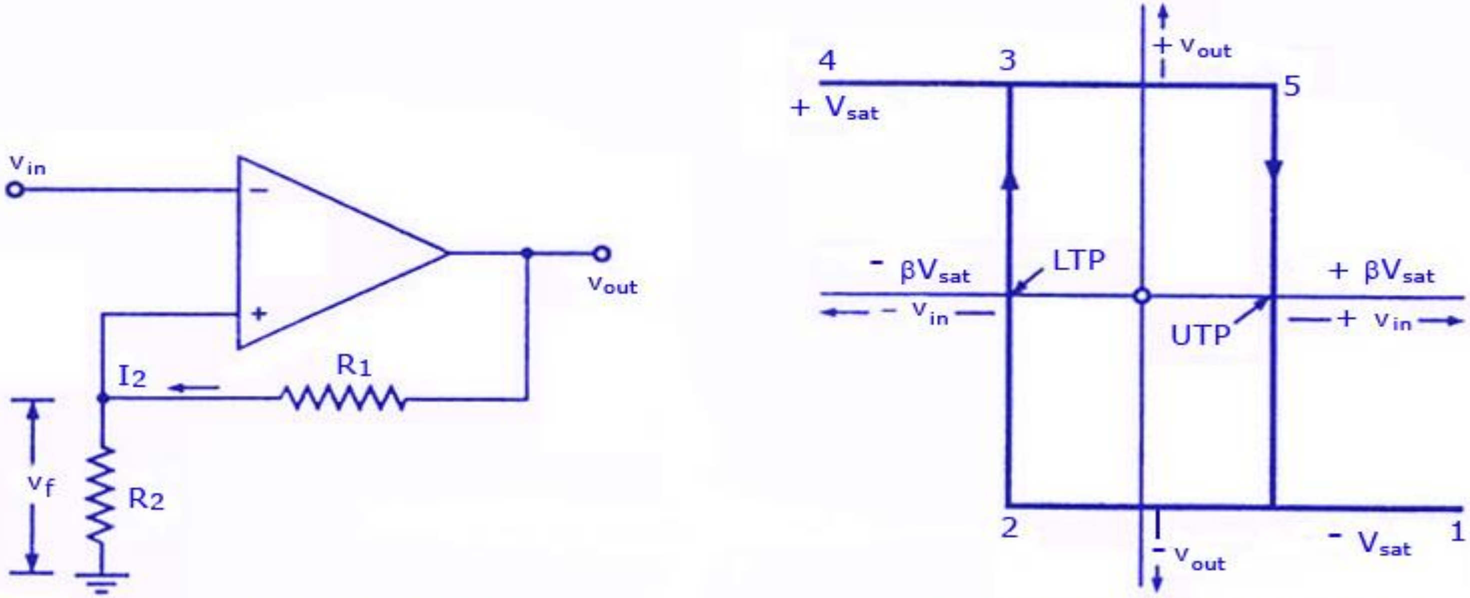
MODULE 4-ANALOG INTEGRATED CIRCUITS

CREDITS-4

COURSE CODE: EC 204

SCHMITT TRIGGER USING OPAMP



(a) Circuit Diagram (b) Input Output Characteristics

Schmitt Trigger

- Assume Vout=+Vsat,then input at non inverting terminal will be βVsat where $\beta = \frac{R2}{R1+R2}$
- When voltage at inverting terminal will be less than Vf then Vo=+Vsat
- When voltage at inverting terminal will be greater than Vf then Vo=-Vsat
- Switching between +Vsat and –Vsat forms a square wave and thus squaring circuit works.

Continued....

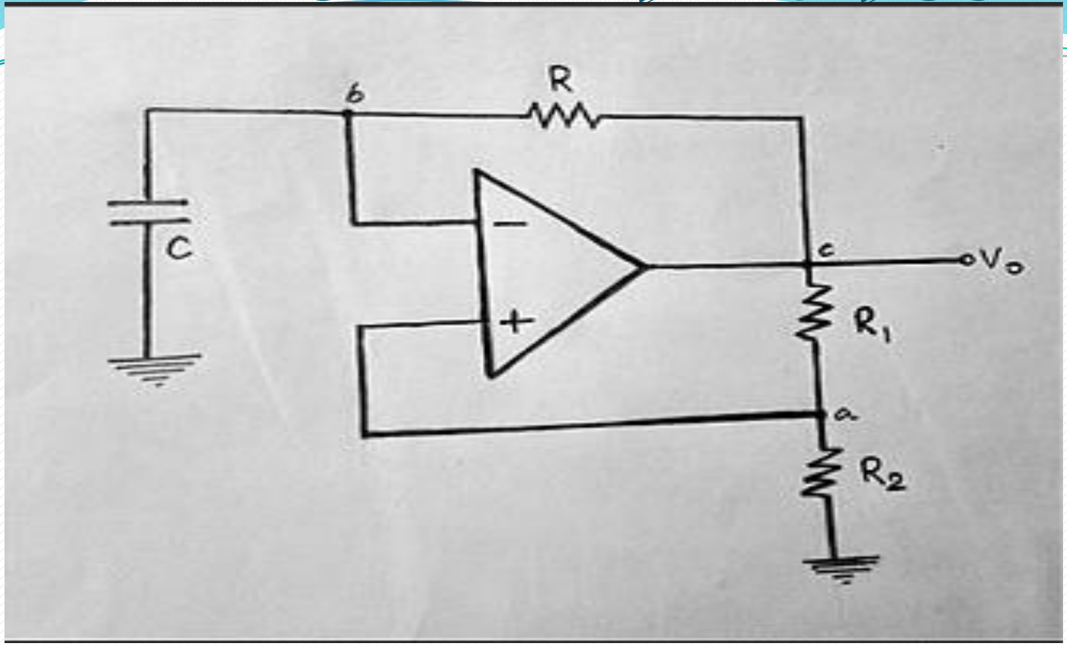
- If positive feedback is added to the comparator circuit ,gain can be increased.
- If the loop gain is unity,gain with feedback is infinite and transits between –Vsat and +Vsat
- Also exhibits a phenomenon called hysteresis/backlash
- Input voltage triggers the o/p voltage Vo every time it exceeds certain voltage levels
- Voltage levels are Upper Threshold voltage(Vut) and Lower Threshold voltage(Vlt)
- Hysterisis width =Vut-Vlt=βVsat-(-βvsat)=2βVsat

