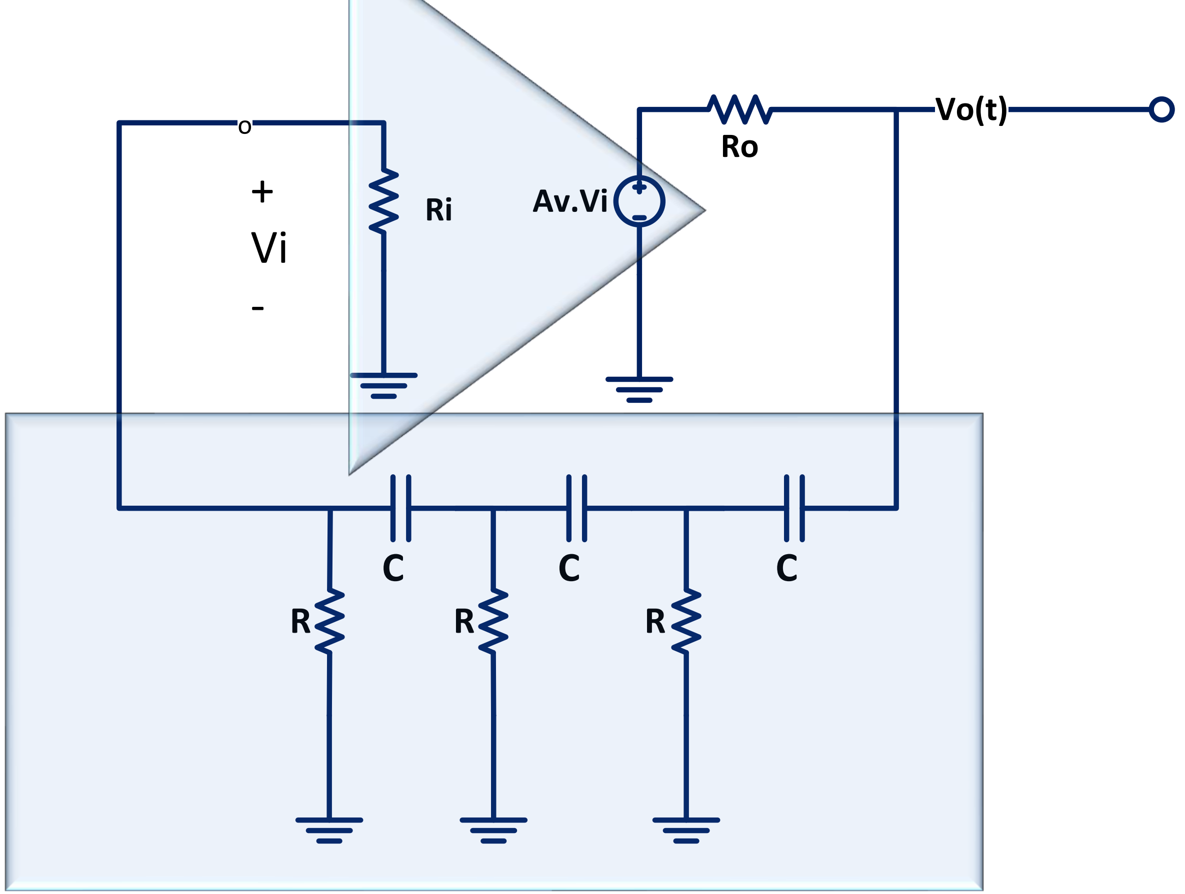


Frequency Determining Network

Oscillators

1) Phase-shift Oscillator

To find $\beta(j\omega) = \frac{V_O(j\omega)}{V_i(j\omega)}$



$$(R - j\frac{1}{\omega C})\, I_1 - R I_2 = V_i$$

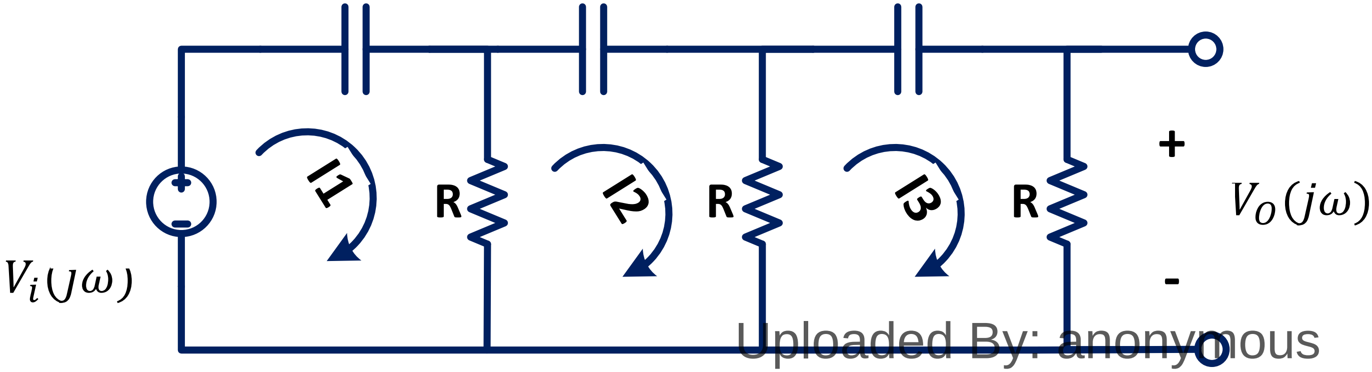
$$-R I_1 + (2R - j\frac{1}{\omega C})\, I_2 - R I_3 = 0$$

$$-R I_3 + (2R - j\frac{1}{\omega C})\, I_3 = 0$$

1/jwc 1/jwc 1/jwc

$R_i >> R$

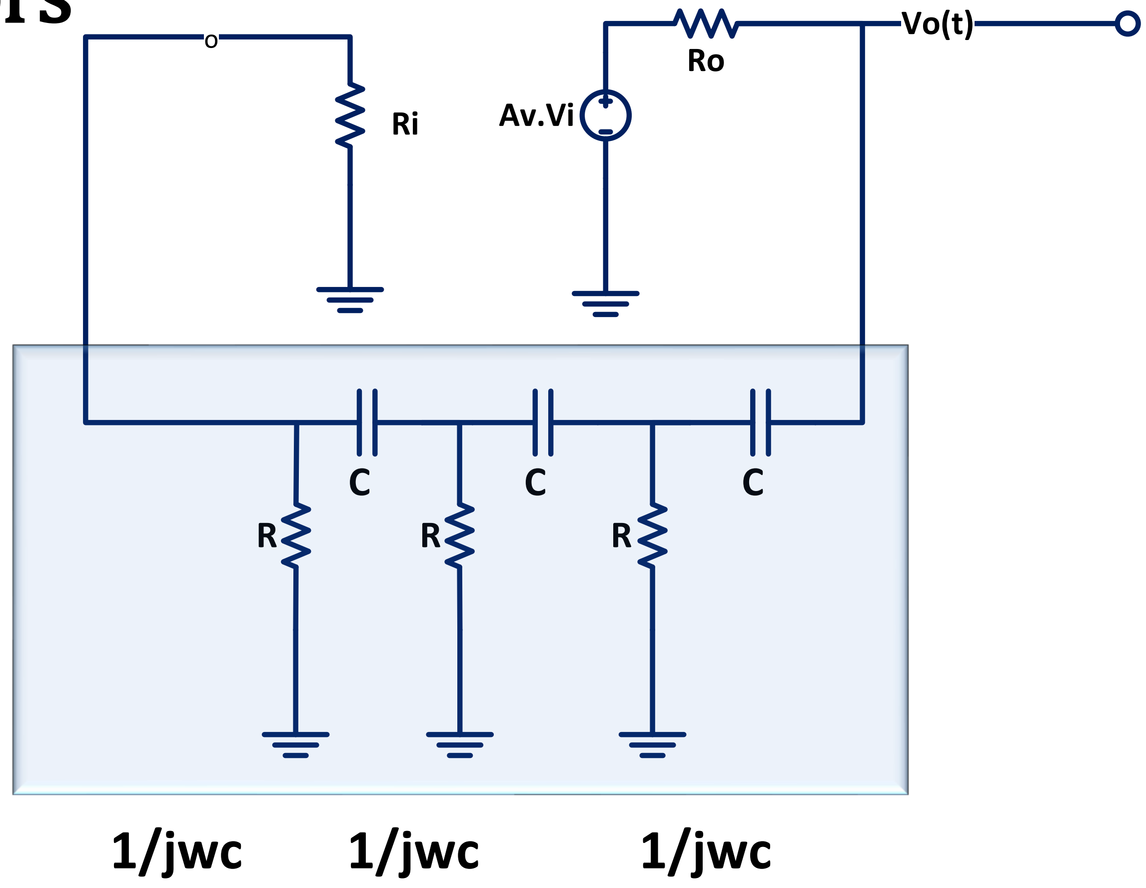
$$I_3 = \frac{R^{2} V_i}{R^3 - \frac{5R}{\omega^2 C^2} + j\left(\frac{1}{\omega^3 C^3} - \frac{6R^2}{\omega C}\right)}$$



Oscillators

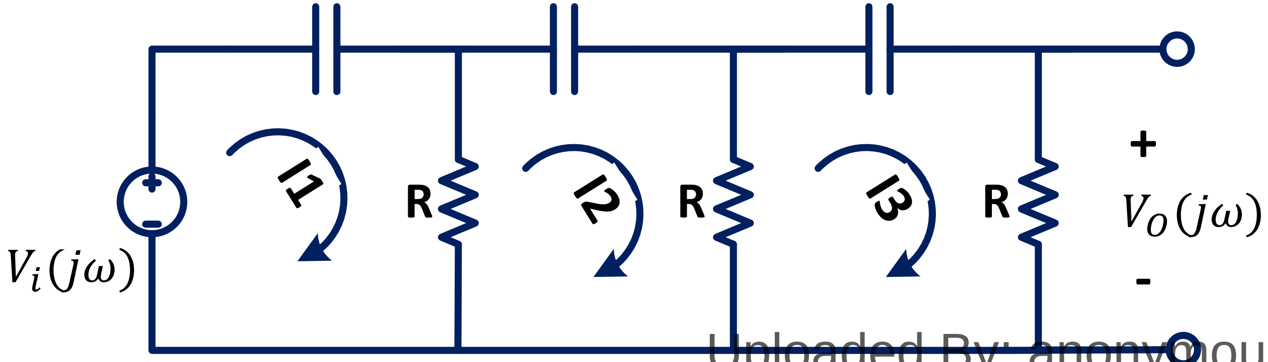
1) Pase-shift Oscillator

To find $\beta(j\omega) = \dfrac{V_O(j\omega)}{V_i(j\omega)}$



$$I_3 = \frac{R^2 \quad V_i}{R^3 - \frac{5R}{\omega^2 C^2} + j\left(\frac{1}{\omega^3 C^3} - \frac{6R^2}{\omega C}\right)}$$

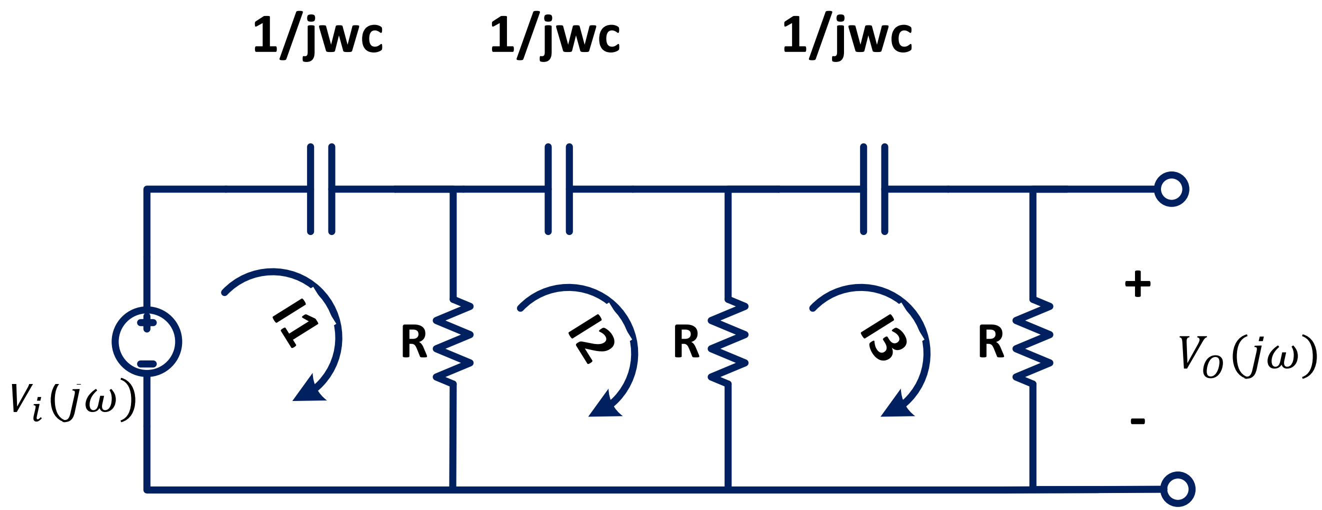
$$Vo = \frac{R^3 \quad V_i}{R^3 - \frac{5R}{\omega^2 C^2} + j\left(\frac{1}{\omega^3 C^3} - \frac{6R^2}{\omega C}\right)}$$



Audio frequency Oscillators

1) Phase-shift Oscillator

To find $\beta(j\omega) = \dfrac{V_O(j\omega)}{V_i(j\omega)}$



$$\beta = \frac{V_O(j\omega)}{V_i(j\omega)}$$

$$\beta(j\omega) = \frac{1}{\left(1 - \frac{5}{\omega^2 C^2 R^2}\right) + j\left(\frac{1}{\omega^3 C^3 R^3} - \frac{6}{\omega CR}\right)}$$

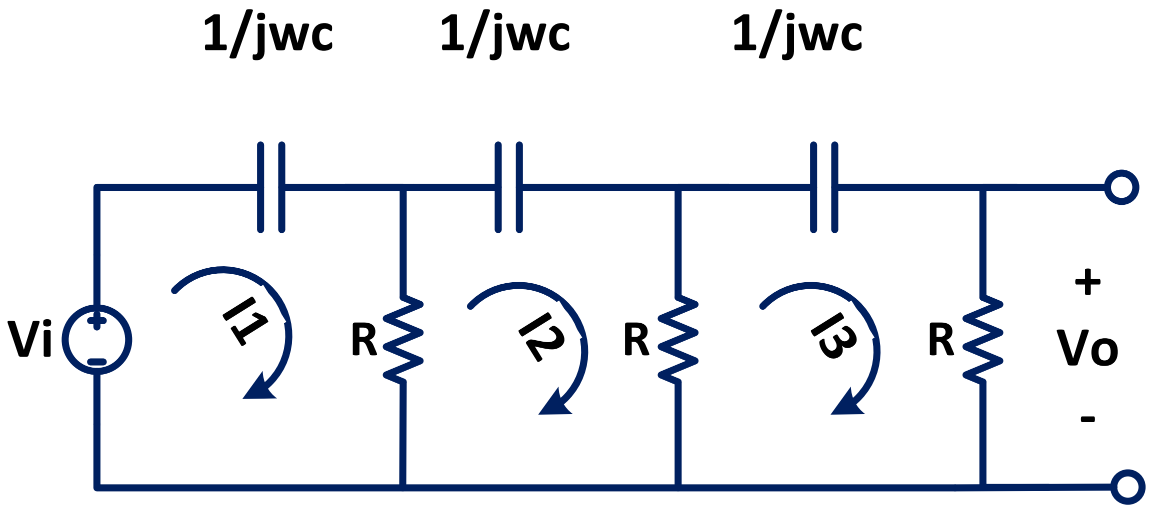
At ω_o ; $\beta(j\omega)$ must be real and negative

$$\frac{1}{\omega^3 C^3 R^3} - \frac{6}{\omega CR} = 0$$

$$\therefore \quad \omega_O = \frac{1}{\sqrt{6}\,RC}$$

Audio frequency Oscillators

1) Phase-shift Oscillator



To find $\beta(j\omega) = \frac{V_O(j\omega)}{V_i(j\omega)}$

$$\beta(j\omega) = \frac{1}{\left(1 - \frac{5}{\omega^2 C^2 R^2}\right) + j\left(\frac{1}{\omega^3 C^3 R^3} - \frac{6}{\omega C R}\right)}$$

At ω_O $\beta(j\omega) = -\frac{1}{29} = \frac{1}{29}\angle 180$

$\therefore A_V \geq 29\angle 180$

$A_V\beta \geq 1\angle 0$

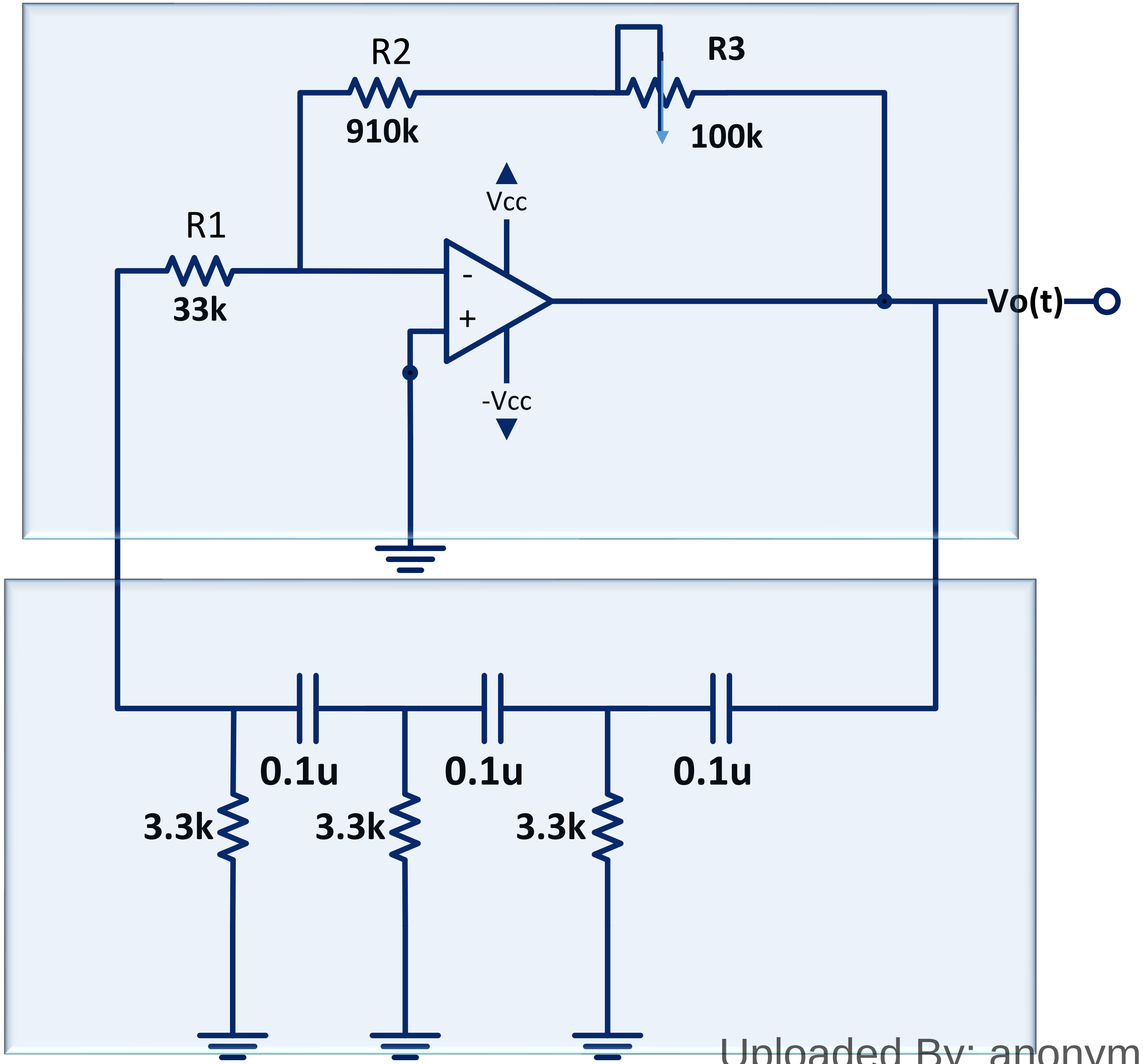
Audio frequency Oscillators

1) Phase-shift Oscillator

$$f_O = \frac{1}{2\pi\sqrt{6}RC} = 197\text{Hz}$$

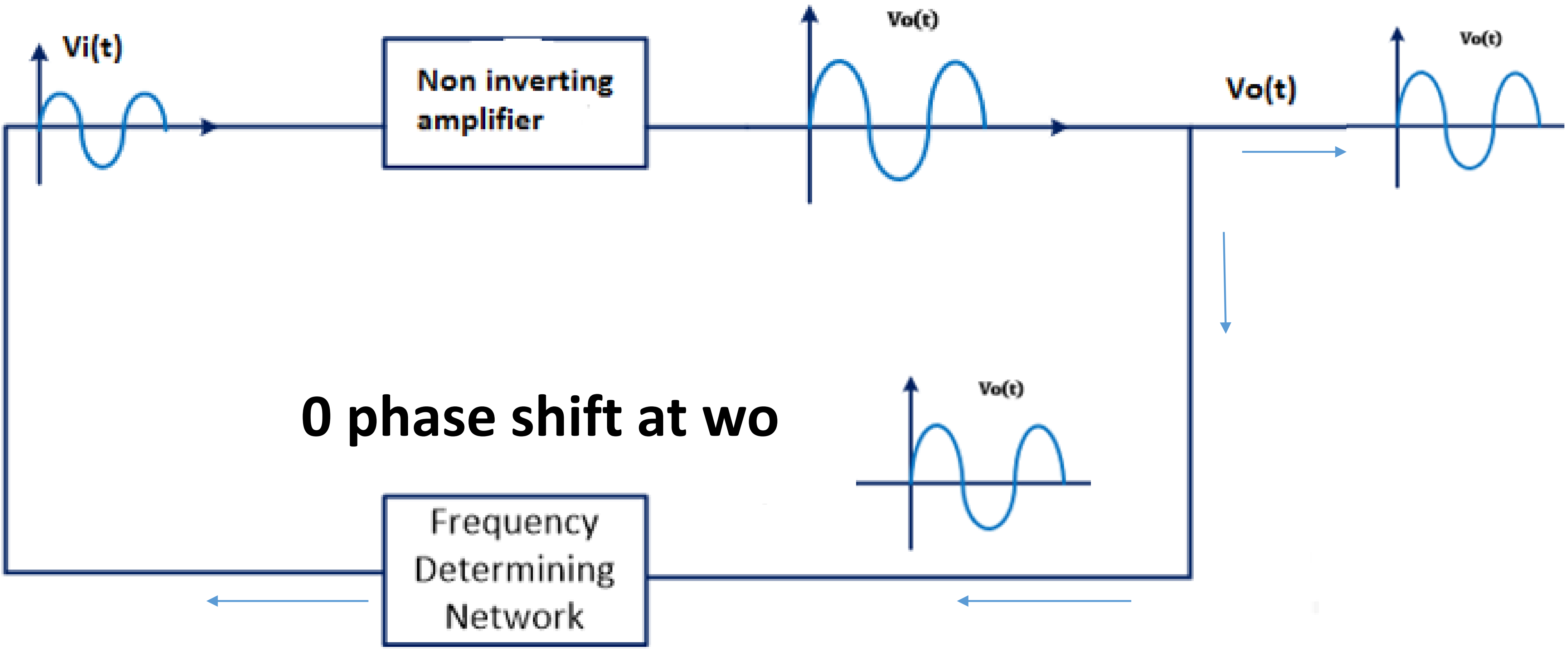
$$A_V = -\left(\frac{R_2+R_3}{R_1}\right) = \begin{cases} -33.9 \\ -27.6 \end{cases}$$

$$A_V \leq -29$$



Audio frequency Oscillators

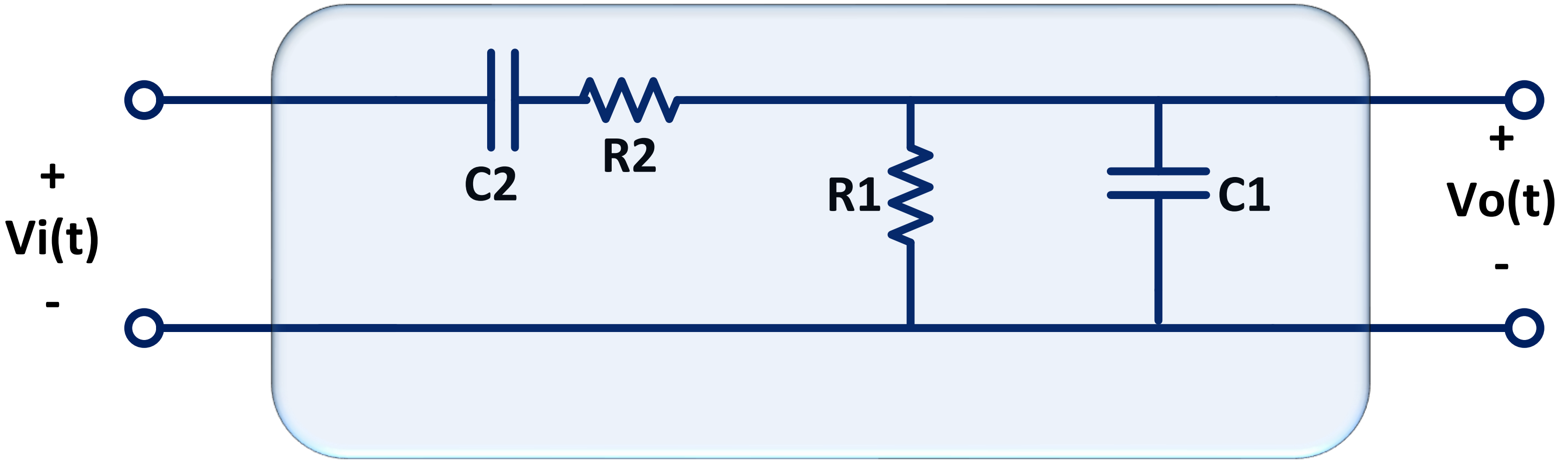
2- Wien Bridge Oscillator

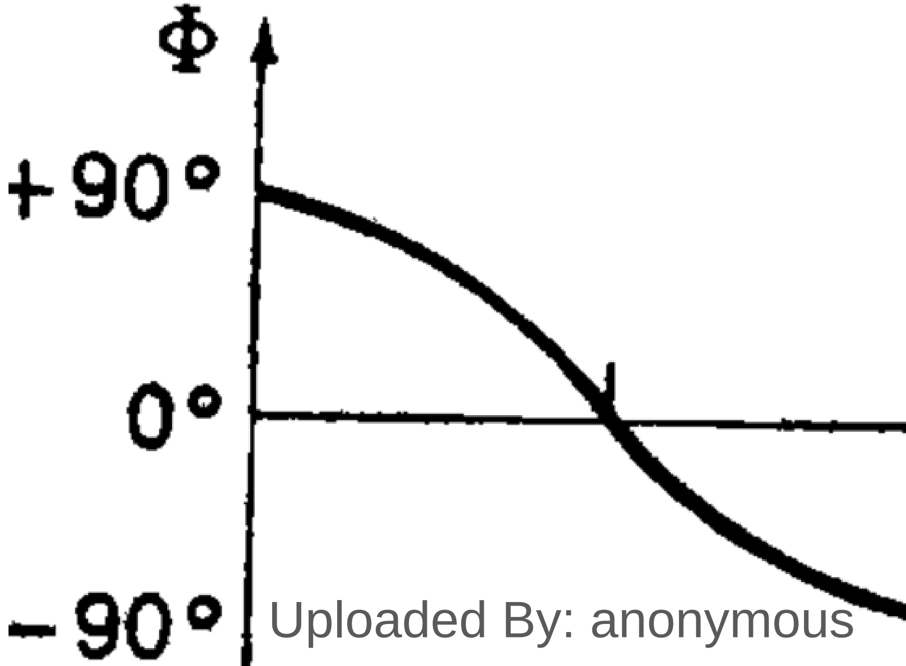


Audio frequency Oscillators

2- Wien Bridge Oscillator

- **The Wien bridge oscillator employs a lead -lag network.**
- **At one particular frequency , the phase shift across the network is 0 , therefore the feedback network is connected to the Op.Amp's noninverting input terminal.**





Audio frequency Oscillators

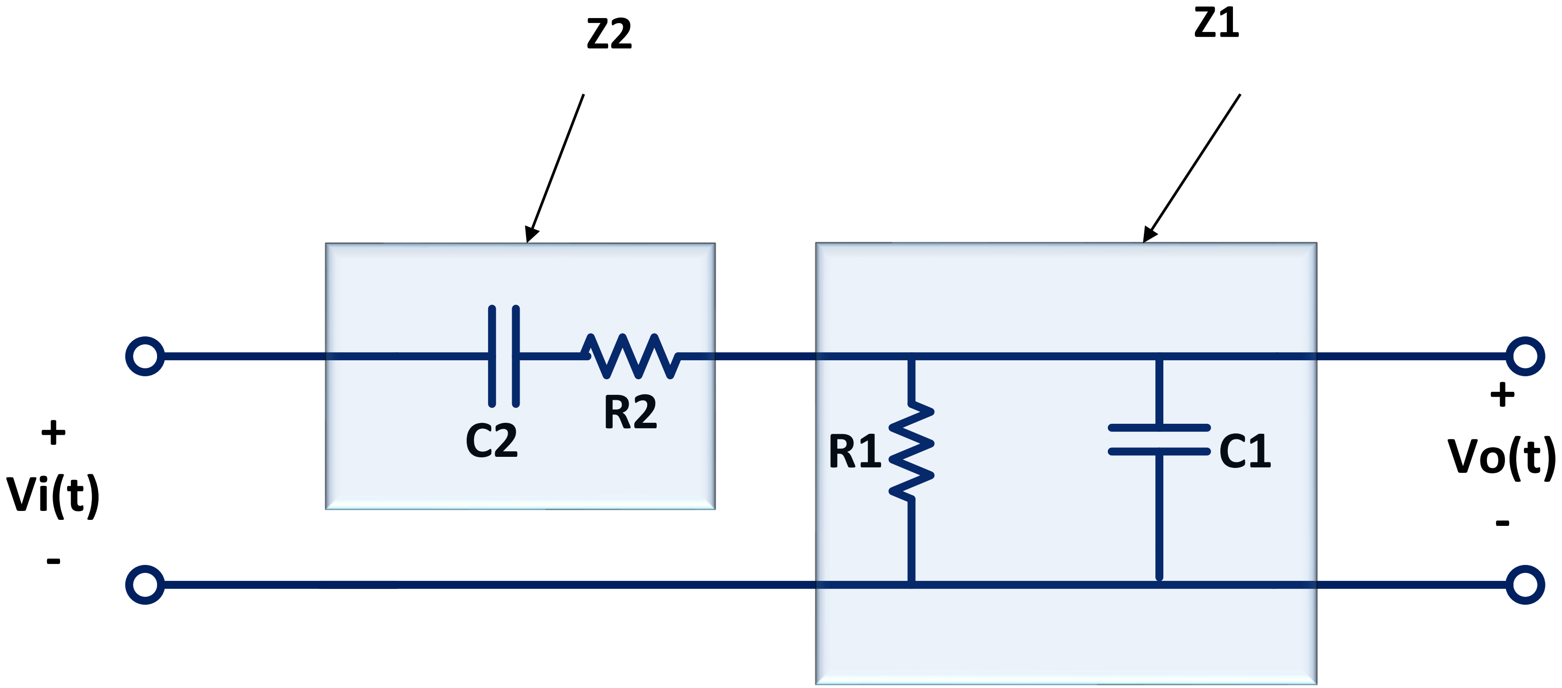
2- Wien Bridge Oscillator

- $Z_1 = R_1 \,/\!/\, \frac{1}{j\omega c_1} = \frac{R_1}{1+jR_{1\omega c_1}}$

- $Z_2 = R_1 + \frac{1}{j\omega c_2}$

- $\beta(j\omega) = \frac{V_o\,(j\omega)}{V_i\,(j\omega)} = \frac{Z_1}{Z_1+Z_2}$

- $\beta(j\omega) = \frac{\omega R_1 C_2}{\omega(R_1 C_1+R_2 C_2+R_1 C_2)+j(\omega^2 R_1 R_2 C_1 C_2-1)}$



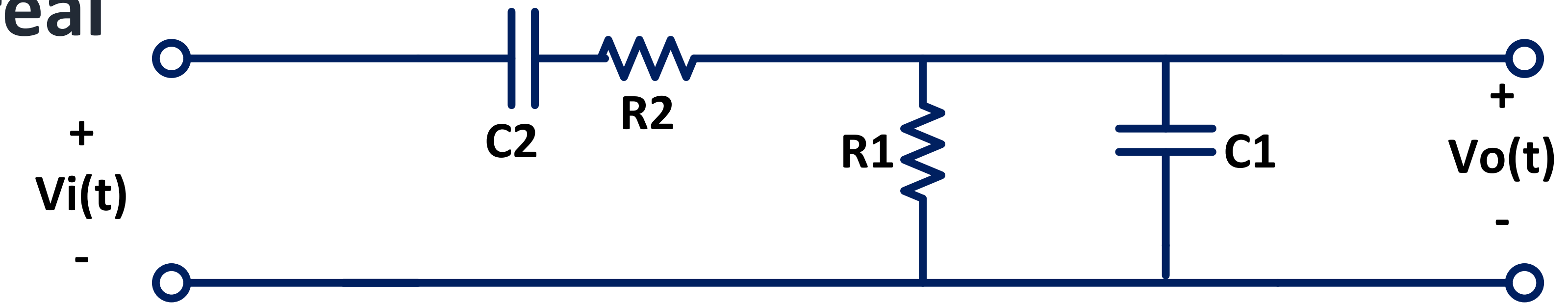
At ω_o ; β(jω) must be real and positive

$\therefore \ \omega^2 R_1 R_2 C_1 C_2 - 1 = 0$

Audio frequency Oscillators

2- Wien Bridge Oscillator

At ω_o ; β(jω)must be real and positive



- $\therefore \omega_o = \frac{1}{\sqrt{R_1 R_2 C_1 C_2}}$
- At ω_o ; $\beta(j\omega) = \frac{1}{1+\frac{R_2}{R_1}+\frac{C_1}{C_2}}$
- If $R_1 = R_2 = R$; and $C_1 = C_2 = C$
- $\omega_o = \frac{1}{RC}$
- $\beta = \frac{1}{3} = \frac{1}{3}\angle 0$
- $\therefore A_v \geq 3\angle 0$
- $A_v \beta \geq 1\angle 0$

Audio frequency Oscillators

2- Wien Bridge Oscillator

Frequency Determining Network

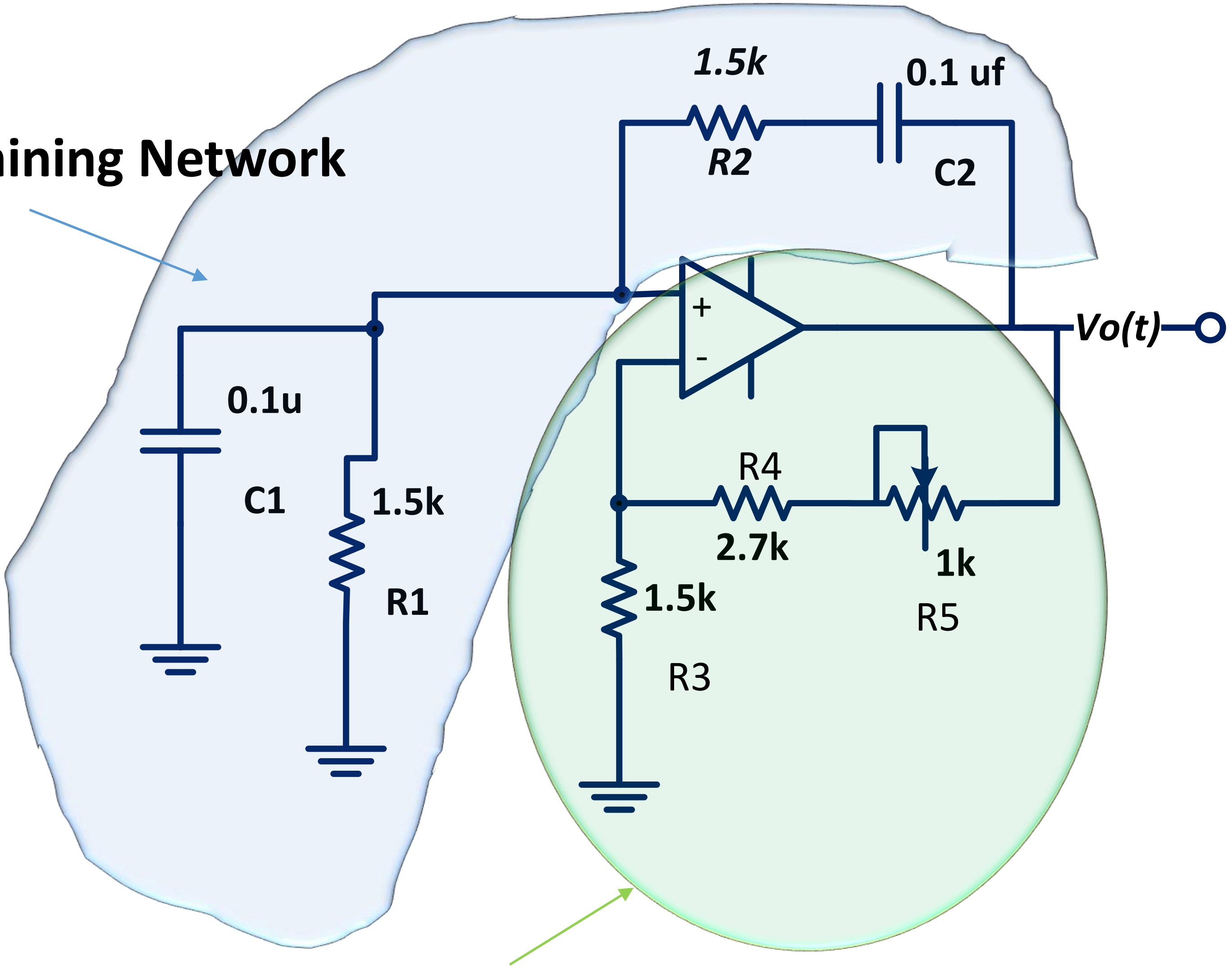
Since C1 = C2 and R1 = R2

$$- \ f_o = \frac{1}{2\pi RC} = 1.06KHz$$

$$\beta = \frac{1}{3}$$

$$\therefore \ A_v \geq 3$$

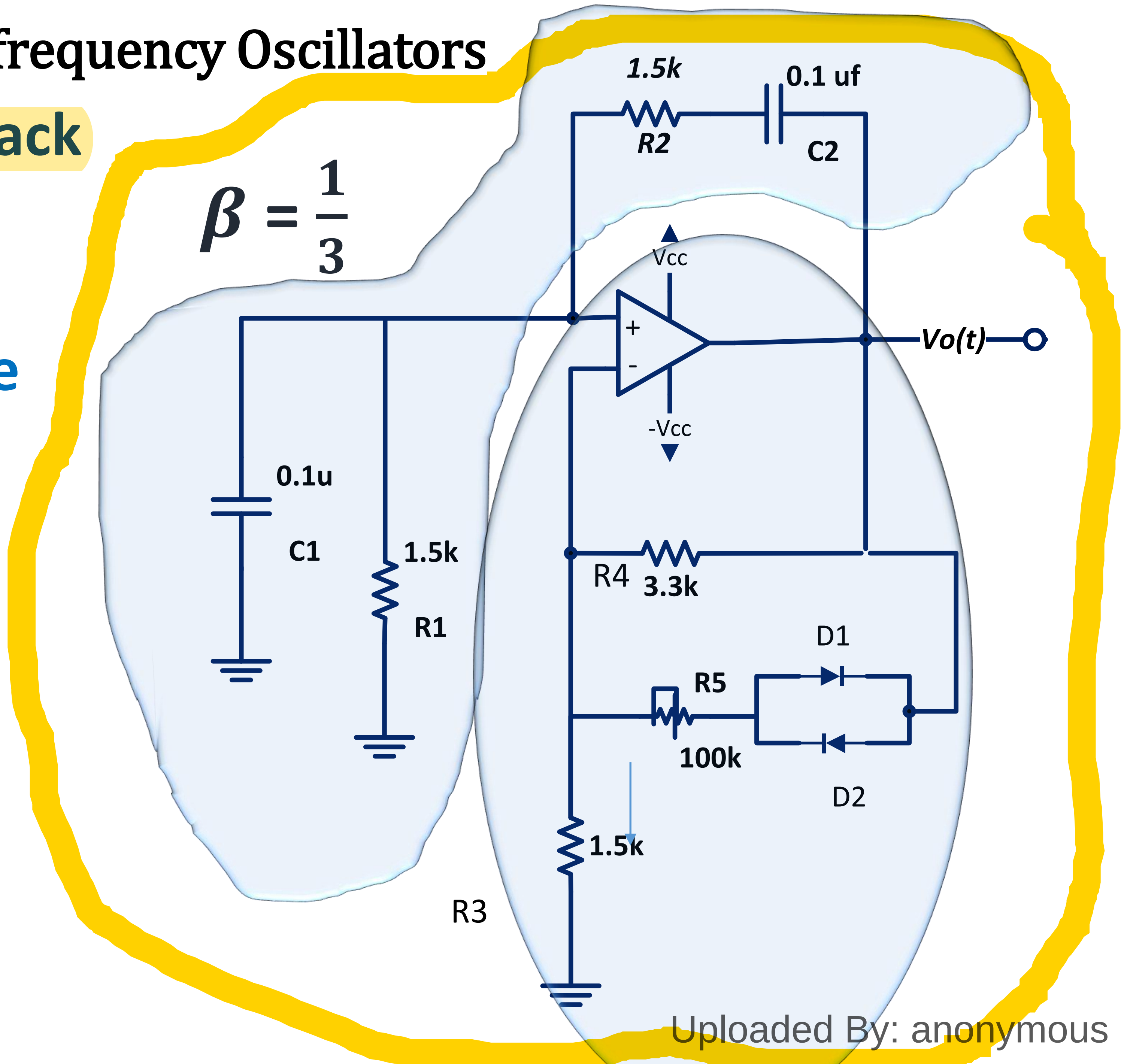
$$A_v = 1 + \frac{R_4 + R_5}{R_3} = \begin{cases} 2.8 \\ 3.47 \end{cases}$$



Non Inverting Amplifier

Audio frequency Oscillators

Adaptive Negative Feedback



At the beginning

D1,D2 are off to build up the oscillation

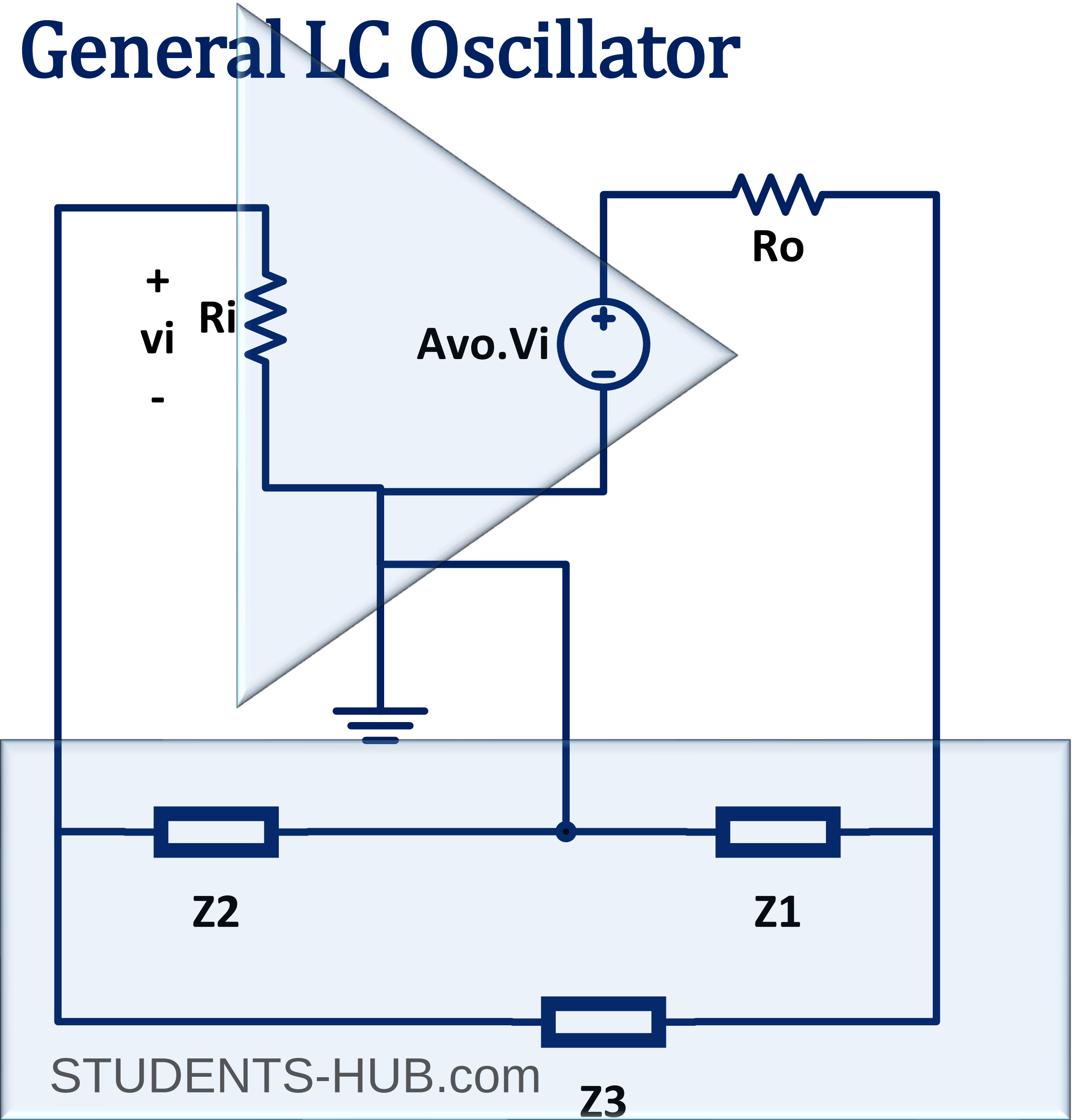
$$A_v = 1 + \frac{R_4}{R_3} = 3.2 > 3$$

Later on D1,D2 are on

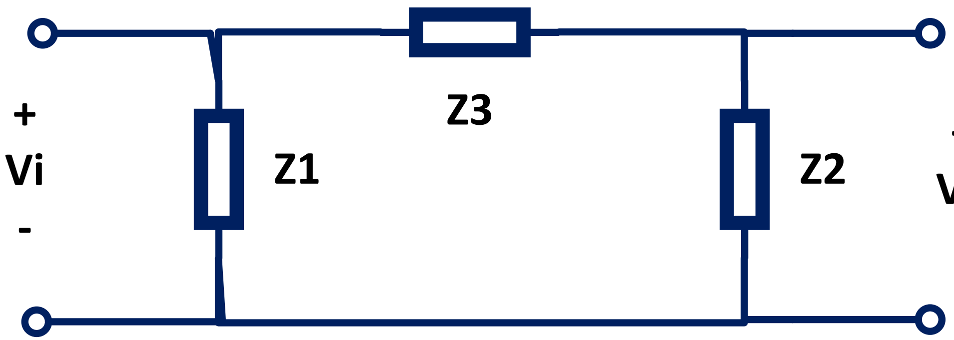
$$A_v = 1 + \frac{R_4 /\!/ R_5}{R_3} = 3$$

High Frequency Harmonic Oscillators

General LC Oscillator



The feedback network



$$R_i >> Z_2$$

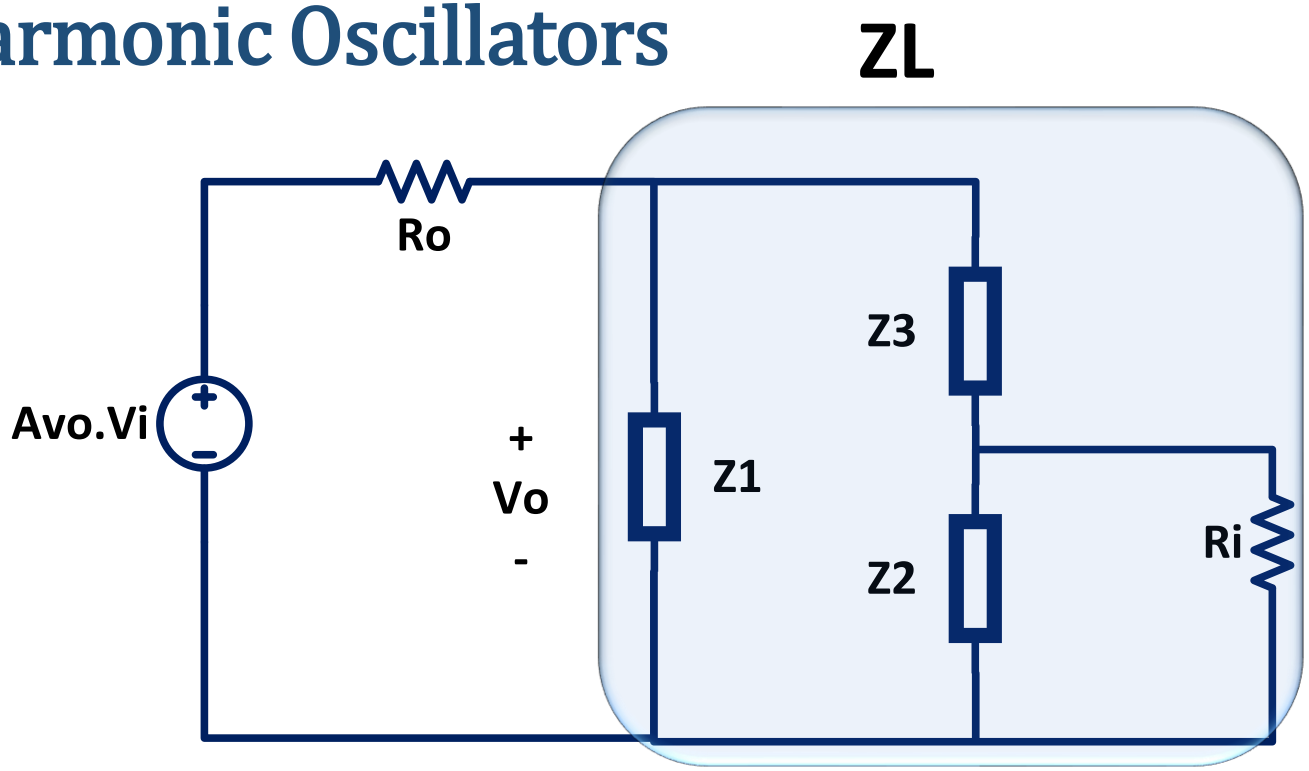
$$\beta\ (j\omega) = \frac{V_o(j\omega)}{V_i(j\omega)} = \frac{Z_2}{Z_2+Z_3}$$

Z1 , Z2 , and Z3 are pure reactive impedances

High Frequency Harmonic Oscillators

General LC Oscillator

To determine A_v



$$A_v(j\omega) = \frac{V_o(j\omega)}{V_i(j\omega)} = \frac{Z_l}{Z_l + R_o} A_{vo}\, V_i$$

$$Z_l = Z_1 \,//\, (Z_2 + Z_3)$$

$$\therefore A_v(j\omega) = \frac{Z_1 (Z_2 + Z_3) A_{vo}}{Z_1 (Z_2 + Z_3) + R_o (Z_1 + Z_2 + Z_3)}$$

$$A_v\beta = \frac{Z_1 Z_2 A_{vo}}{Z_1 (Z_2 + Z_3) + R_o (Z_1 + Z_2 + Z_3)}$$

$R_i \gg Z_2$

$\therefore$ At ω_o

1. $Z_1 + Z_2 + Z_3 = 0$
2. $A_v\beta = -\frac{Z_2}{Z_1} A_{vo}$

$A_v\,\beta \geq 1\angle 0$

$$\therefore A_{vo} \leq -\frac{Z_1}{Z_2}$$

Z_1, Z_2 and Z_3 pure reactive impedances

High Frequency Harmonic Oscillators

Example of LC Oscillators

Oscillator type	Z1	Z2	Z3	Amplifier
Hartley	**L**	**L**	**C**	**Inverting**
	L	**C**	**L**	**Follower**
Colpitts	**C**	**C**	**L**	**Inverting**
	L	**C**	**C**	**Non-Inverting**
Clapp	**C**	**C**	**LC**	**Inverting**
Pierce crystal	**C**	**C**	**XTAL**	**Inverting**

High Frequency Harmonic Oscillators

Colpitts Oscillator

At ω_o:

$$Z_1 + Z_2 + Z_3 = 0$$

$$-j\frac{1}{\omega_o C_1} - j\frac{1}{\omega_o C_2} + j\omega_o L = 0$$

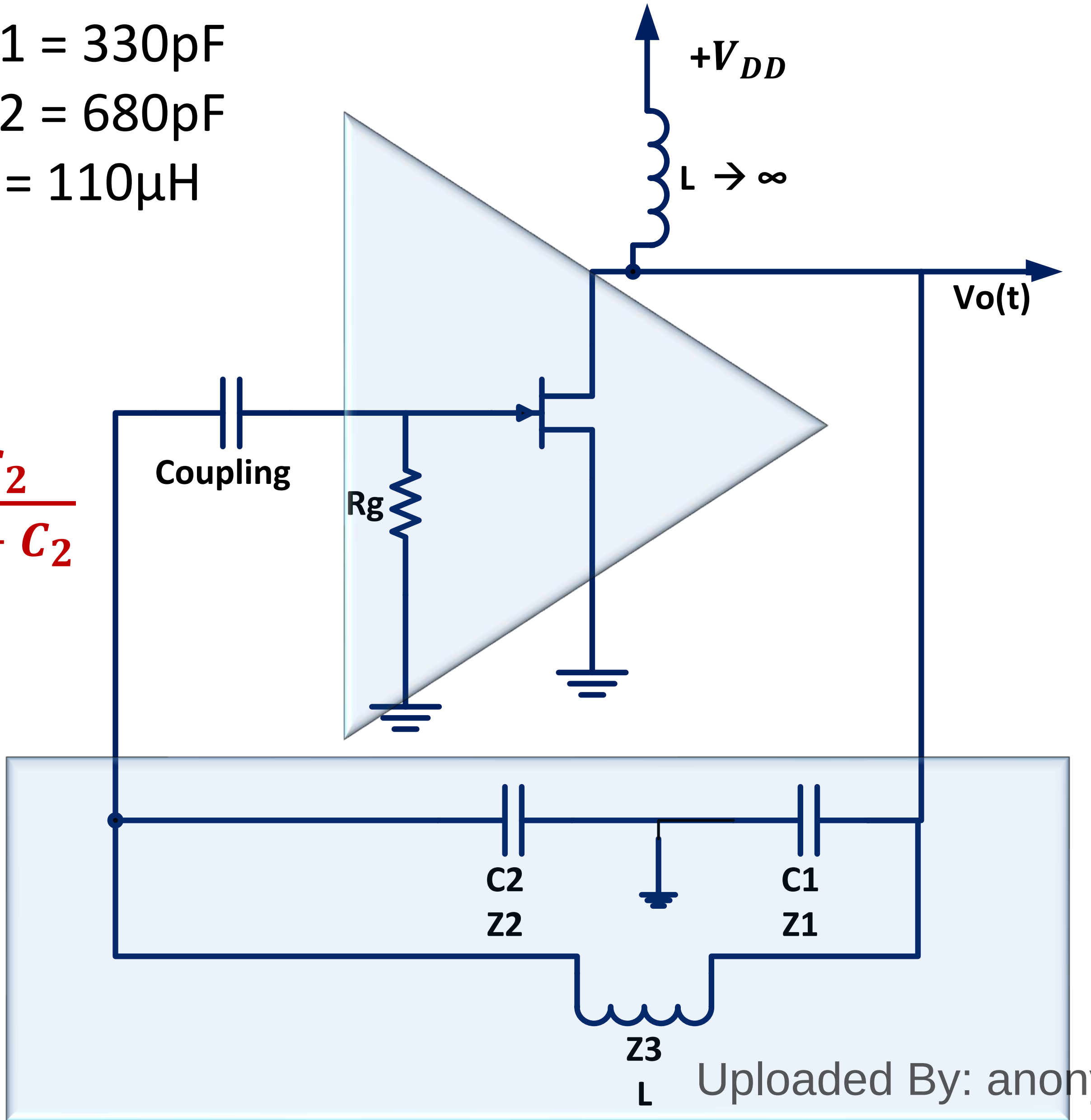
$$\therefore\ \omega_o = \frac{1}{\sqrt{LC_T}} \quad , \quad C_T = \frac{C_1 C_2}{C_1 + C_2}$$

$$f_o = \frac{\omega_o}{2\pi} = 1.02\text{MHz}$$

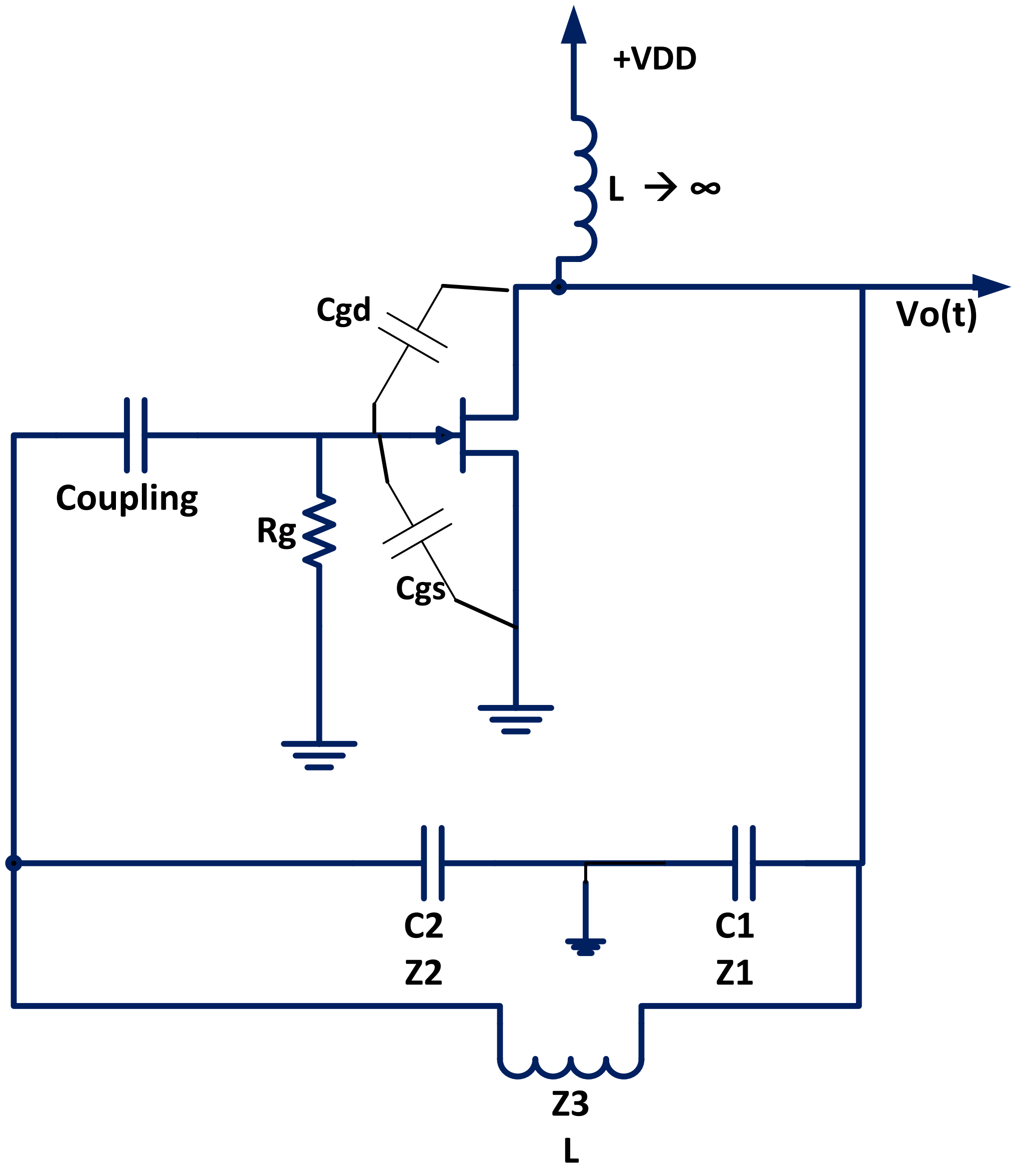
$$A_{vo} \le -\frac{Z_1}{Z_2} = -\frac{C_2}{C_1}$$

$$A_{vo} \le -2.06$$

C1 = 330pF
C2 = 680pF
L = 110µH

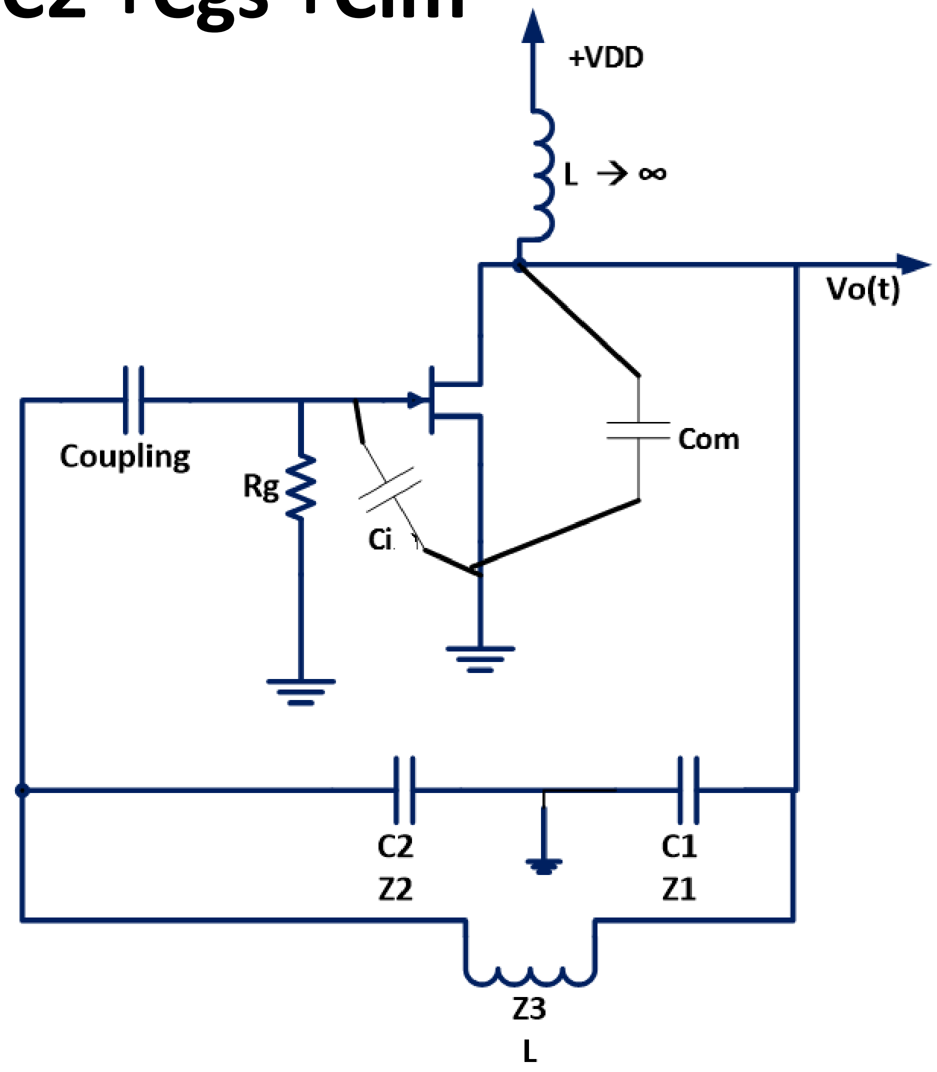


At high frequency



$$C1' = C1 + Com$$

$$C2' = C2 + Cgs + Cim$$



High Frequency Harmonic Oscillators

Clapp Oscillator

At ω_o

$$Z_1 + Z_2 + Z_3 = 0$$

$$-j\frac{1}{\omega_o\ C_1} - j\frac{1}{\omega_o\ C_2} - j\frac{1}{\omega_o\ C_3} + j\omega_o L = 0$$

$$\therefore\ \omega_o = \frac{1}{\sqrt{LC_T}}$$

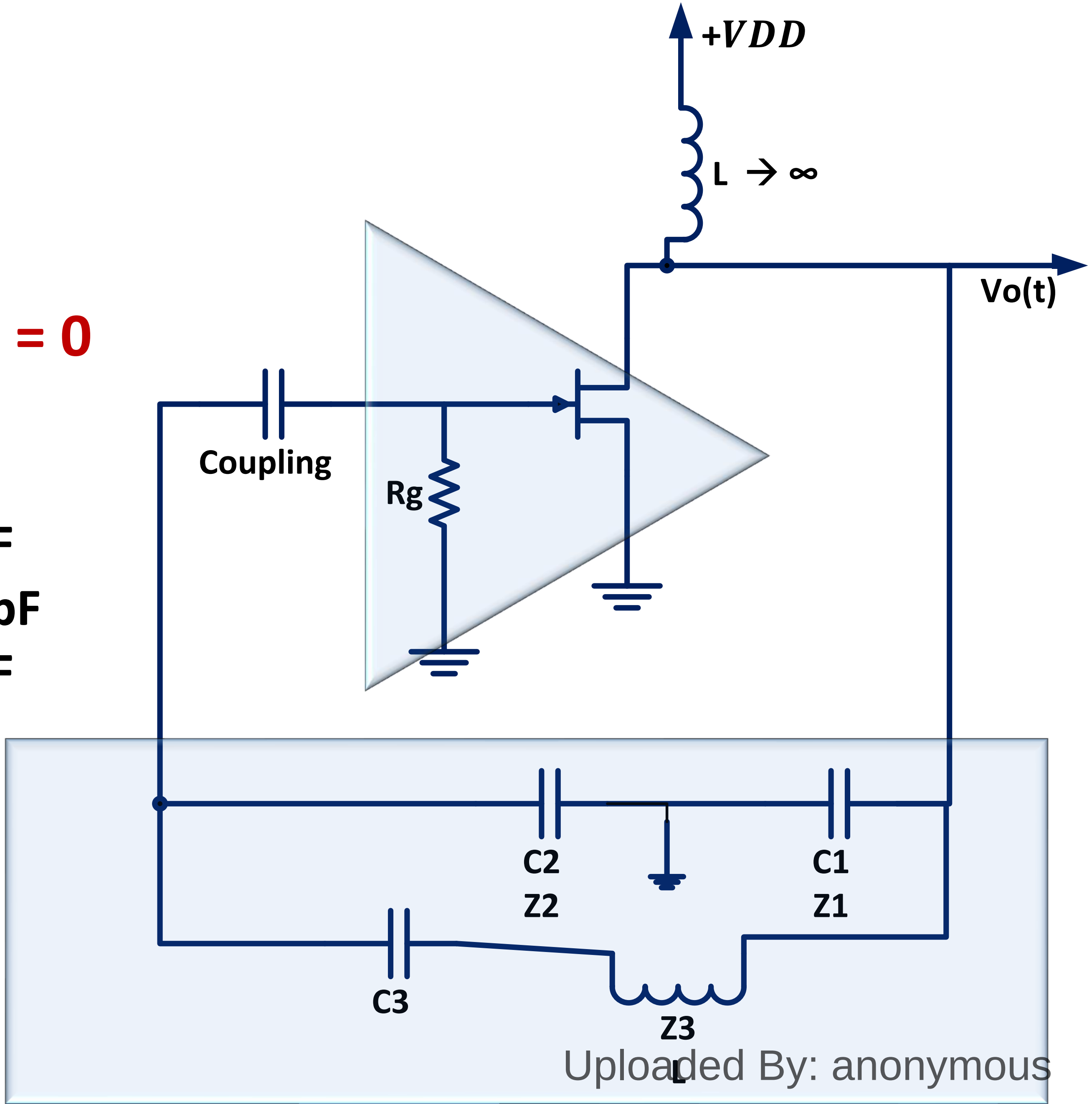
$$\frac{1}{C_T} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3}$$

$$C_T = 212.7PF$$

$$f_o = \frac{\omega_o}{2\pi} = 1.04MHz$$

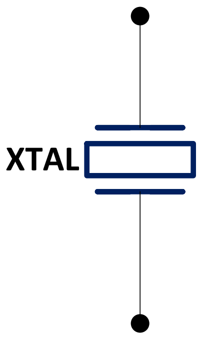
$$A_{vo} \le -\frac{Z_1}{Z_2} = -\frac{C_2}{C_1}$$

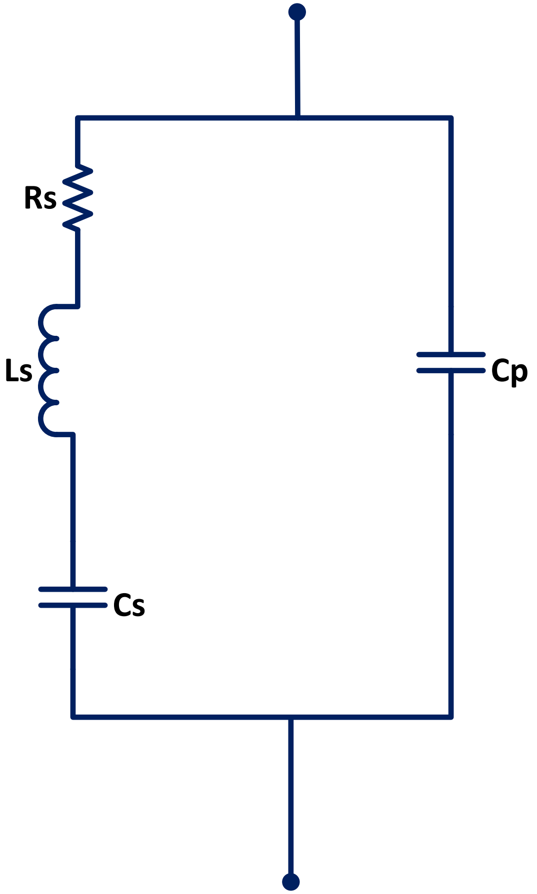
C1 = 680pF
C2 = 1500pF
C3 = 390pF
L = 110µH

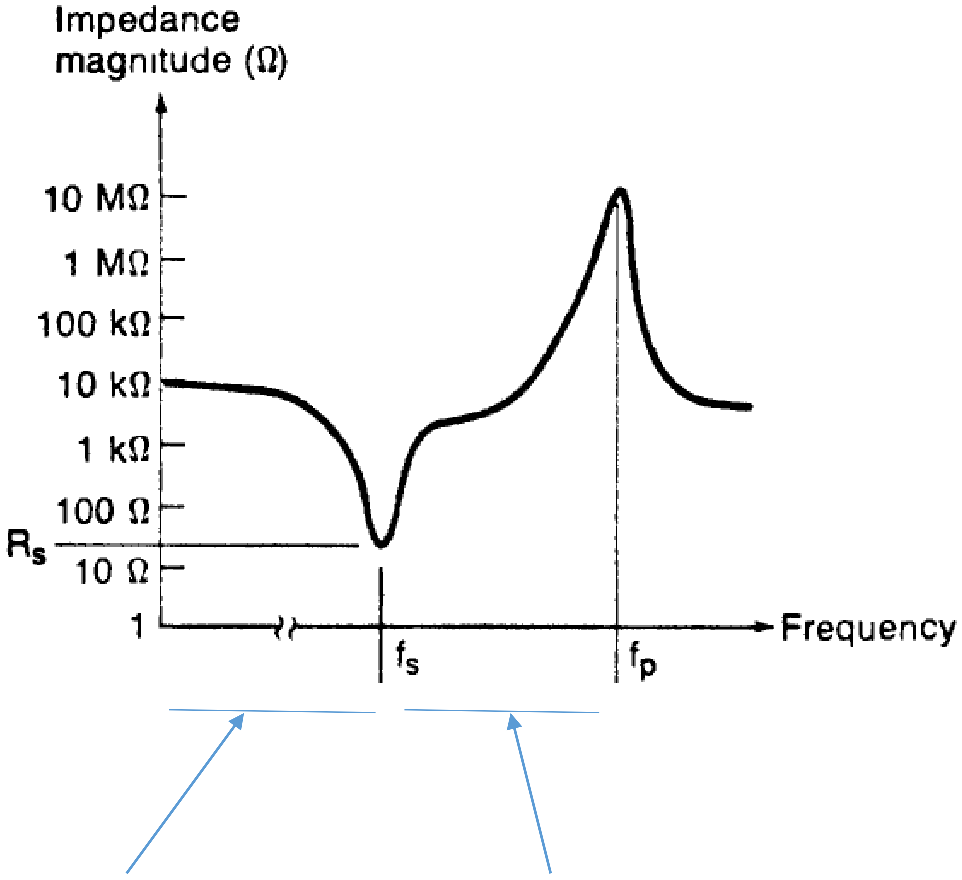


High Frequency Harmonic Oscillators

The Crystal







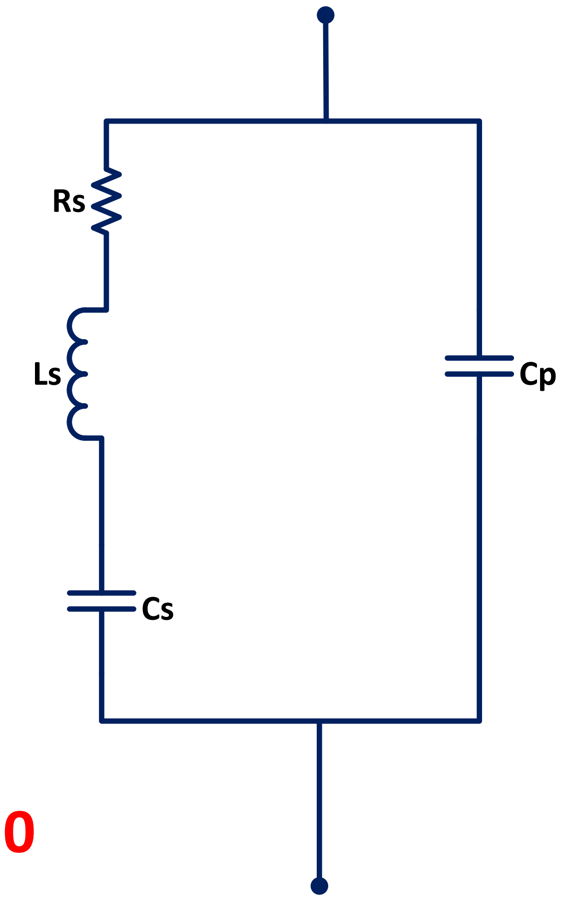
Capacitive

Inductive

Oscillators

High Frequency Harmonic Oscillators

The Crystal



R_s is very small

$$Z(j\omega) = \frac{\left(j\omega L_s + \frac{1}{j\omega\, C_3}\right)\ \frac{1}{j\,\omega\ C_p}}{j\omega_o L_s + \frac{1}{j\omega\ C_3} + \frac{1}{j\omega\ C_p}}$$

$$Z(j\omega) = \frac{-j}{\omega\, C_p}\ \frac{\omega^2 - \frac{1}{L_s\ C_s}}{\omega^2 - \frac{C_s + C_p}{L_s\ C_s C_p}}$$

$$\omega^2 - \frac{1}{L_s\ C_s} = 0$$

$$\omega^2 - \frac{C_s + C_p}{L_s\ C_s C_p} = 0$$

$$\therefore\ \omega_s = \frac{1}{\sqrt{L_s C_s}}$$

$$\therefore\ \omega_p = \frac{1}{\sqrt{L_s\left(\frac{C_s\ C_p}{C_s + C_p}\right)}}$$

Series resonance

Parallel resonance

Oscillators

High Frequency Harmonic Oscillators

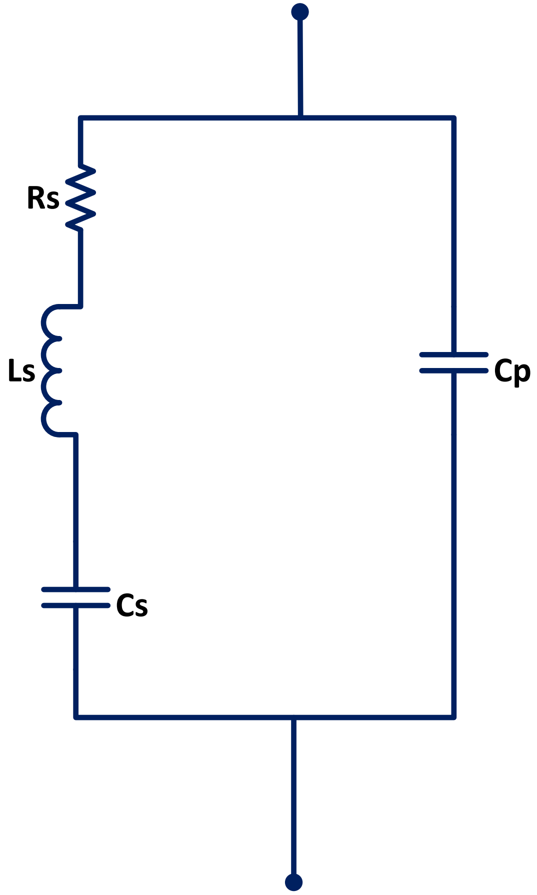
The Crystal

$C_s = 0.0060\text{PF}$

$L_s = 0.165609\text{H}$

$R_s = 10\Omega$

$C_P = 13.0\text{PF}$



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

$$f_s = 5.048967\text{MHz}$$

$$\omega_p = \frac{1}{\sqrt{L_s\left(\frac{C_s\,C_p}{C_s+C_p}\right)}}$$

$$f_p = 5.050145\text{MHz}$$

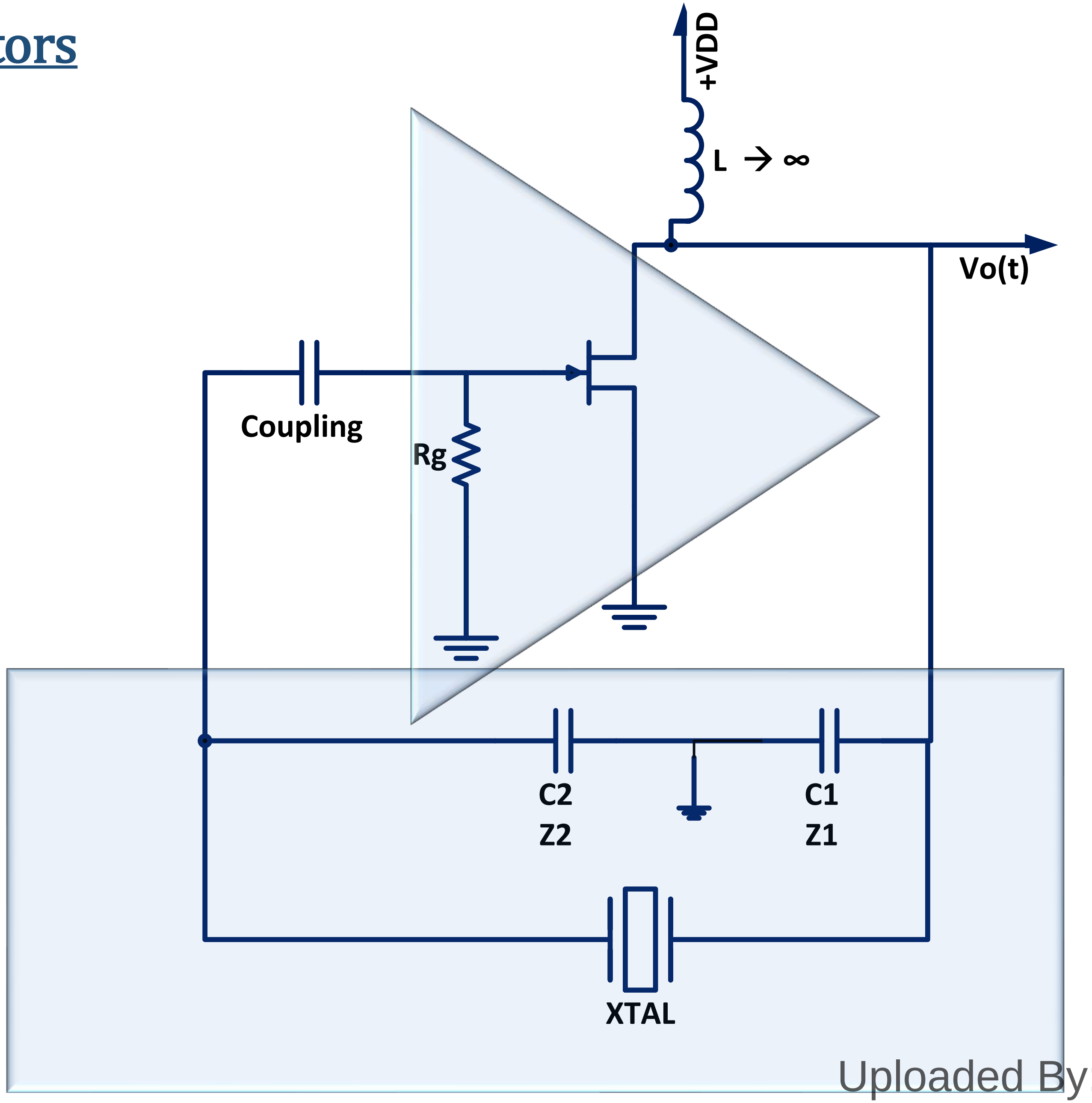
$$f_p - f_s = 1.179\text{KHz}$$

Oscillators

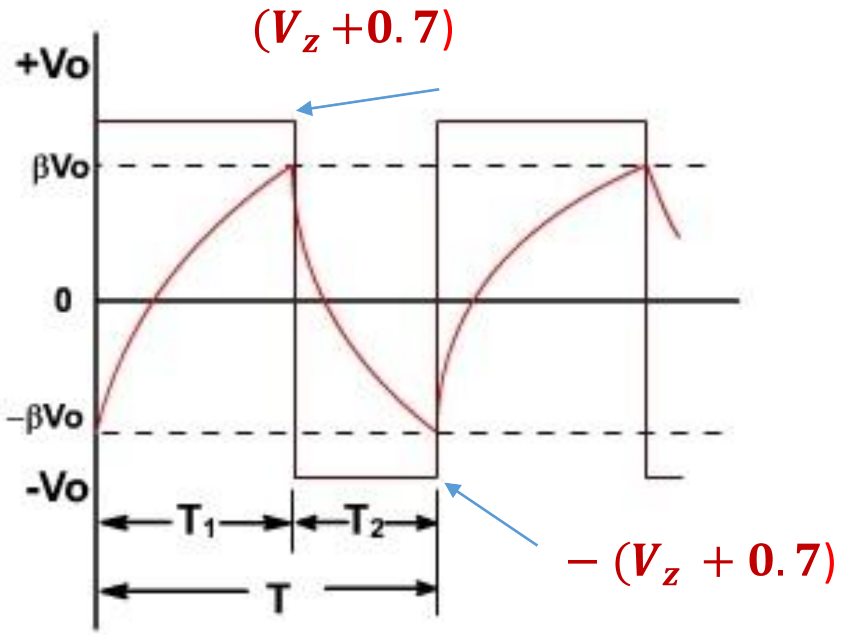
High Frequency Harmonic Oscillators

Pierce crystal oscillator.

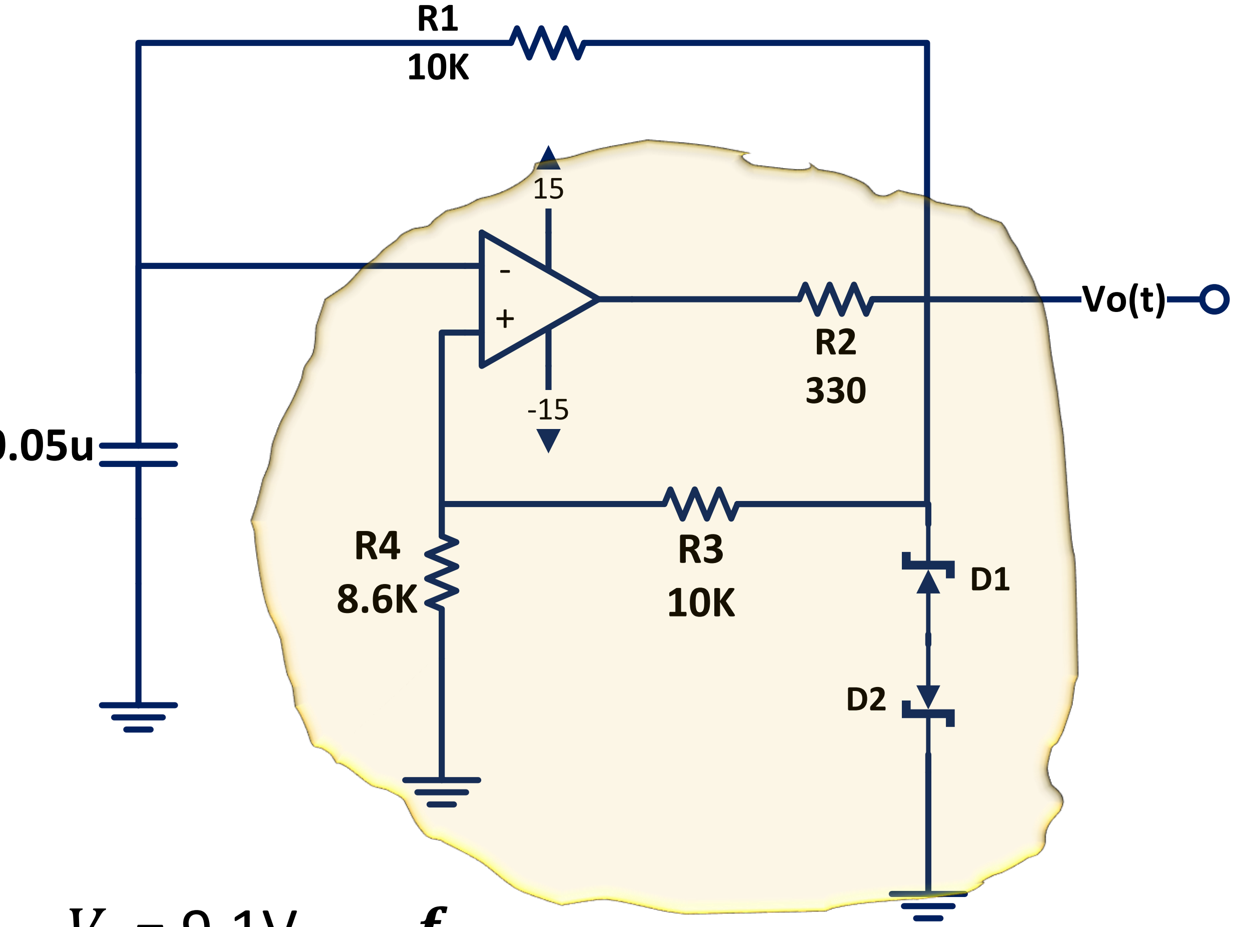
$$w_p > w_o > w_s$$



Oscillators



An OP Relaxation Oscillator



$V_Z = 9.1V$ $f_o = 1KhZ$

-The Op. Amp relaxation oscillator shown is a square _wave generator .

-The circuit's frequency of oscillation is dependent on the charge and discharge of a capacitor C_1 through a resistor R_1.

- The "heart" of the oscillator is an inverting Op. Amp comparator . the comparator uses positive feedback .

Oscillators

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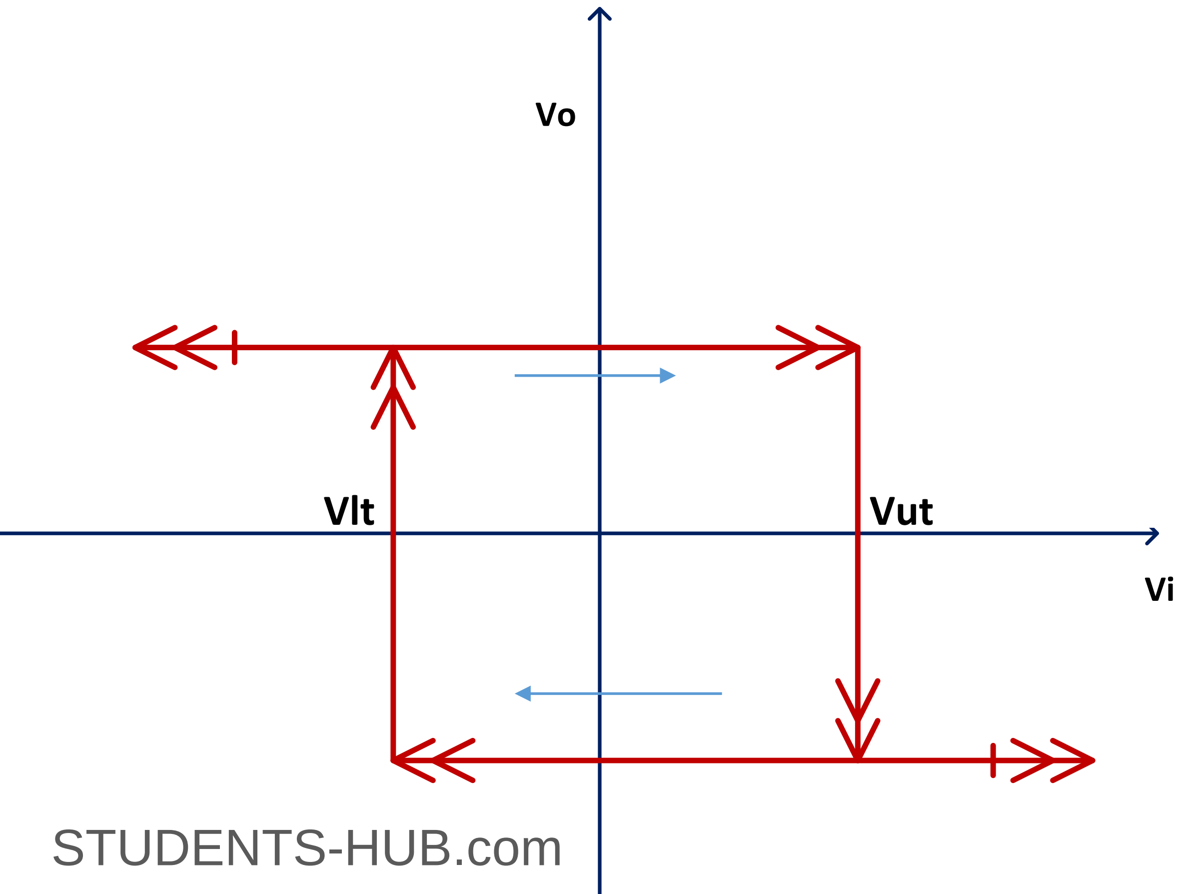
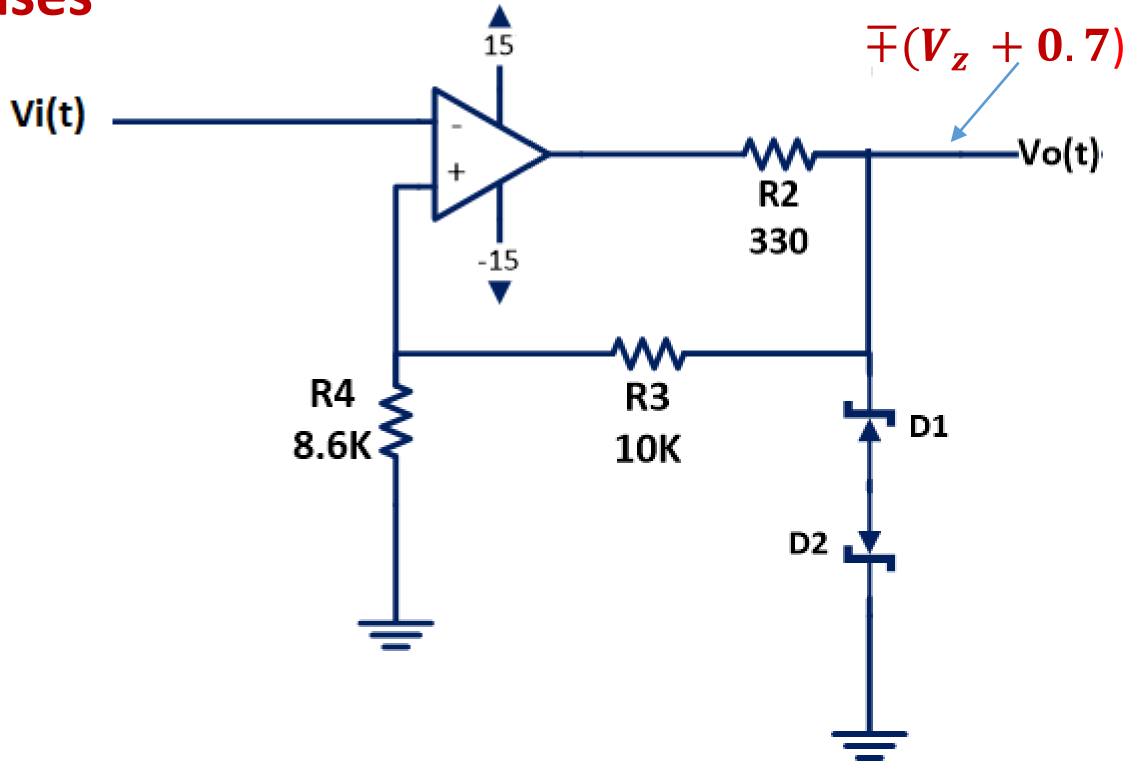


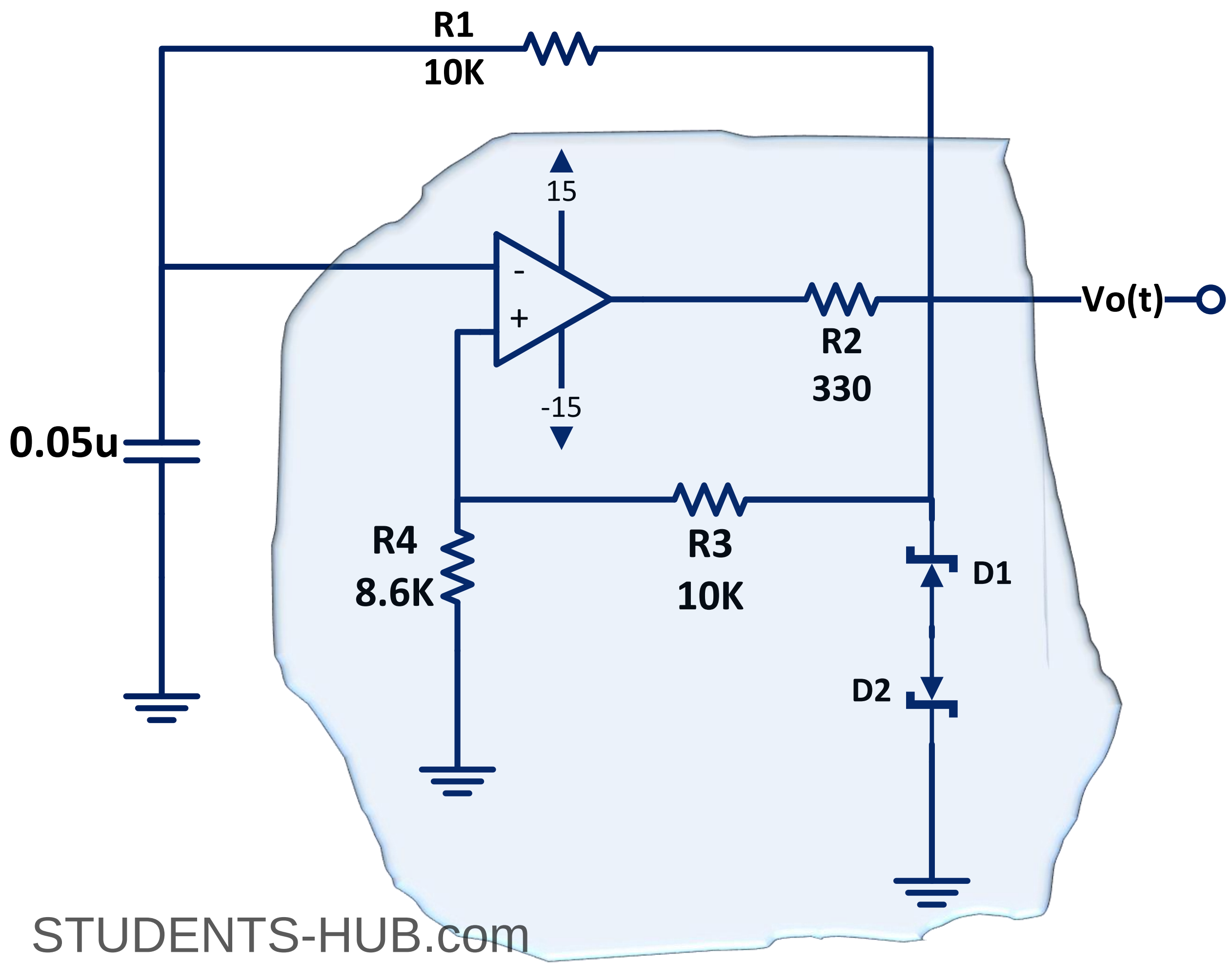
Inverting Schmitt trigger

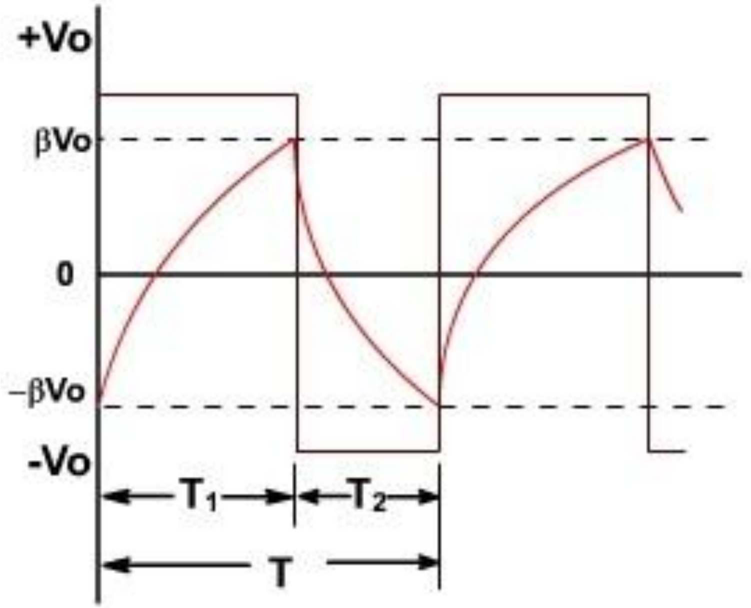


- $V_{UT} = \frac{R_4}{R_4+R_3}(V_z + 0.7) = \beta(V_z + 0.7)$
- $V_{LT} = -\frac{R_4}{R_4+R_3}(V_z + 0.7) = -\beta(V_z + 0.7)$

Oscillators

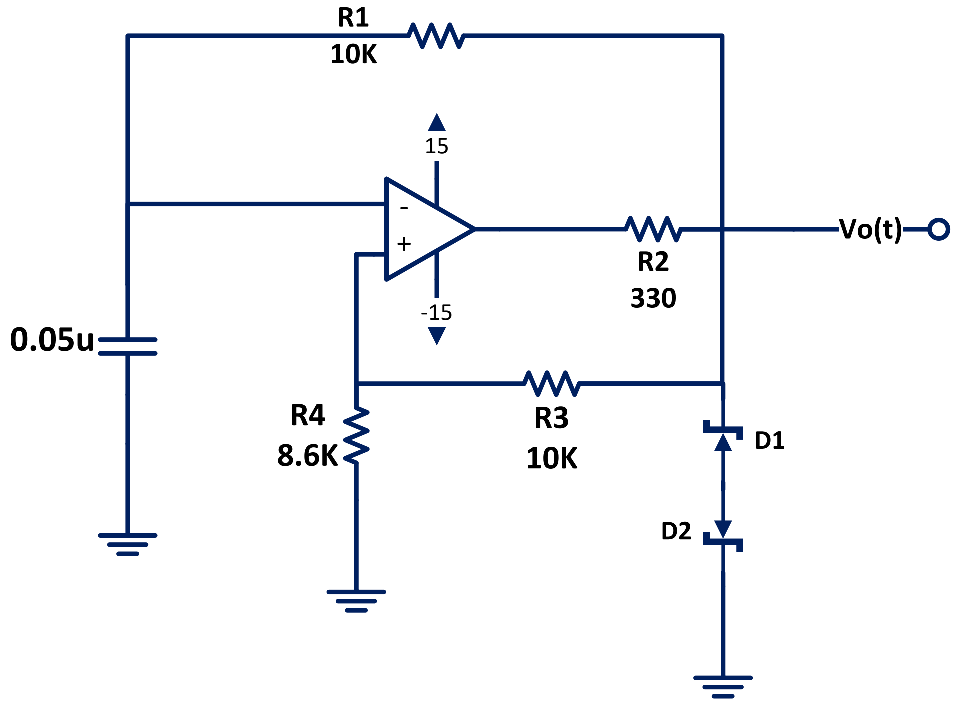
An OP Relaxation Oscillator





- $V_{out} = \pm(V_z + 0.7)$
- $V_{UT} = \frac{R_4}{R_4+R_3}(V_z + 0.7) = \beta(V_z + 0.7)$
- $V_{LT} = -\frac{R_4}{R_4+R_3}(V_z + 0.7) = -\beta\,(V_z + 0.7)$

Oscillators



An OP Relaxation Oscillator

- $V_{out} = \pm(V_z + 0.7)$
- $V_{UT} = \frac{R_4}{R_4+R_3}(V_z + 0.7) = \beta\,(V_z + 0.7)$
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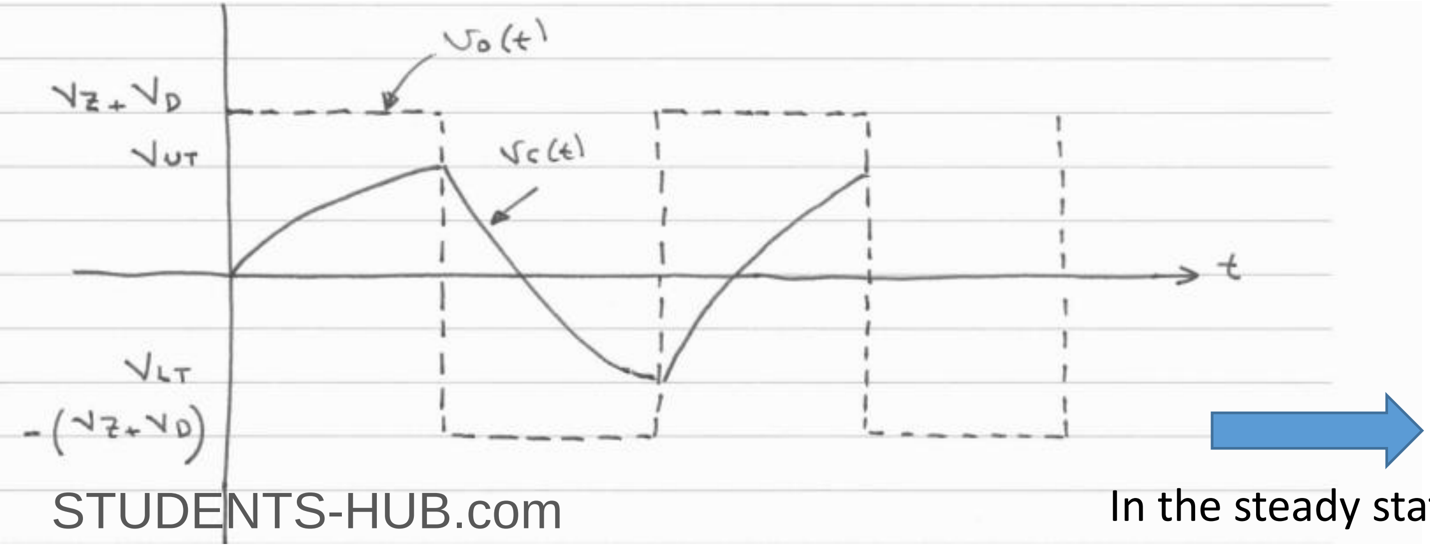
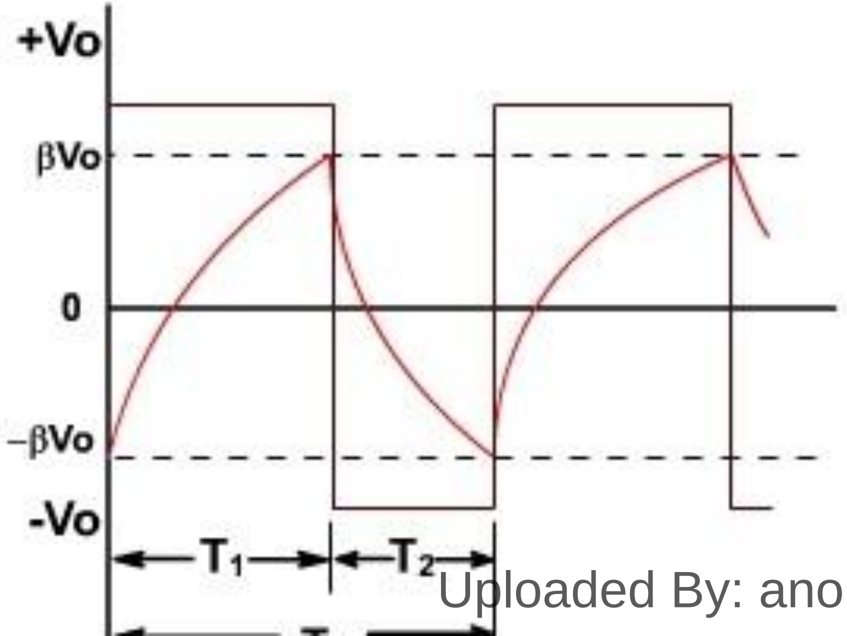
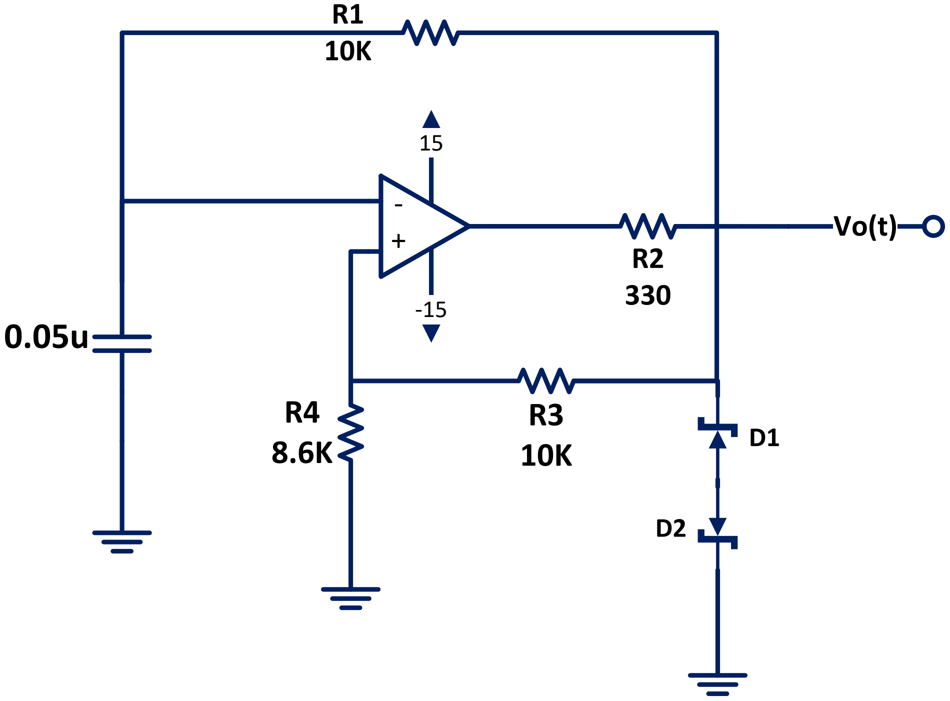


In the steady state



Oscillators

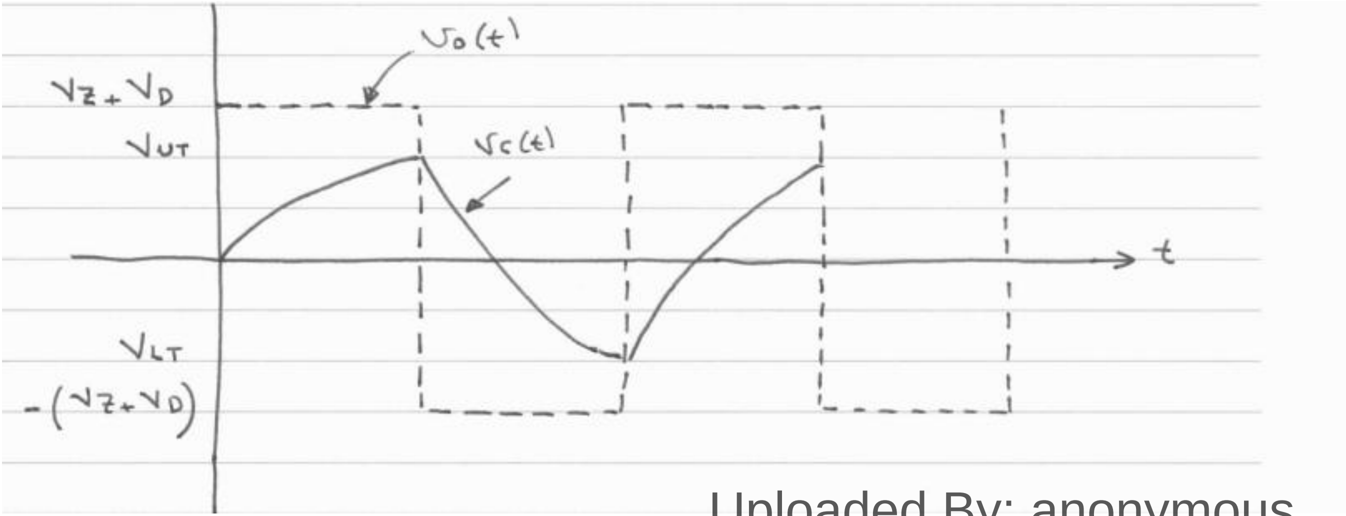


- When the output of the comparator is positive ,capacitor C_1 will charge through resistor R_1.

- The capacitor will attempt to charge to V_{out}=V_z+ 0.7.

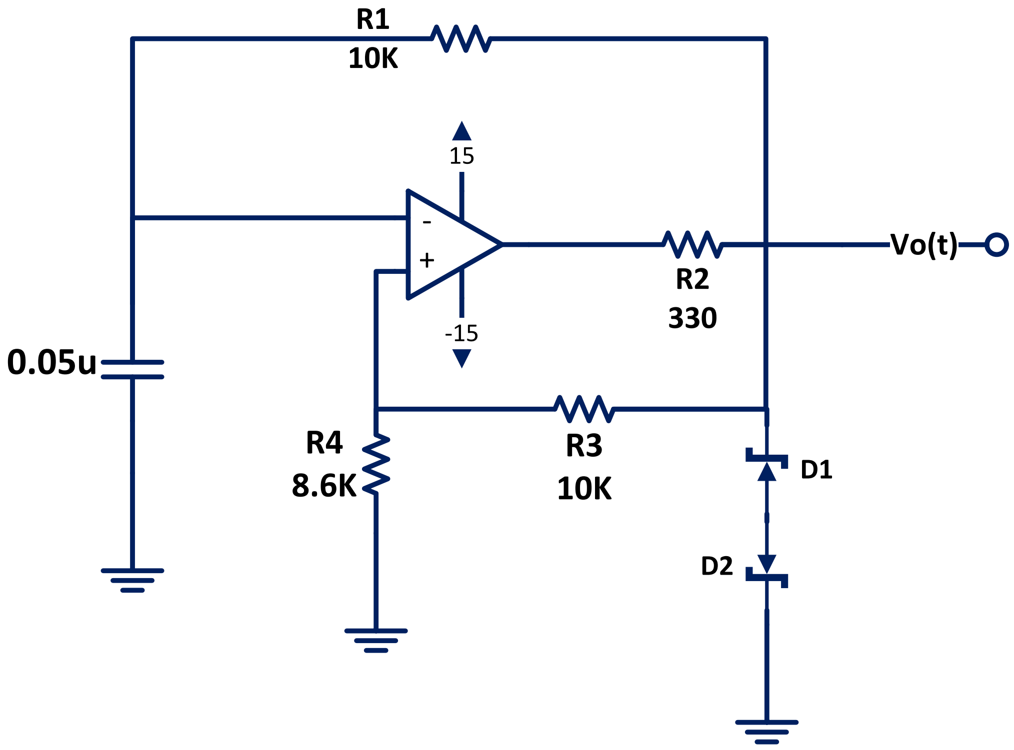
- When the voltage a cross the capacitor reaches the upper threshold voltage V_{UT} ,the comparators output will immediately switch to

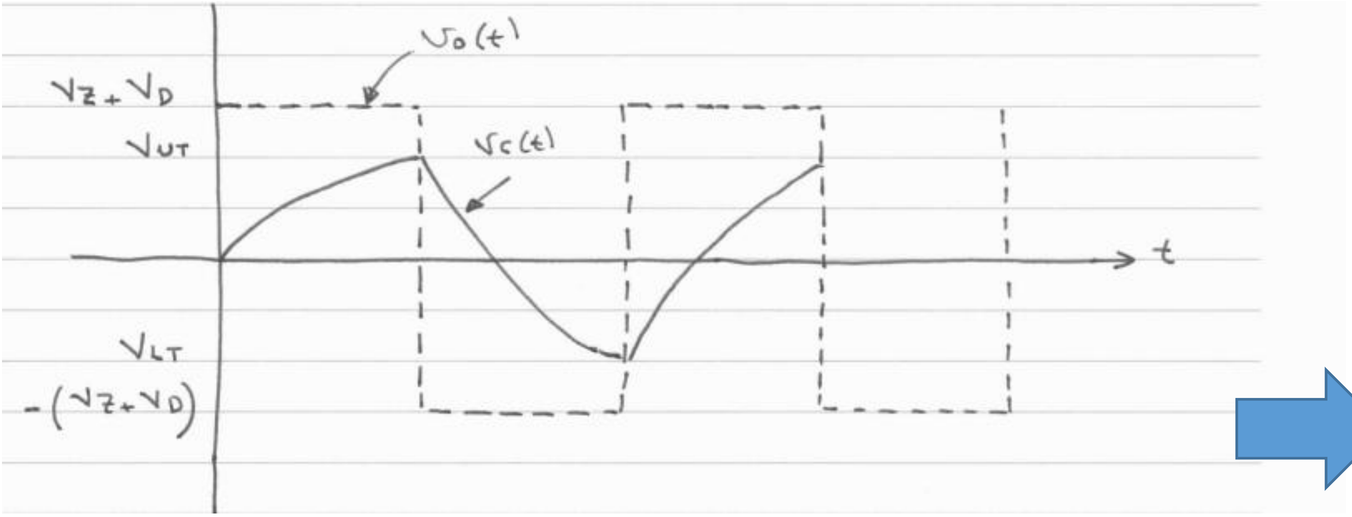
  V_{out}= - (V_z+ 0.7).

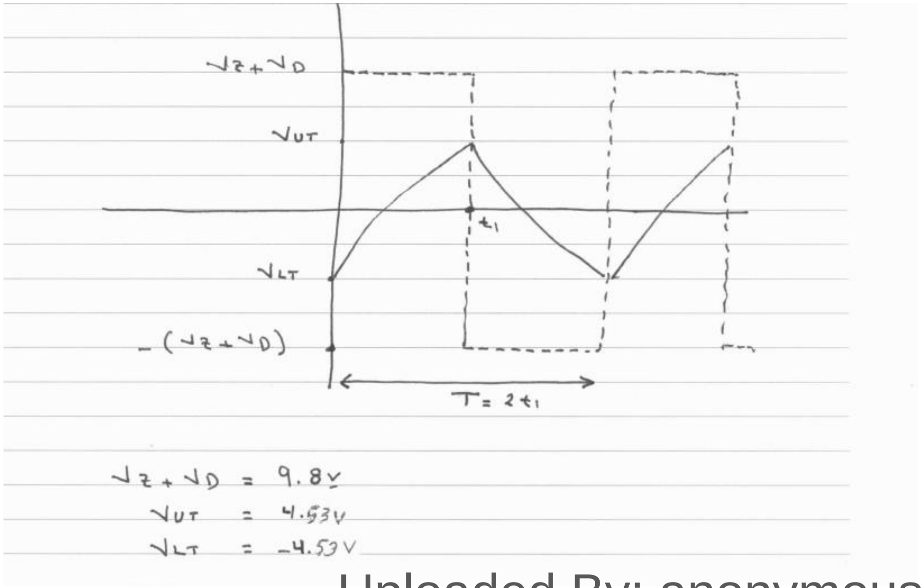


- The capacitor will than start to discharge from the positive upper threshold voltage toward the negative output voltage .

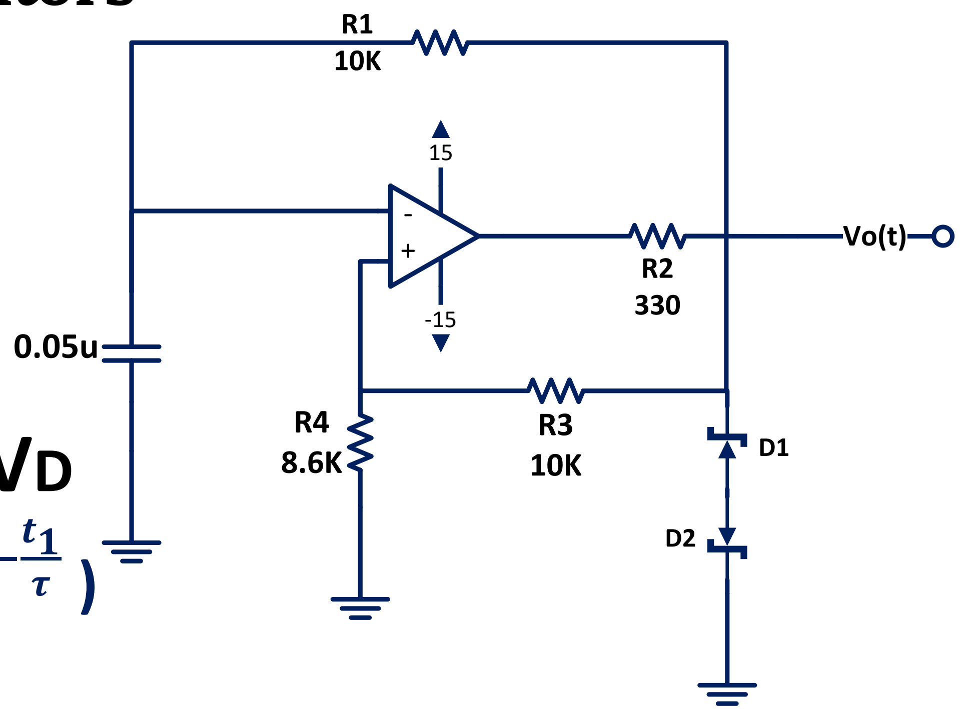
- When the voltage across the capacitor reaches the lower threshold voltage V_{LT} , the comparators output will immediately switch to V_{out}= + (V_z+ 0.7).







Oscillators



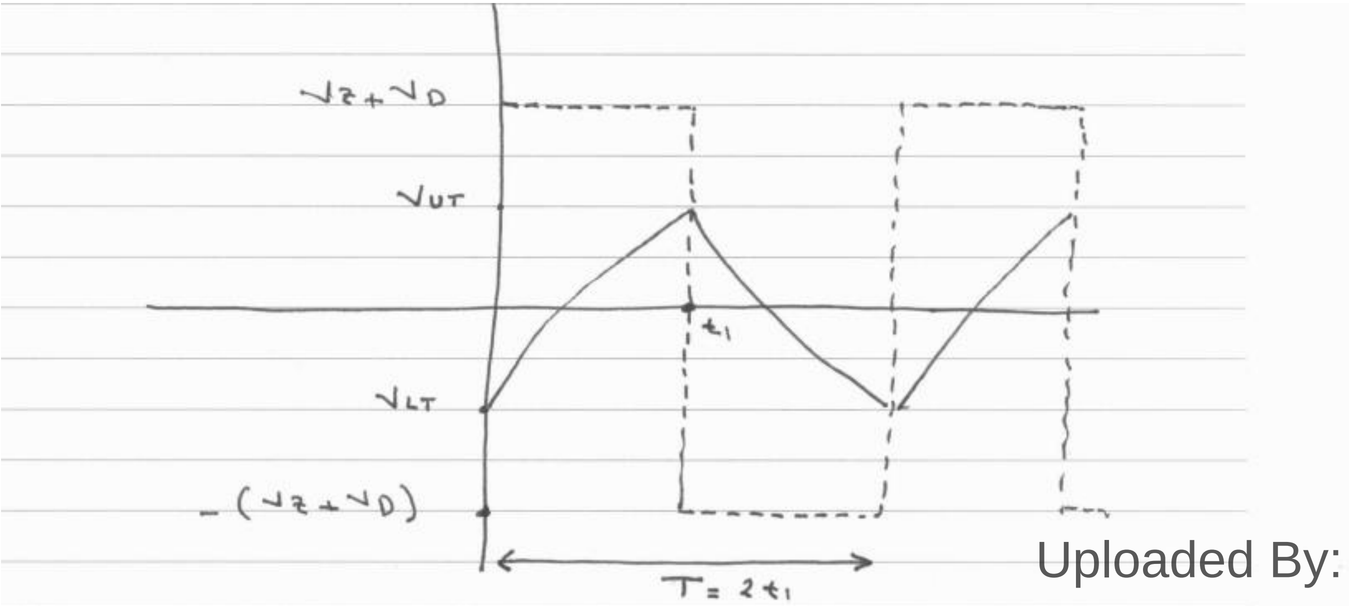
To determine the frequency of oscillation

- $V_c(t) = V_I + (V_f - V_I)(1 - e^{-\frac{t}{\tau}})$
- At t_1 : $V_c(t1) = \beta V_{out}$

$$\frac{R_4}{R_4 + R_3} = \beta$$

$$V_{out} = V_Z + V_D$$

- $\beta V_{out} = -\beta V_{out} + (V_{out} - (-\beta V_{out}))(1 - e^{-\frac{t_1}{\tau}})$
- dividing both side by V_{out}
- $\beta = -\beta + (1+\beta)(1 - e^{-\frac{t_1}{\tau}})$
- $2\beta = (1+\beta)(1 - e^{-\frac{t_1}{\tau}})$
- $\frac{2\beta}{(1+\beta)} = (1 - e^{-\frac{t_1}{\tau}})$



- $e^{-\frac{t_1}{\tau}} = \frac{1-\beta}{1+\beta}$

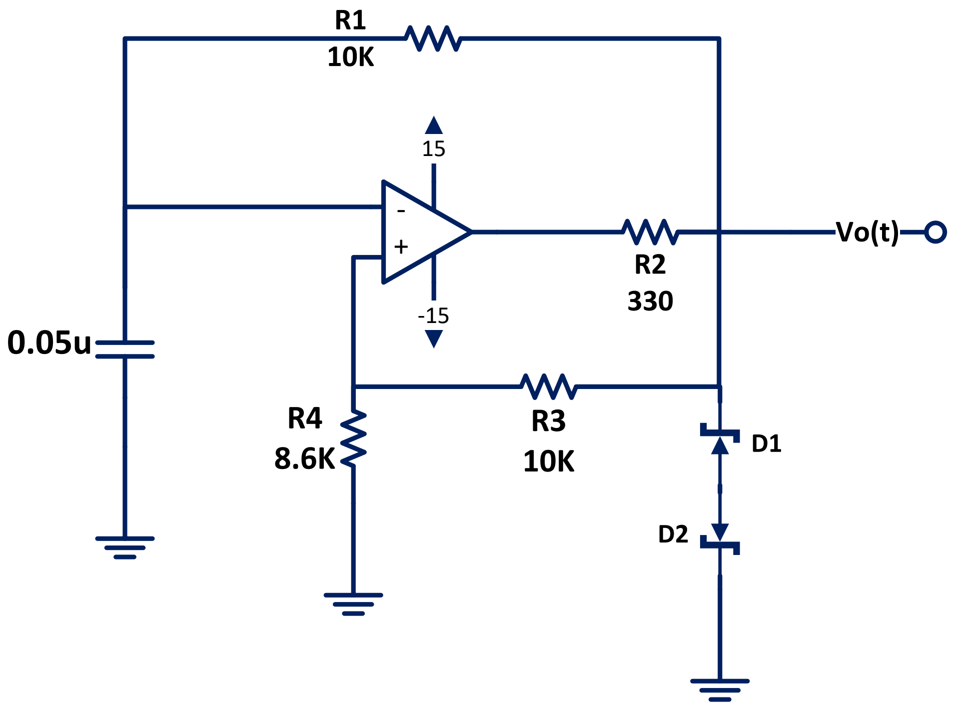
- $-\frac{t_1}{\tau} = ln\frac{1-\beta}{1+\beta}$

- $t_1 = \tau\ ln\frac{1+\beta}{1-\beta} = R_1C_1\ ln\frac{1+\beta}{1-\beta}$

- $T = 2t_1 = 2R_1C_1\ \ln(\frac{1+\beta}{1-\beta})$

  $f_o = \frac{1}{T}$

- $\therefore\ f_o = \frac{1}{T} = \frac{1}{2R_1C_1\ \ ln(\frac{1+\beta}{1-\beta})}$



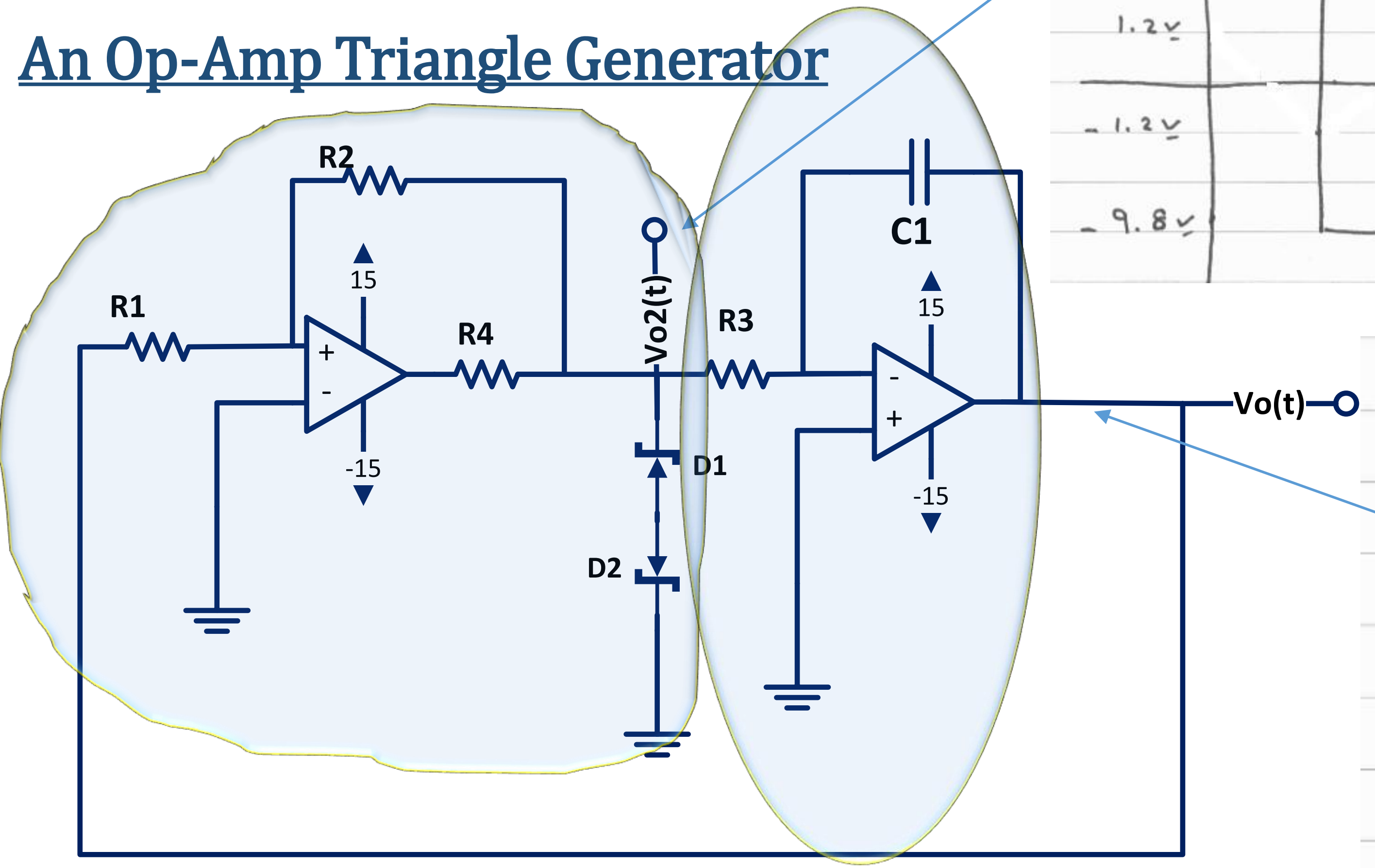
- If $R_4 = 0.859R_3$ → $\beta = 0.462$

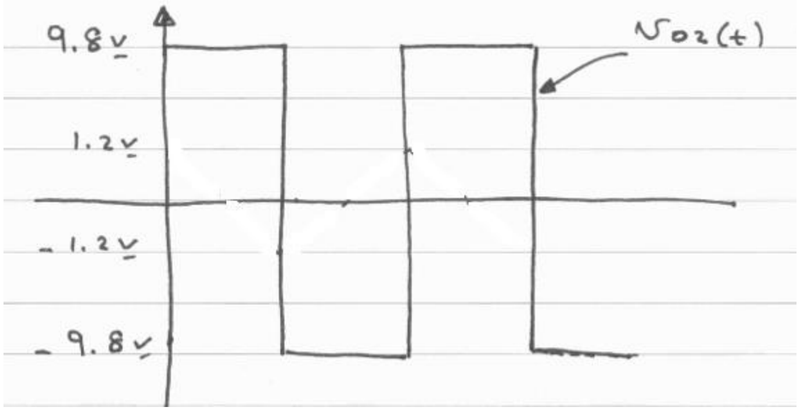
- $\ln(\frac{1+\beta}{1-\beta}) = 1$

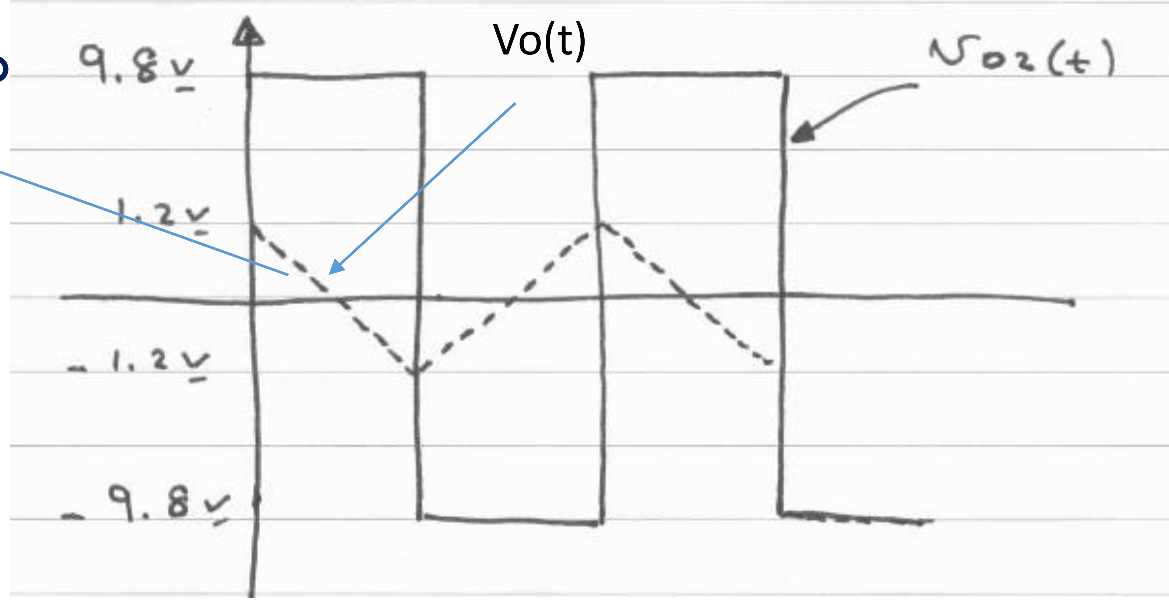
$\therefore f_o = \frac{1}{2R_1C_1}$

Oscillators

An Op-Amp Triangle Generator







V_Z = 9.1v

R_1 = 100KΩ

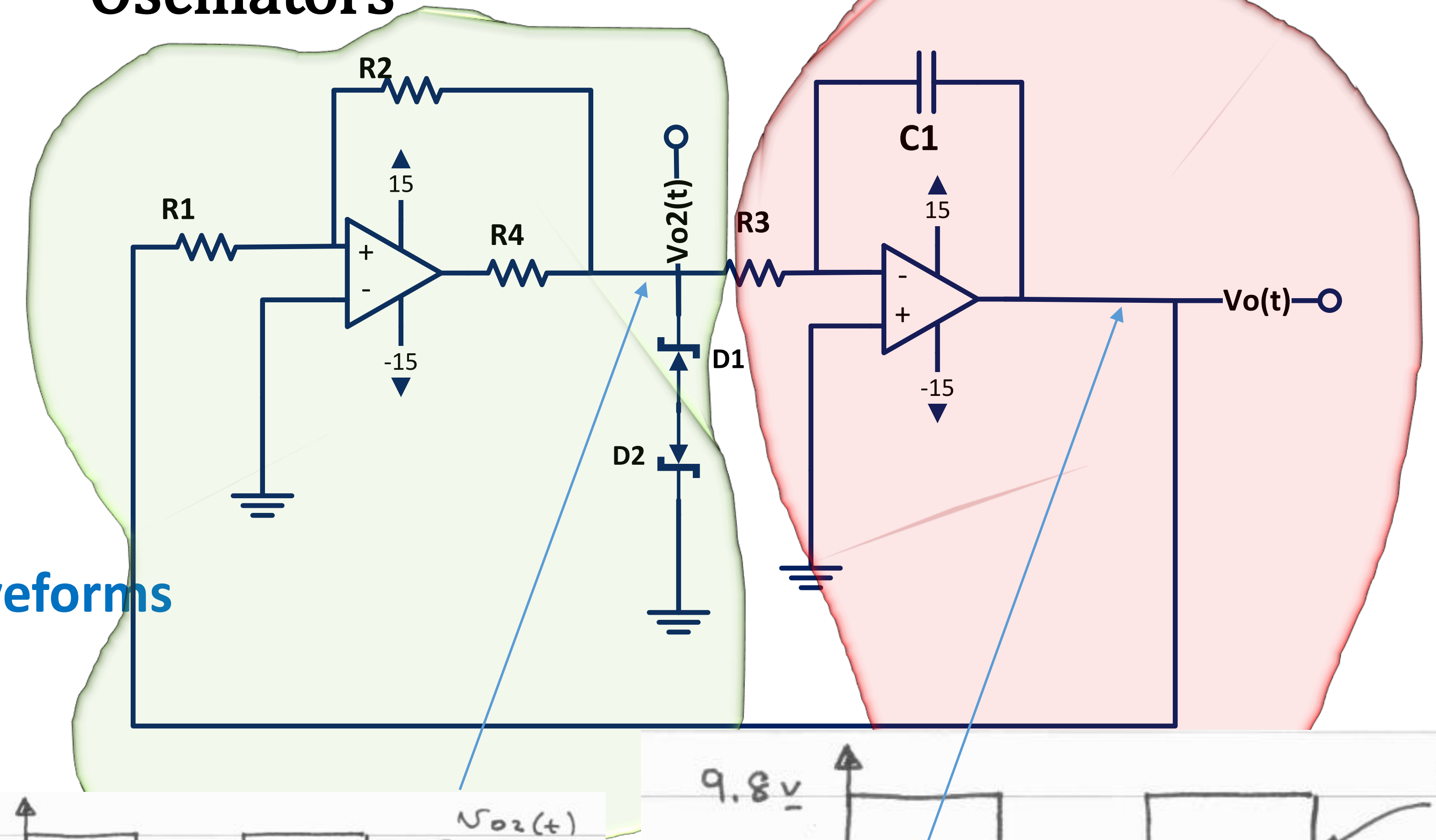
R_2 = 820 KΩ

$V_Z + V_D$ = 9.8v

$\frac{R_1}{R_2}(V_Z + V_D)$ = 1.2v

Oscillators

An Op-Amp Triangle Generator



It consists of two stages

a) Non inverting Schmitt trigger comparator

b) Inverting integrator

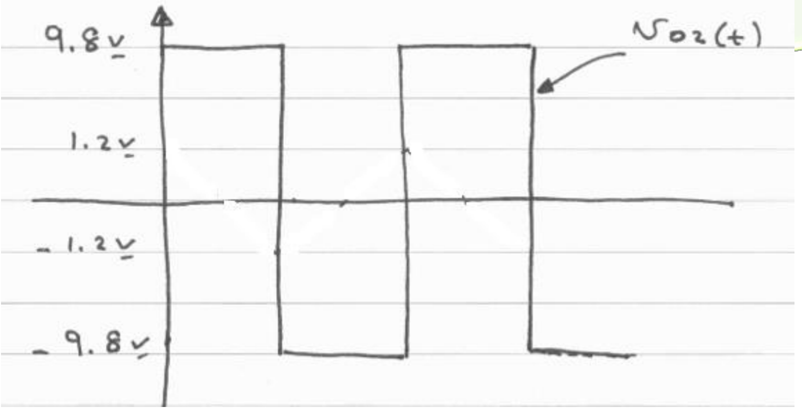
It provide two different output waveforms

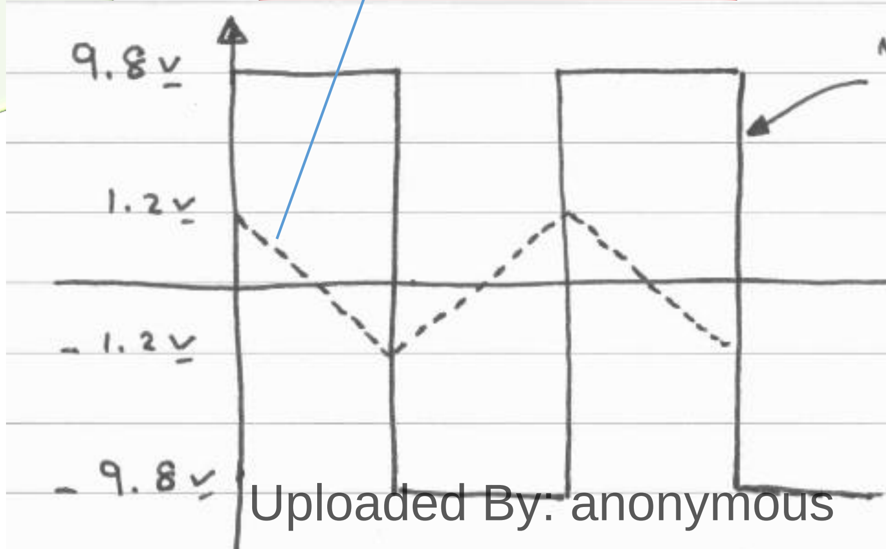
a) Square wave

b) Triangle wave

$$V_{UT} = \frac{R_1}{R_2}(V_Z + V_D) = 1.2\text{v}$$

$$V_{LT} = -\frac{R_1}{R_2}(V_Z + V_D) = -1.2\text{v}$$





Inverting Integrator

Assuming that $V_c(0^-) = 0$

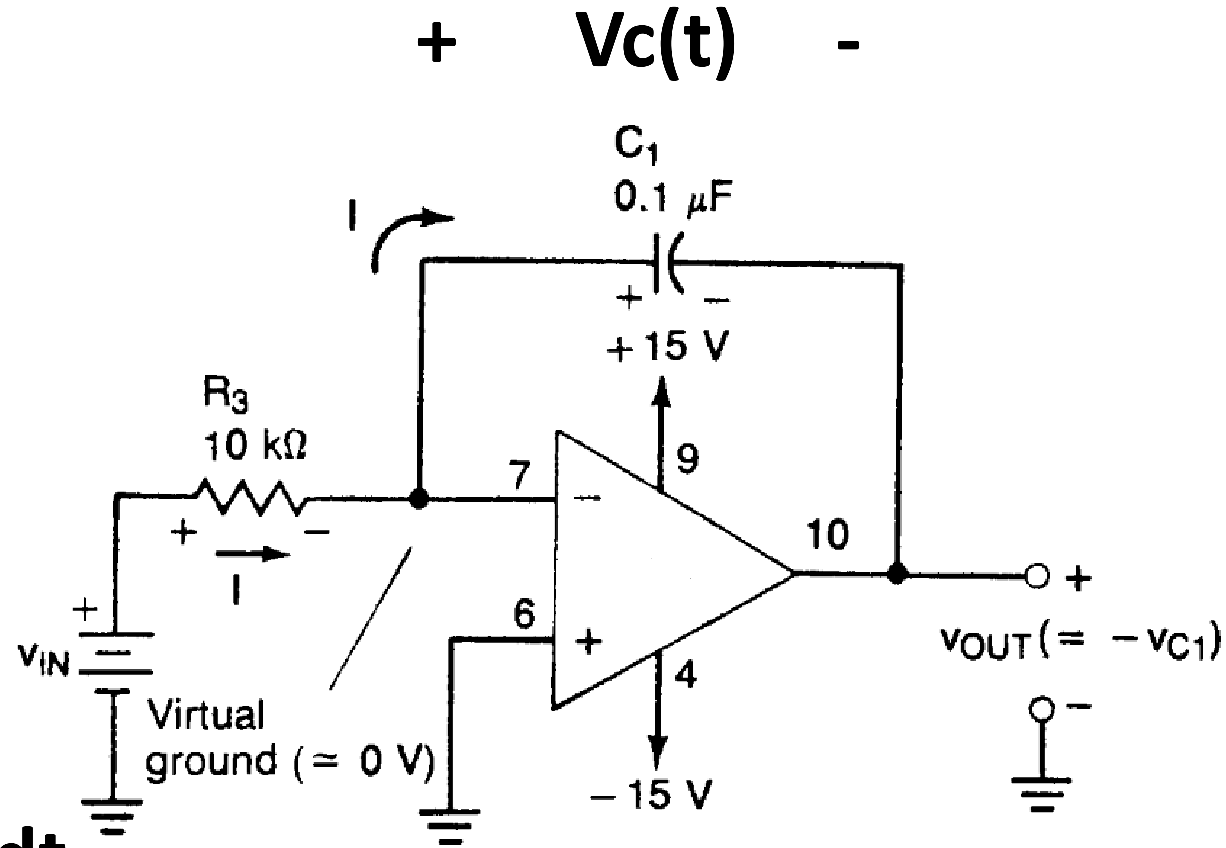
$$V_{out} = -V_c(t)$$

$$V_c(t) = \frac{1}{C_1}\int_0^t i_{in}(t)\,dt$$

$$i_{in}(t) = \frac{V_{in}(t)}{R_3}$$

$$V_{out} = -\frac{1}{R_3C_1}\int_0^t V_{in}(t)\,dt$$

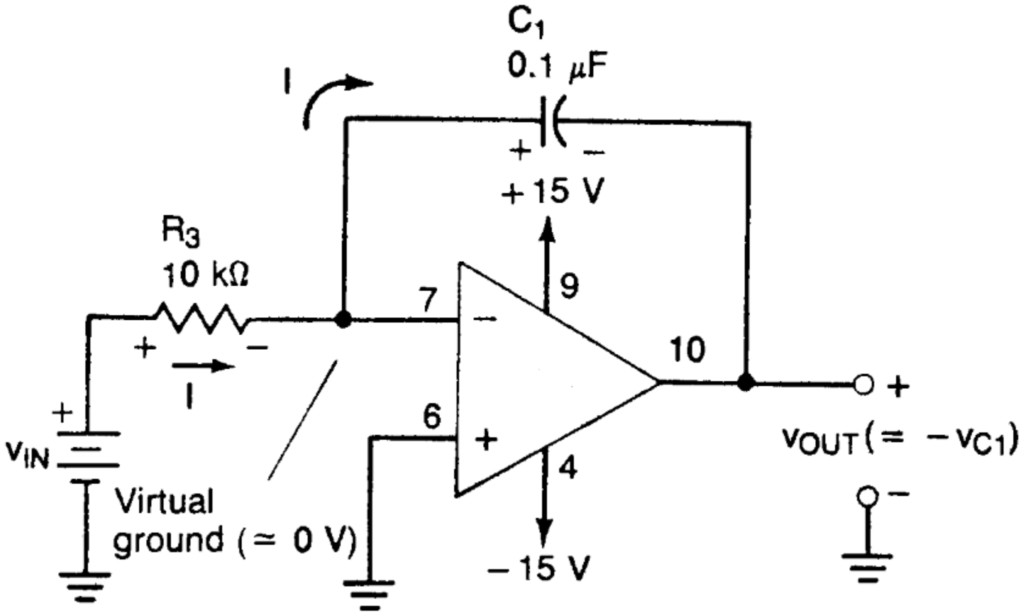
$$V_{in}(t) = V_{in} \quad \text{, DC}$$



$$\therefore \quad V_{out} = -\frac{V_{in}}{R_3C_1}t$$

Inverting Integrator

$$V_{out} = -\frac{V_{in}}{R_3 C_1} t$$



Assuming that V_i = -10mV ,

find $V_o\ (t)$ at 0.1s and 0.2s

$V_{out} = -\frac{V_{in}}{R_3 C_1} t$ = $-\frac{V_{in}}{(10k\Omega)(0.1\mu F)} t$ = -1000V_{in}

If v_{in} is -10mV and t is 0.1s

$V_{out} = -$ 1000V_{in}t = -(1000)(-10mv)(0.1s)

= 1v

And in 0.2s

$V_{out} = -$ 1000V_{in}t = -(1000)(-10mv)(0.2s)

=2v

Assuming that +V_{sat} is 13 v we may solve the time to reach saturation

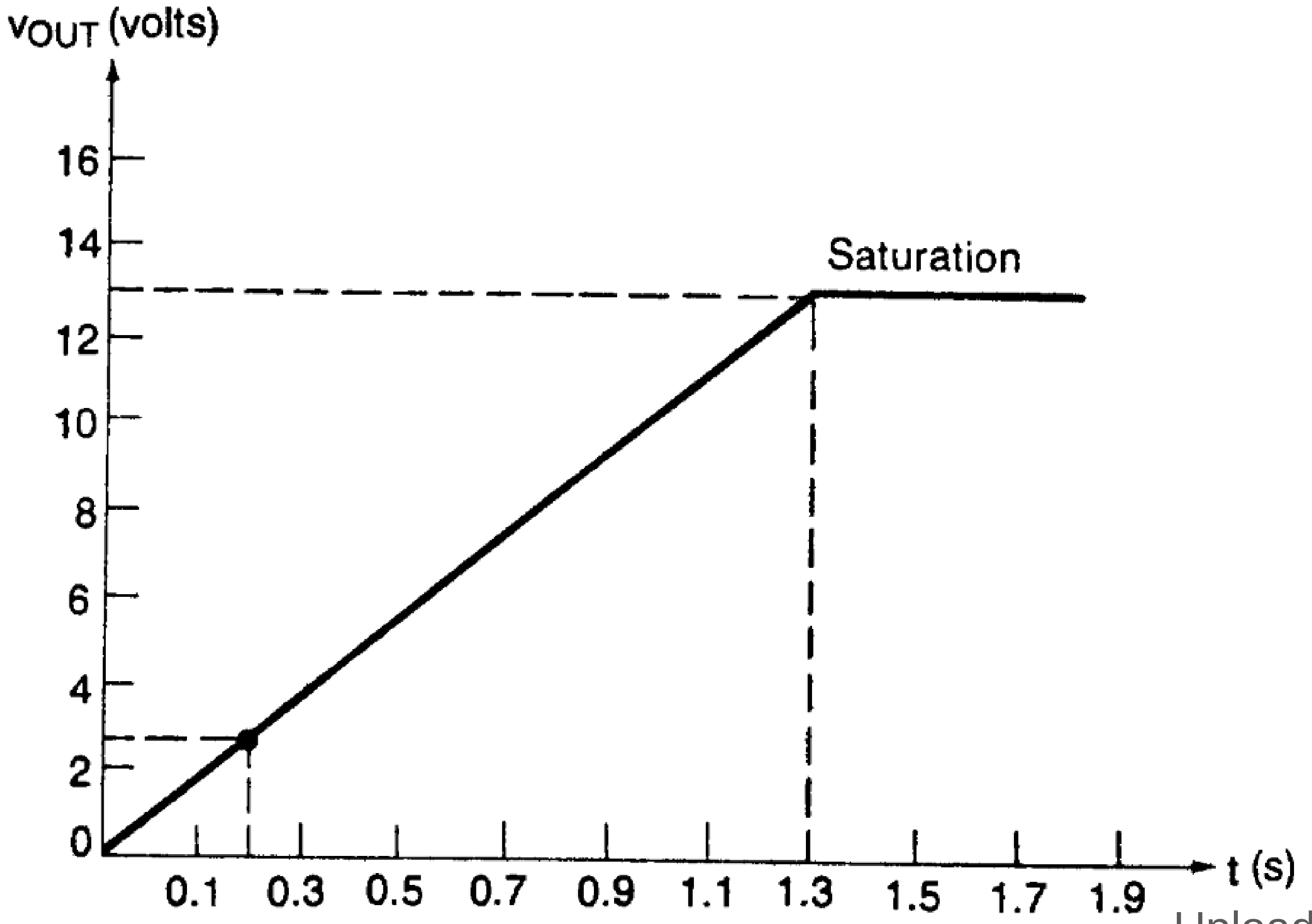
$V_{out} = -\frac{V_{in}}{R_3 C_1} t$ = +V_{sat}

t = $\frac{+V_{sat}}{-v_{in}} R_3 C_1$= $\frac{13v}{-(-10mv)}$(10kΩ)(0.1μf)

= (1300)(1ms)=1.3s

Oscillators

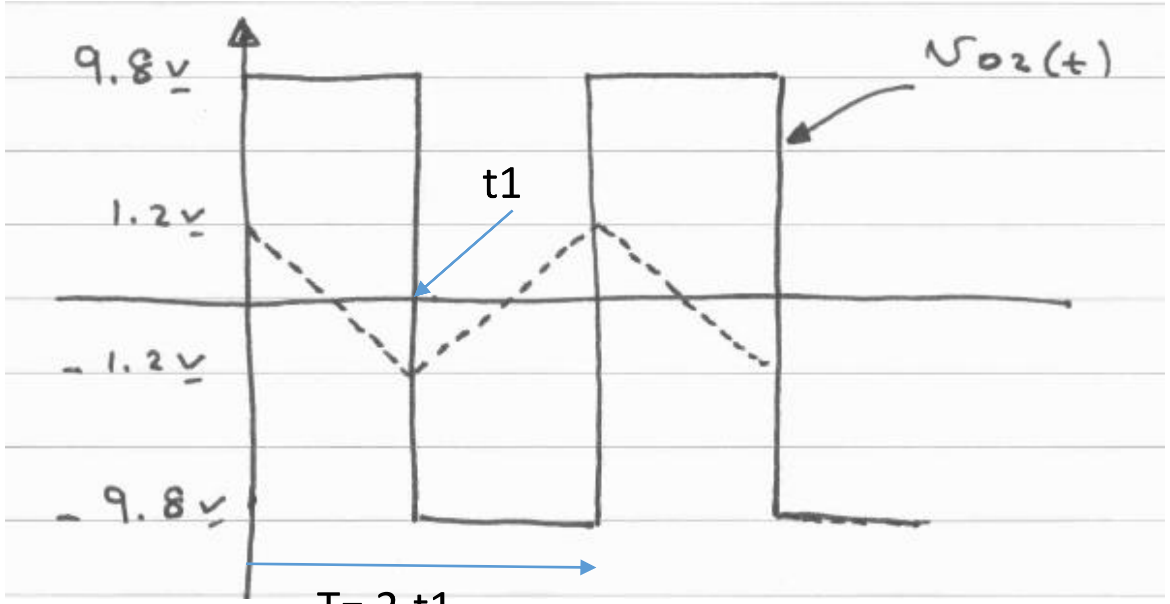
Inverting Integrator



Oscillators

Inverting Integrator

To determine f_o



For $t_1 \geq t \geq 0$

$$V_o(t) = V_{UT} - \frac{V_{in}}{R_3C_1}t$$

$$V_{UT} = \frac{R_1}{R_2}(V_Z + V_D)$$

$$V_{in} = V_Z + V_D$$

$$V_o(t) = \frac{R_1}{R_2}(V_Z + V_D) - \frac{V_Z + V_D}{R_3C_1}t$$

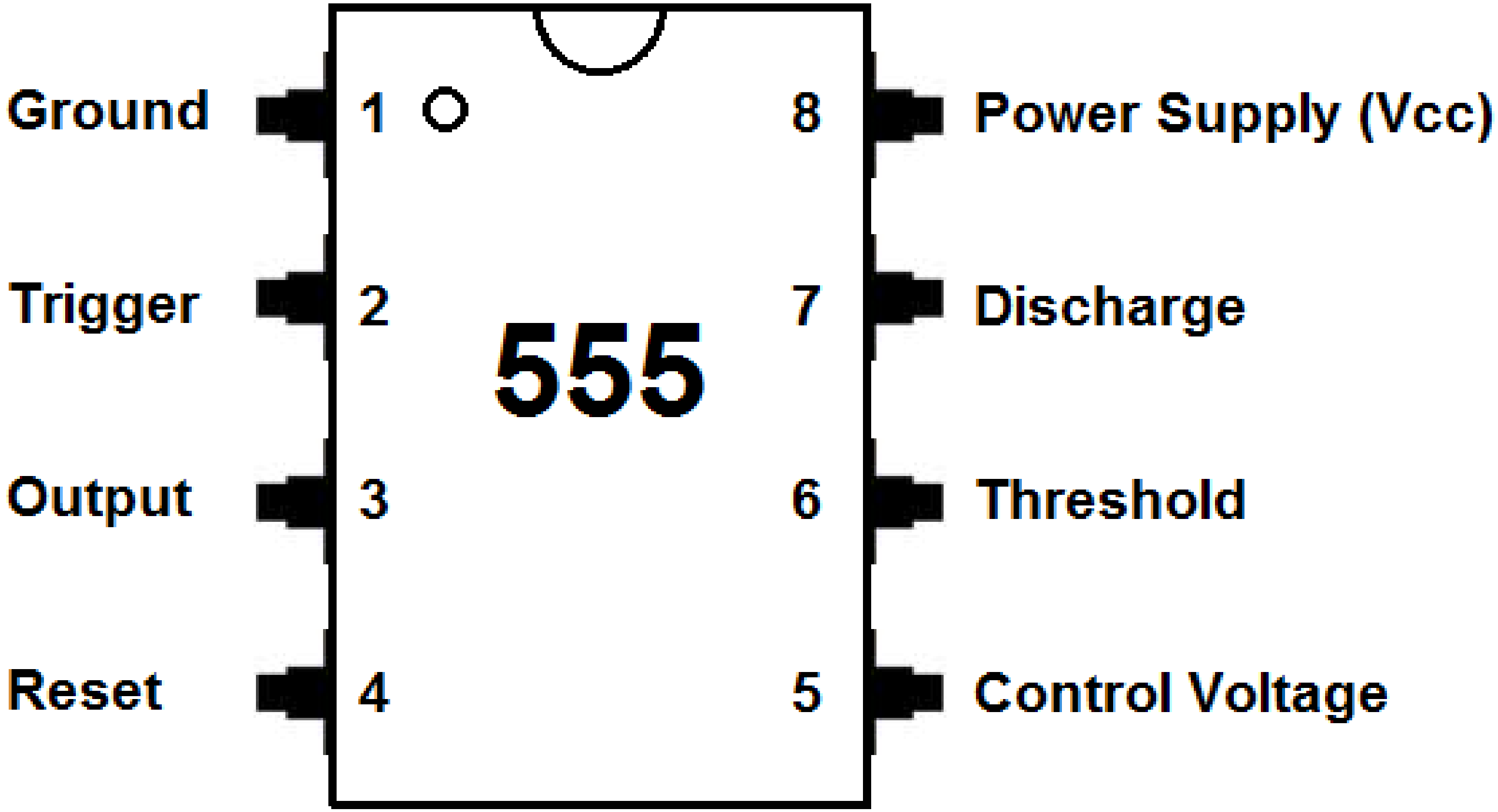
At t = t_1 ; $V_o(t_1) = -\frac{R_1}{R_2}(V_Z + V_D) = V_{LT}$

$$\therefore t_1 = \frac{2R_1R_3C_1}{R_2}$$

$$f_o = \frac{1}{T} = \frac{1}{2\,t_1} = \frac{R_2}{4R_1R_3C_1}$$

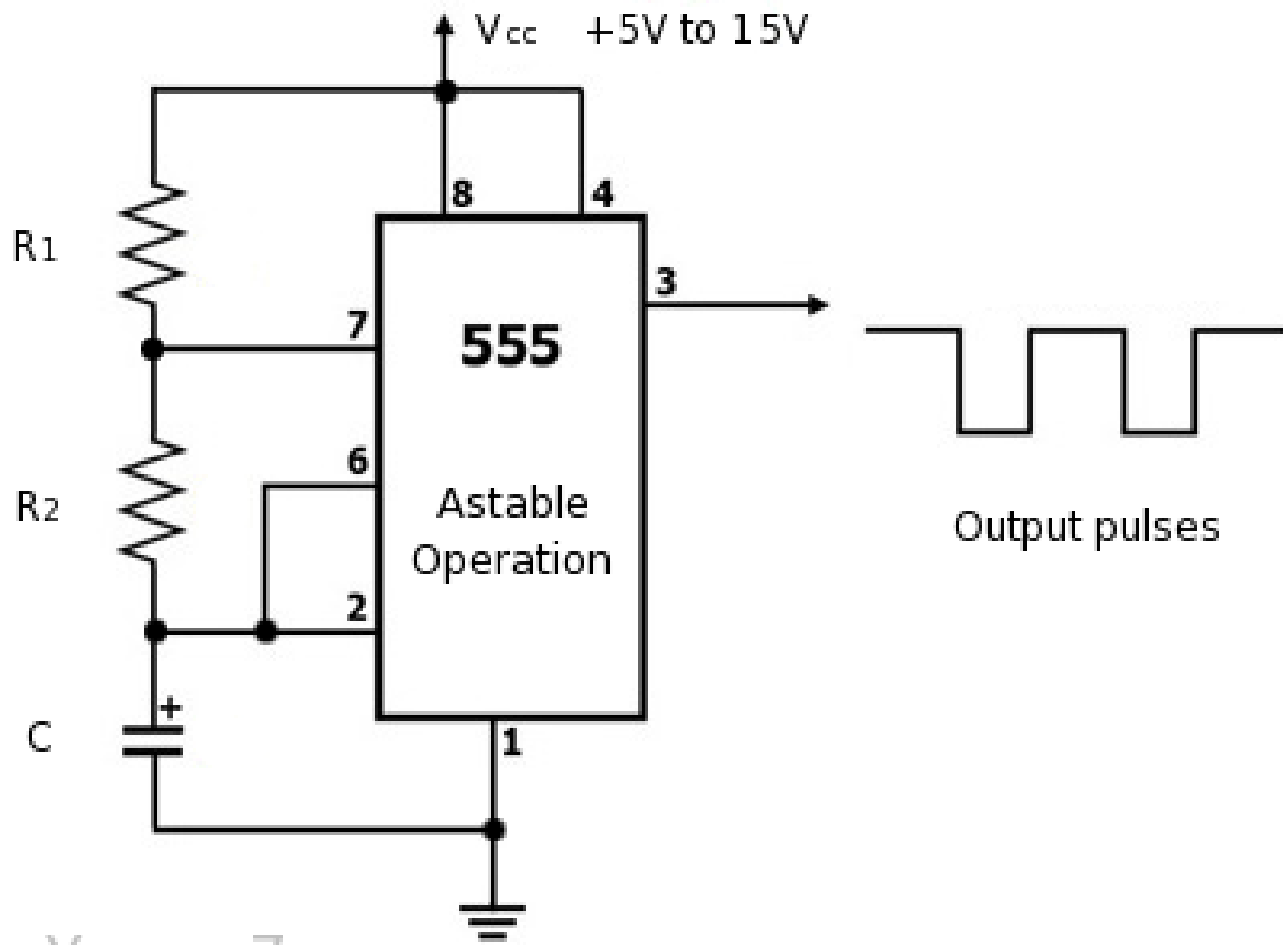
Oscillators

The 555 Timer As an Oscillator.



Oscillators

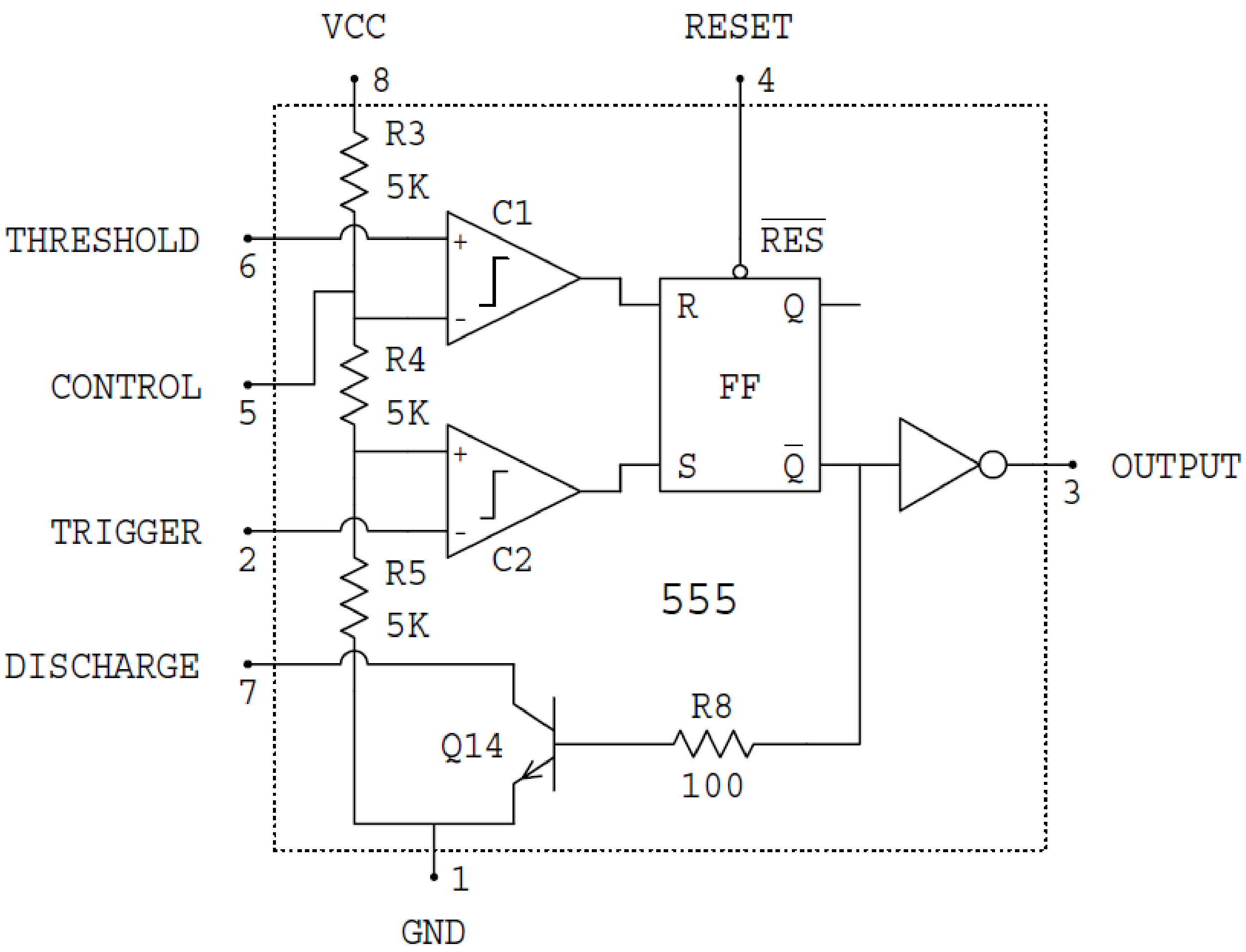
The 555 Timer As an Oscillator.



Oscillators

The 555 Timer As an Oscillator.

Functional block diagram of the 555 integrated circuit timer



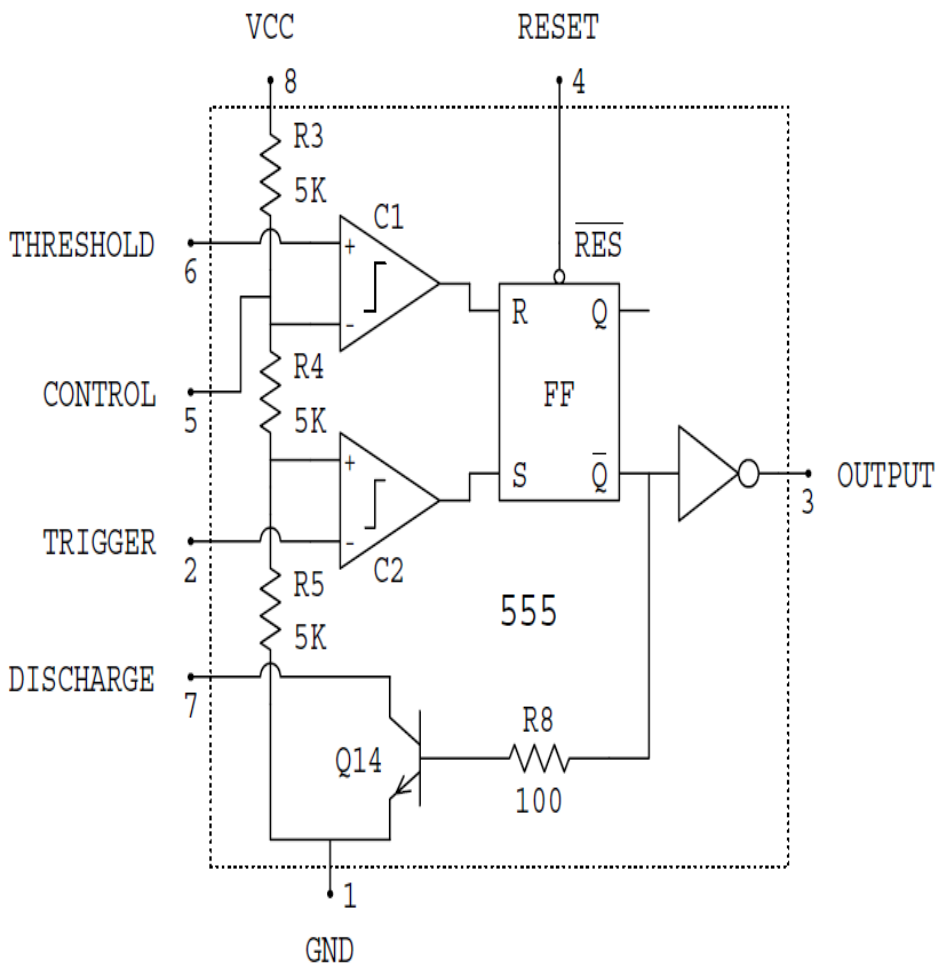
Oscillators

The 555 Timer As an Oscillator.

Internal Component of 555

- **Two comparators**
- **Three R (5K) that set the trigger Levels**
- **Transistor that act as a switch**
- **S R Latch**
-

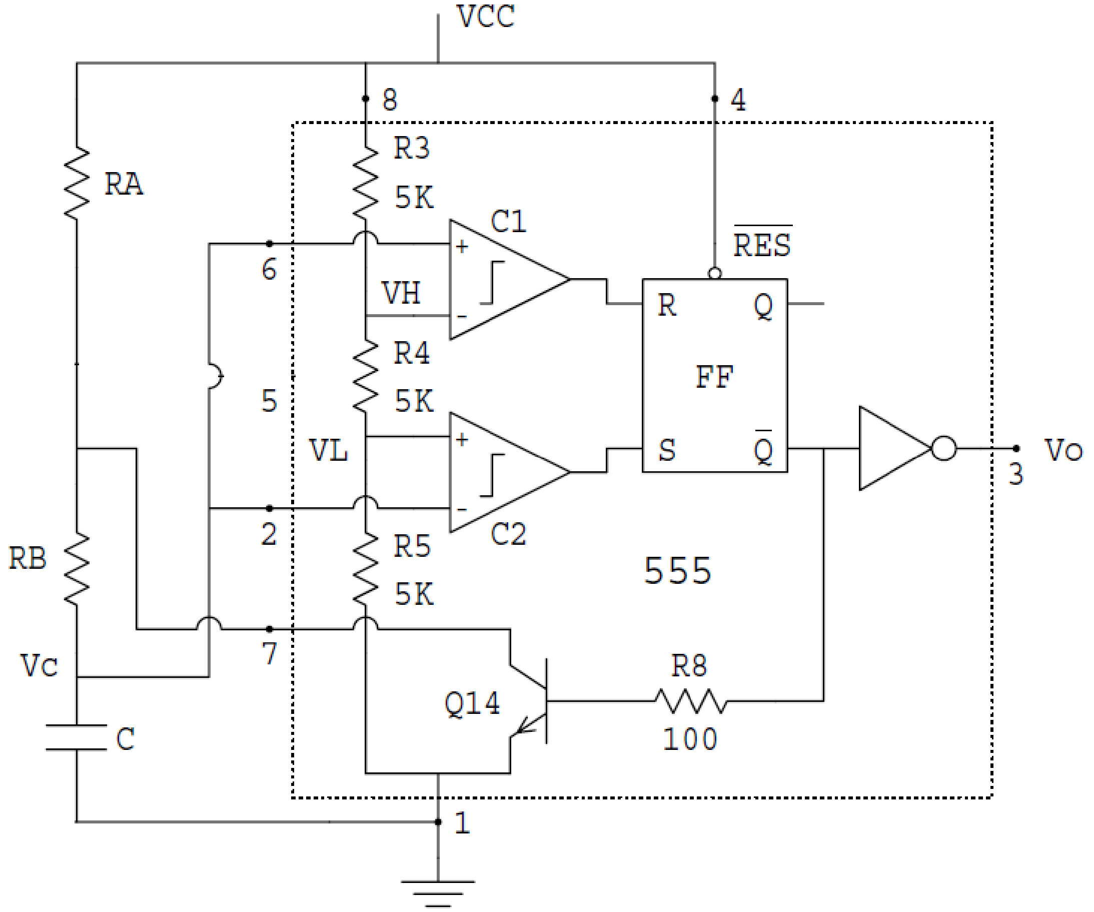
S	R	Q_n
0	0	Q_n no change
1	0	1
0	1	0
1	1	Forbidden



Oscillators

The 555 Timer As an Oscillator.

555 timer as an a stable circuit



The 555 Timer As an Oscillator.

Operation of the 555 timer oscillator.

At the beginning

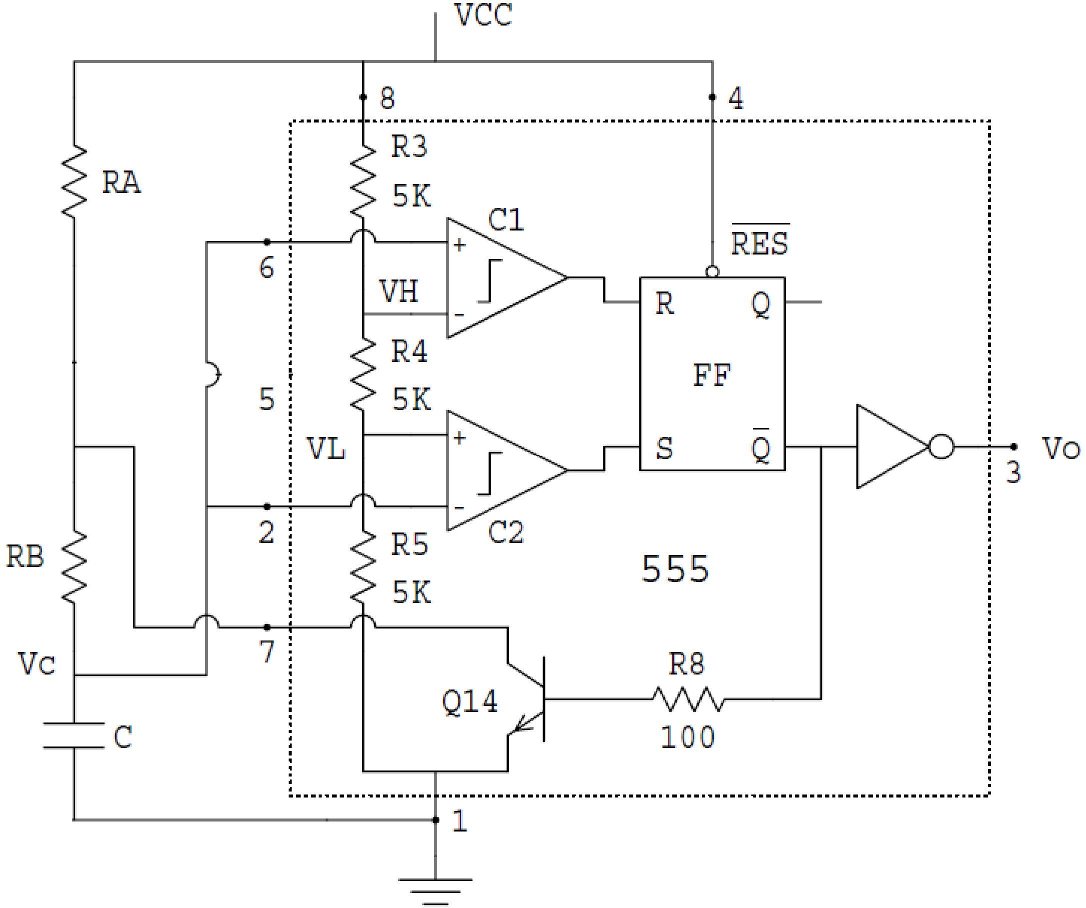
$$V_C(0^+) = V_C(0^-) = 0$$

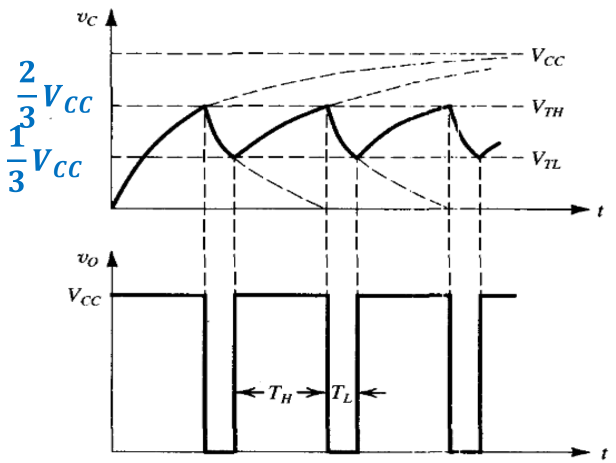
$\therefore R = 0\ ,\quad S = 1$

$\therefore Q = 1\ ,\quad \overline{Q} = 0$

∴Transistor is off

∴ The capacitor starts charging





$$\tau_c = (R_A + R_B)C$$

- When $V_C(t) > \frac{1}{3}V_{CC}$

$\therefore$ R = 0 , and S = 0

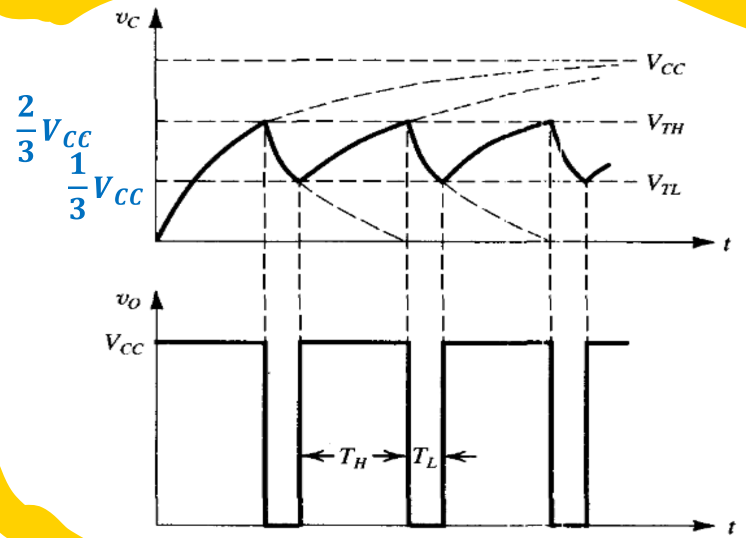
No change

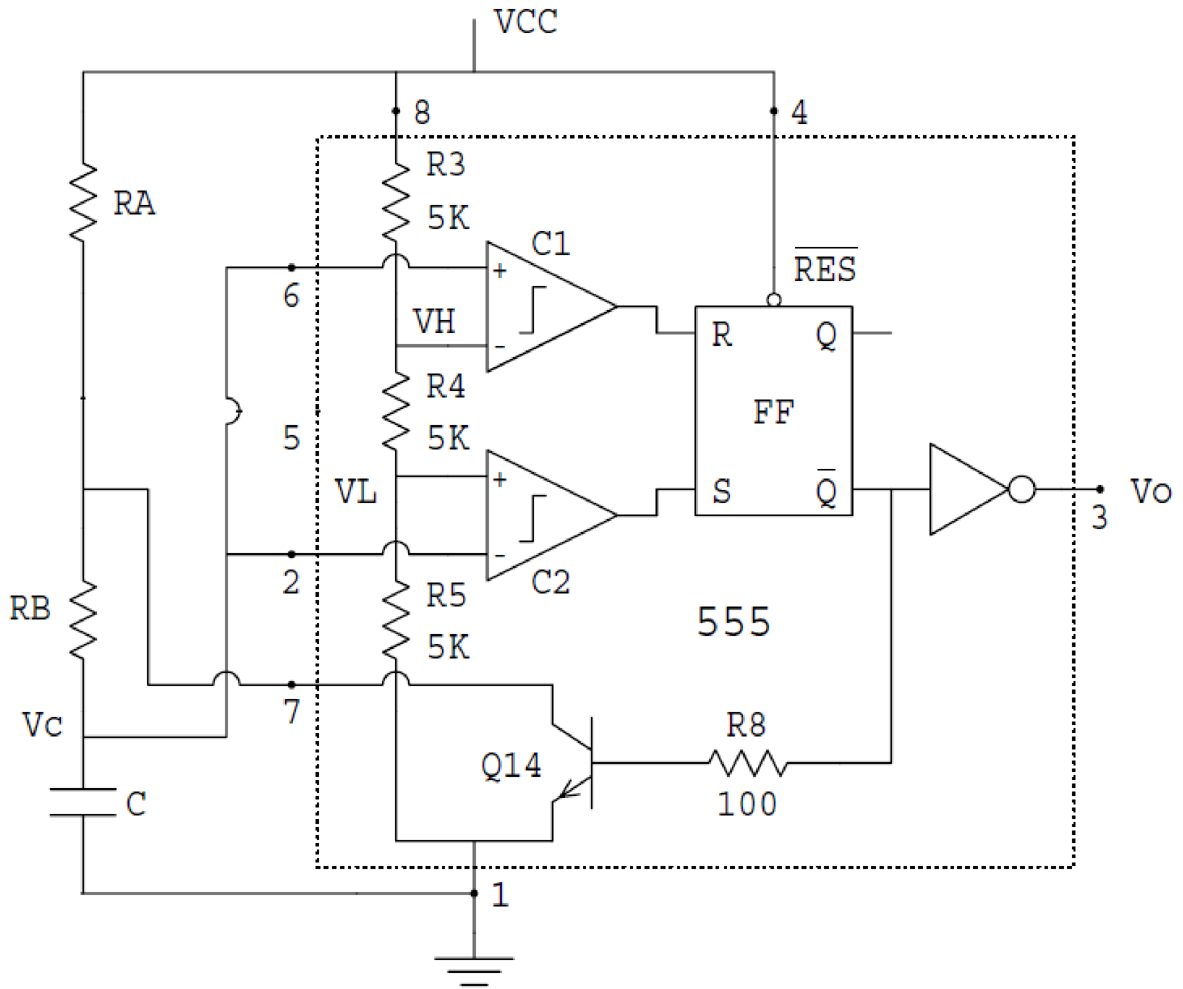
$\therefore$ Q = 1 ,and $\overline{Q} = 0$

$\therefore$ The transistor is still off

$\therefore$ The capacitor is still charging

$\tau_C = (R_A + R_B)C$





- **When $V_C(t) > \frac{2}{3}V_{CC}$**

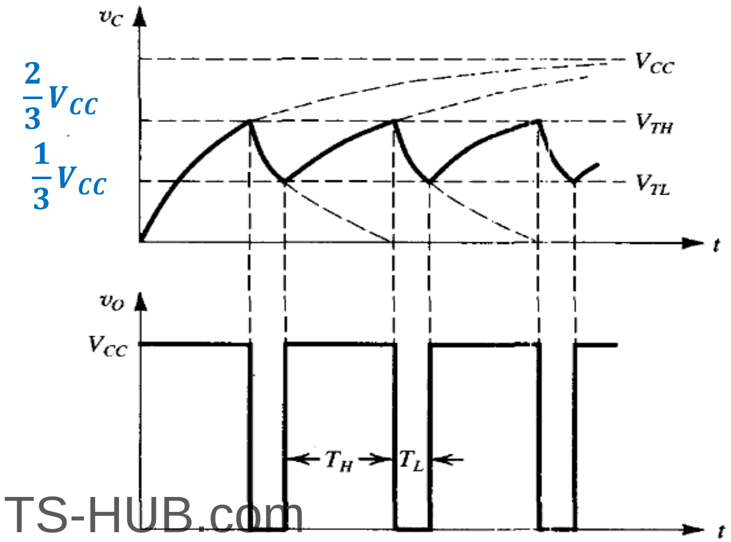
$\therefore$ R = 1 , and S = 0

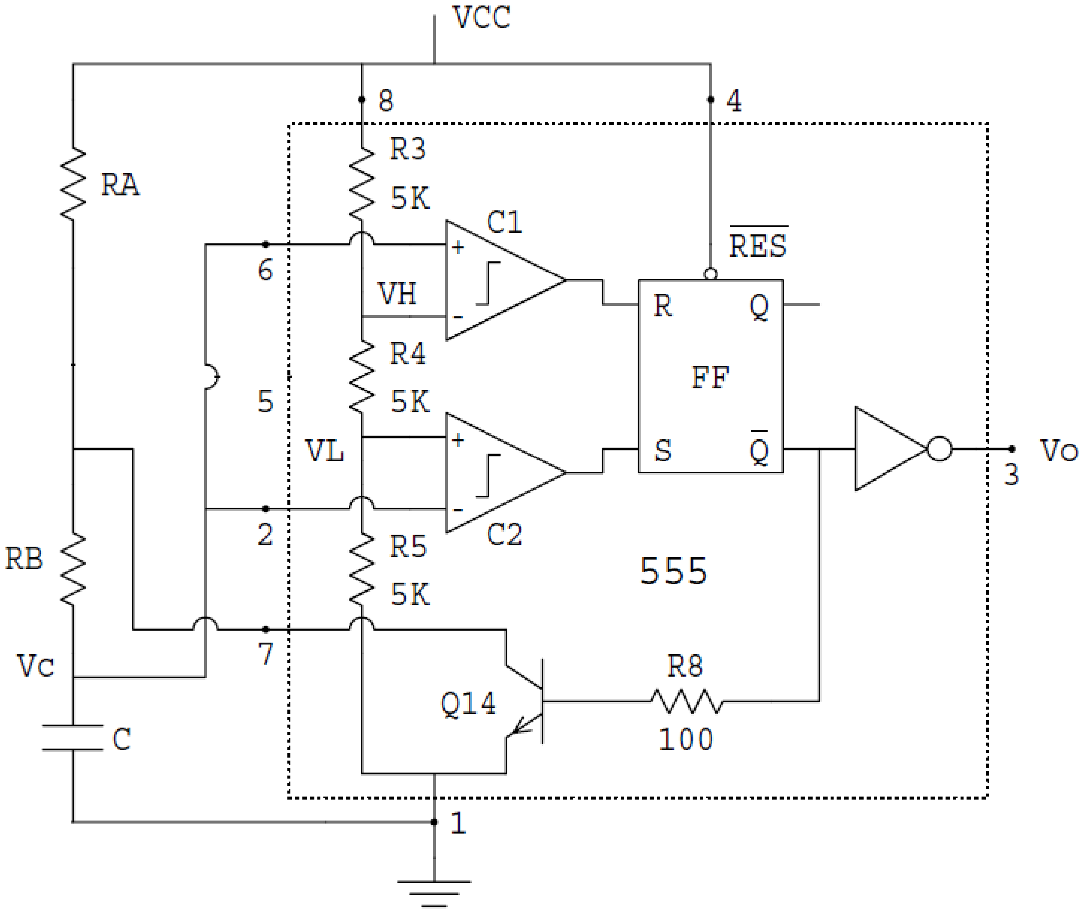
$\therefore$ Q = 0 , and $\overline{Q}$ = 1

$\therefore$ The transistor turns on

$\therefore$ The capacitor starts discharging

$\tau_d = R_B C$





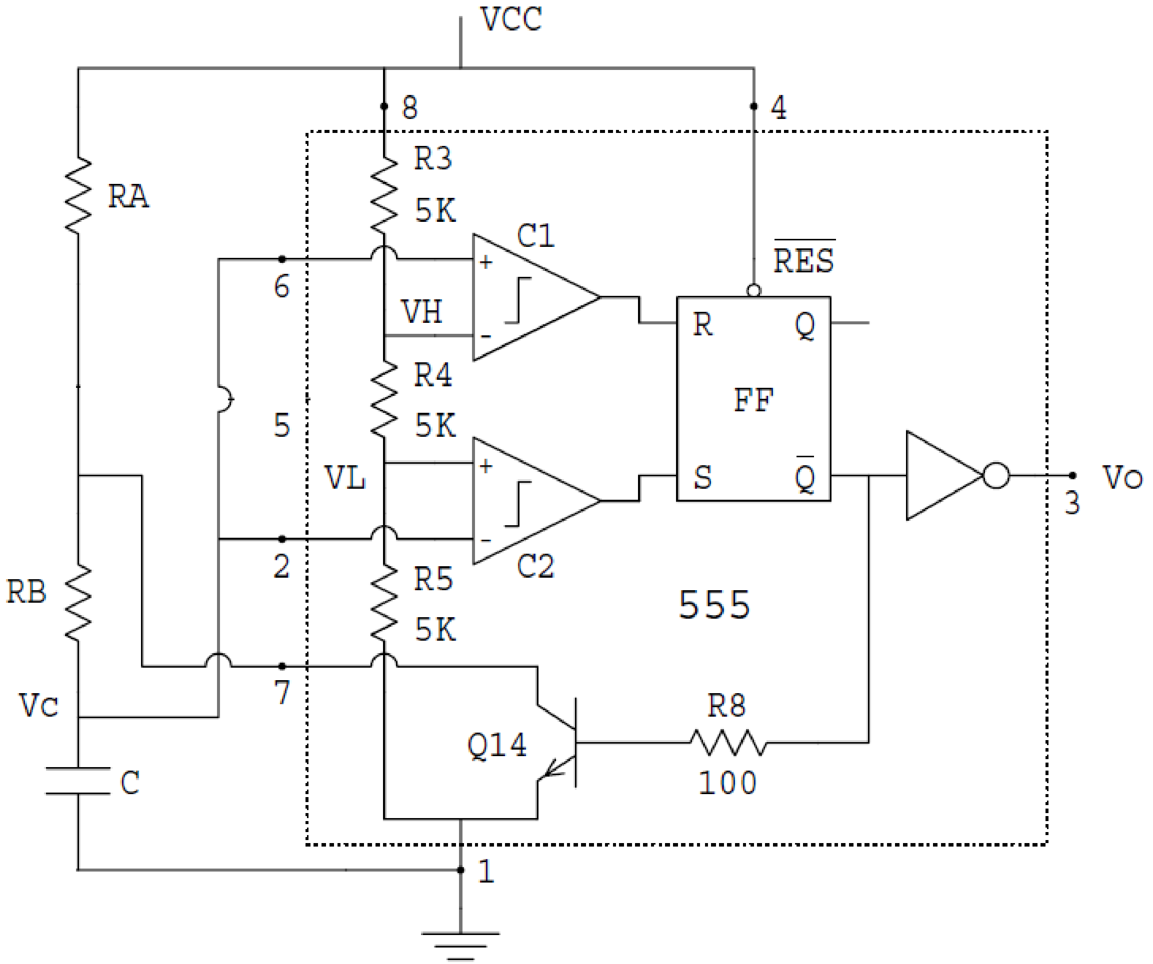
When $V_C(t) < \frac{1}{3}V_{CC}$

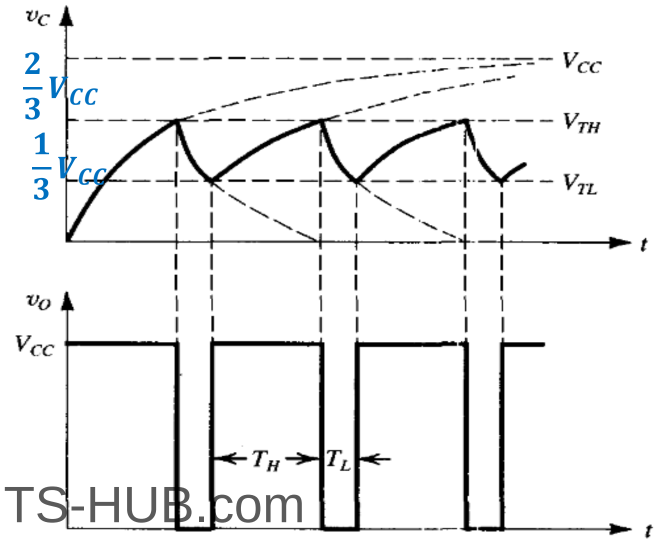
$\therefore S = 1$, and $R = 0$

$\therefore Q = 1$,and $\overline{Q} = 0$

∴ The transistor turn Off

∴The capacitor starts charging

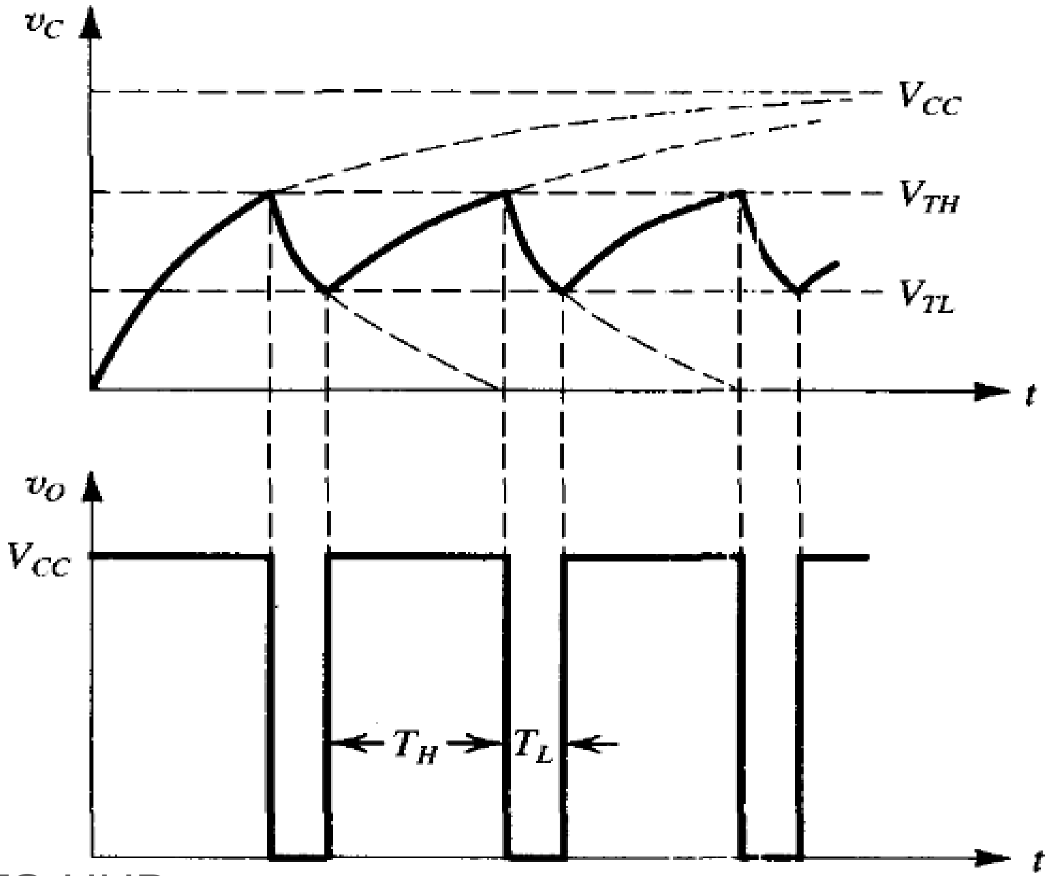


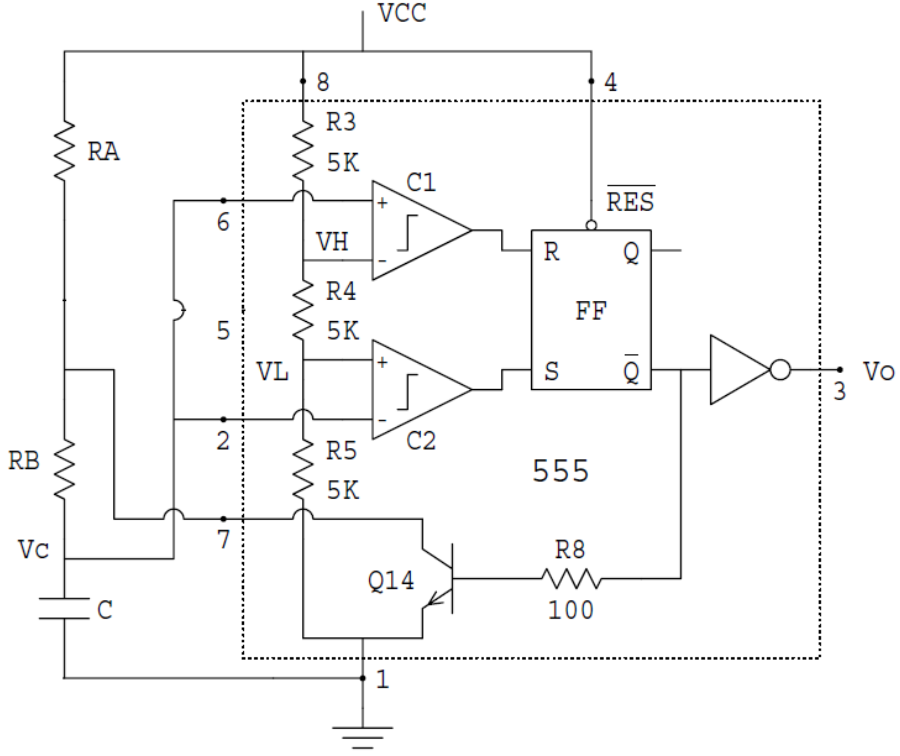


Oscillators

The 555 Timer As an Oscillator.

Operation of the 555 timer oscillator.

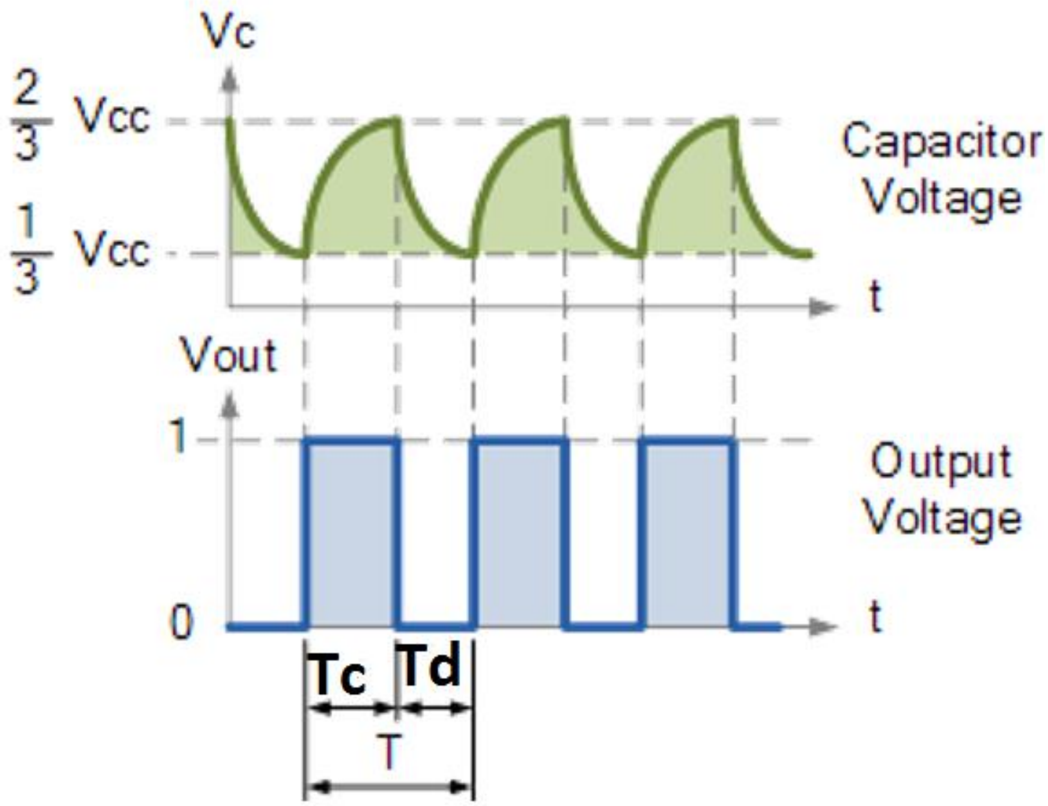




Oscillators

The 555 Timer As an Oscillator.

Operation of the 555 timer oscillator.



1. To find T_C

$$V_c(t) = V_I + (V_f - V_I)(1 - e^{-\frac{t}{\tau}})$$

$$V_c(T_C) = \frac{2}{3}V_{CC} \; ; \quad V_I = \frac{1}{3}V_{CC} \; ; \quad V_f = V_{CC}$$

$$\tau_c = (R_A + R_B)C$$

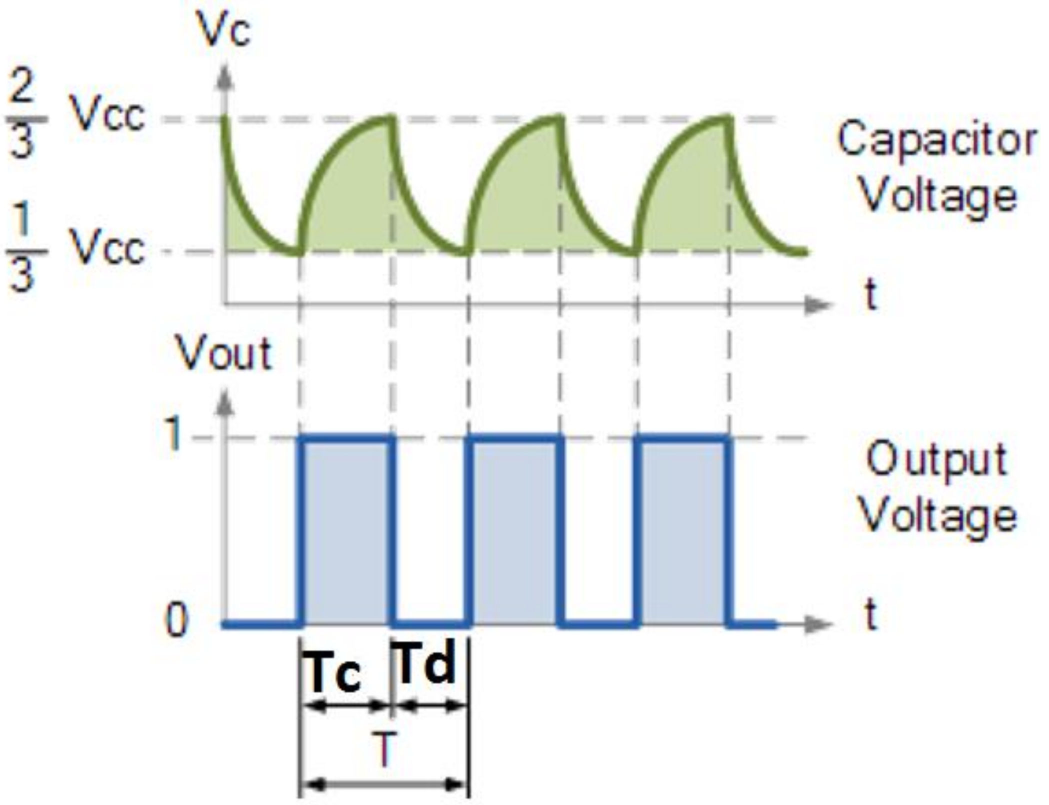
$$V_c(T_C) = \frac{2}{3}V_{CC} = \frac{1}{3}V_{CC} + (V_{CC} - \frac{1}{3}V_{CC})(1 - e^{-\frac{t}{\tau}})$$

$$T_C = \tau_c \ln 2 = (R_A + R_B)C \ln 2$$

Oscillators

The 555 Timer As an Oscillator.

Operation of the 555 timer oscillator.



2-To find T_d

$$V_c(t) = V_I + (V_f - V_I)(1 - e^{-\frac{t}{\tau}})$$

$$V_c(T_d) = \frac{1}{3}V_{CC} \; ; \quad V_I = \frac{2}{3}V_{CC} \; ; \quad V_f = 0$$

$$\tau_d = R_B C$$

$$V_c(T_d) = \frac{1}{3}V_{CC} = \frac{2}{3}V_{CC}\,(0 - \frac{2}{3}V_{CC}\,)\,(1 - e^{-\frac{t}{\tau}})$$

$$\therefore T_d = \tau_d \ln 2 = R_B C \ln 2$$

The 555 Timer As an Oscillator.

Operation of the 555 timer oscillator.

3- To find T

$$T = T_C + T_d = (R_A + 2R_B)C \ln 2$$

$$T = 0.693\,(R_A + 2R_B)C$$

4- To find F

$$F = \frac{1}{T} = \frac{1}{0.693\,(R_A+2R_B)C}$$

5- To find Duty cycle

$$\text{Duty cycle} = D = \frac{T_C}{T} = \frac{R_A+R_B}{R_A+2R_B}$$

Function Generator

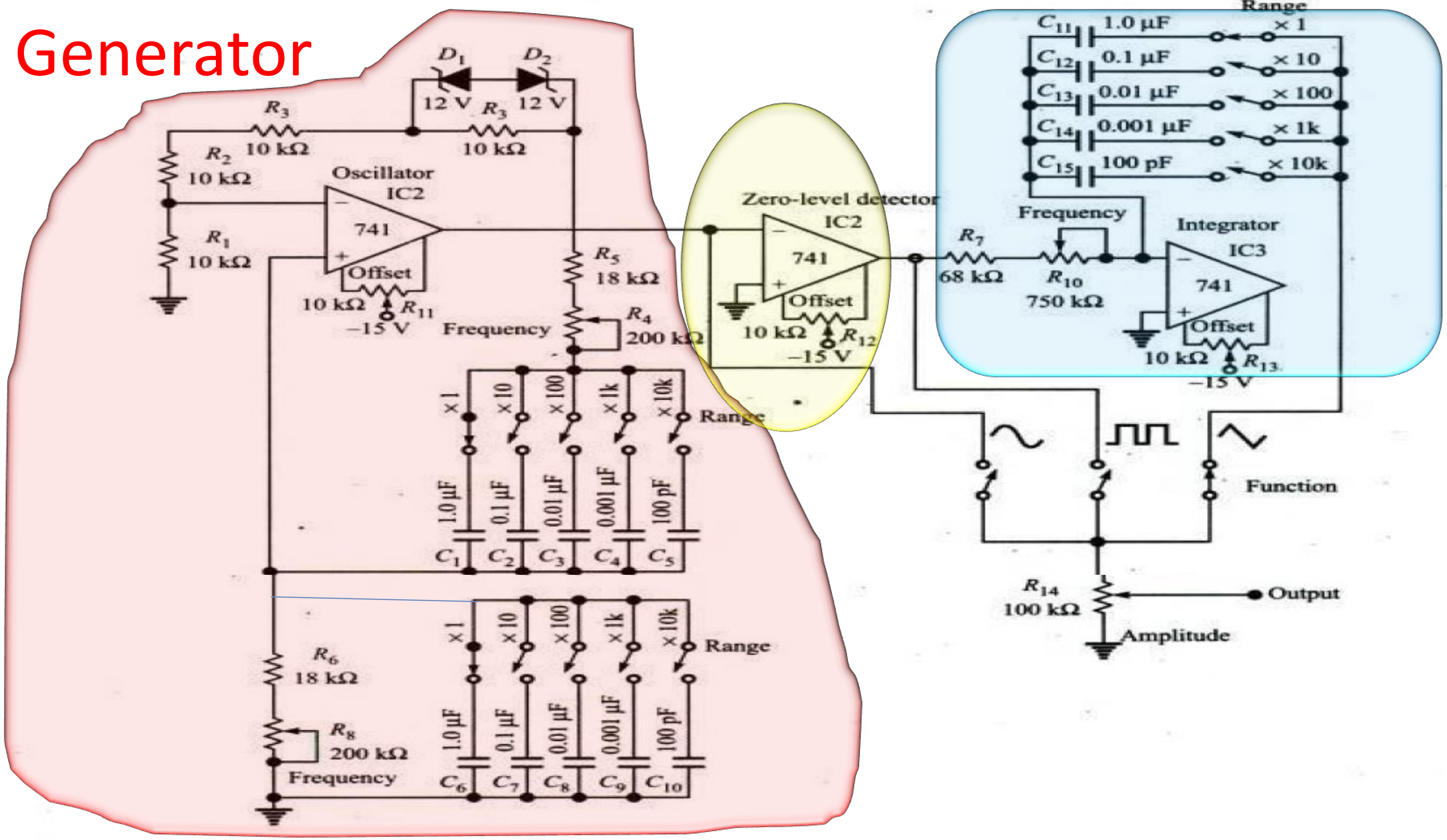


Fig. 16.3 *Schematic of the function generator*