1.R1=50kΩ,R2=100Ω,Vref=0V.Vi=1Vpp,Vsat=+/-14V.Determine Vut and Vlt

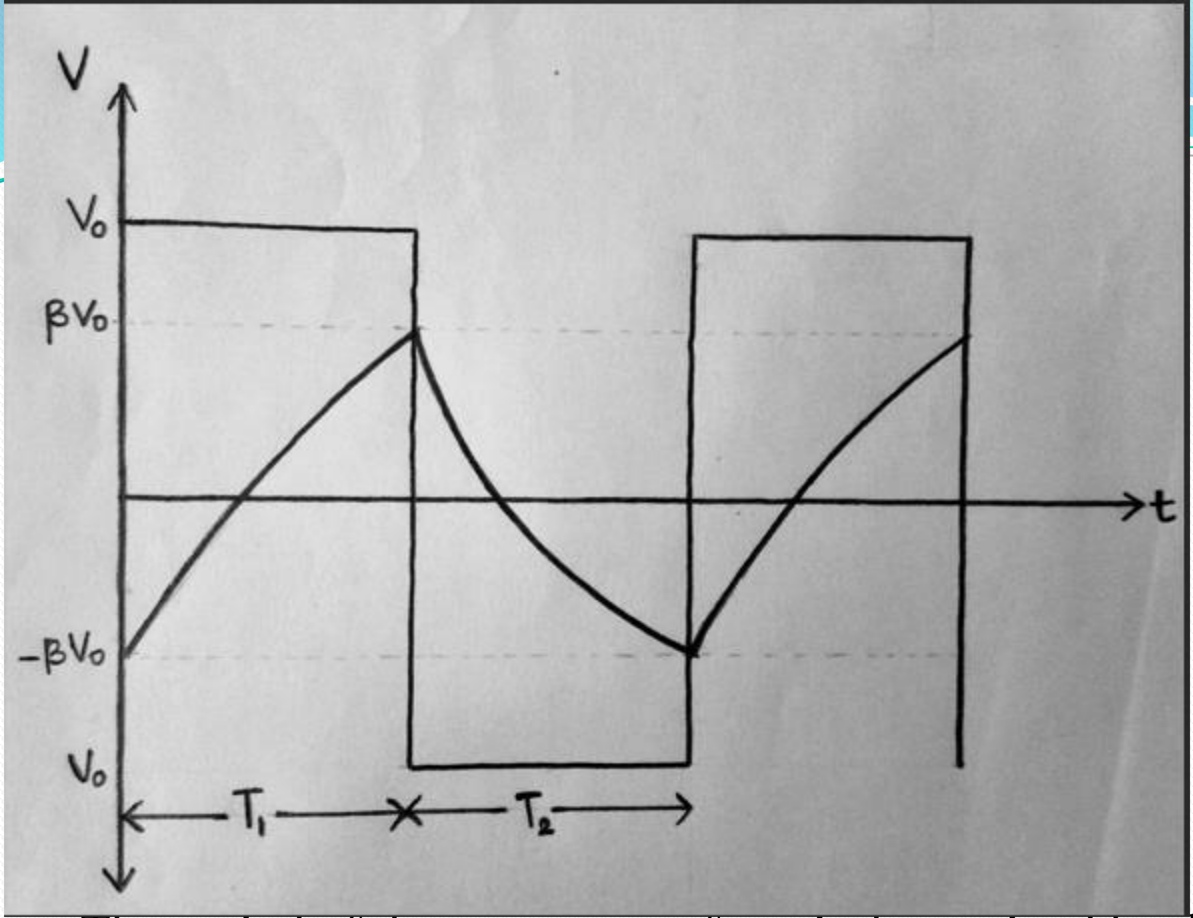
$$Vut=\frac{100}{50100}*14=28mV$$

$$Vlt=\frac{100}{50100}*-14=-28mV$$

ASTABLE MULTIVIBRATOR USING OPAMP



- Assume Vo=+Vsat voltage at non inverting terminal be βVsat where $\beta = \frac{R2}{R1+R2}$
- At the same time capacitor charges through R.When voltage at the inverting terminal is less than βVsat ,o/p remains to be at +Vsat and when voltage increases beyond βVsat ,o/p switches to –Vsat.Then the V+= -βVsat
- At that time capacitor charges to –Vsat.o/p remains to be at –Vsat until V- is is more negative than -βVsat.When it becomes less negative than -βVsat ,o/p becomes +Vsat. Thus square waveform is generated.



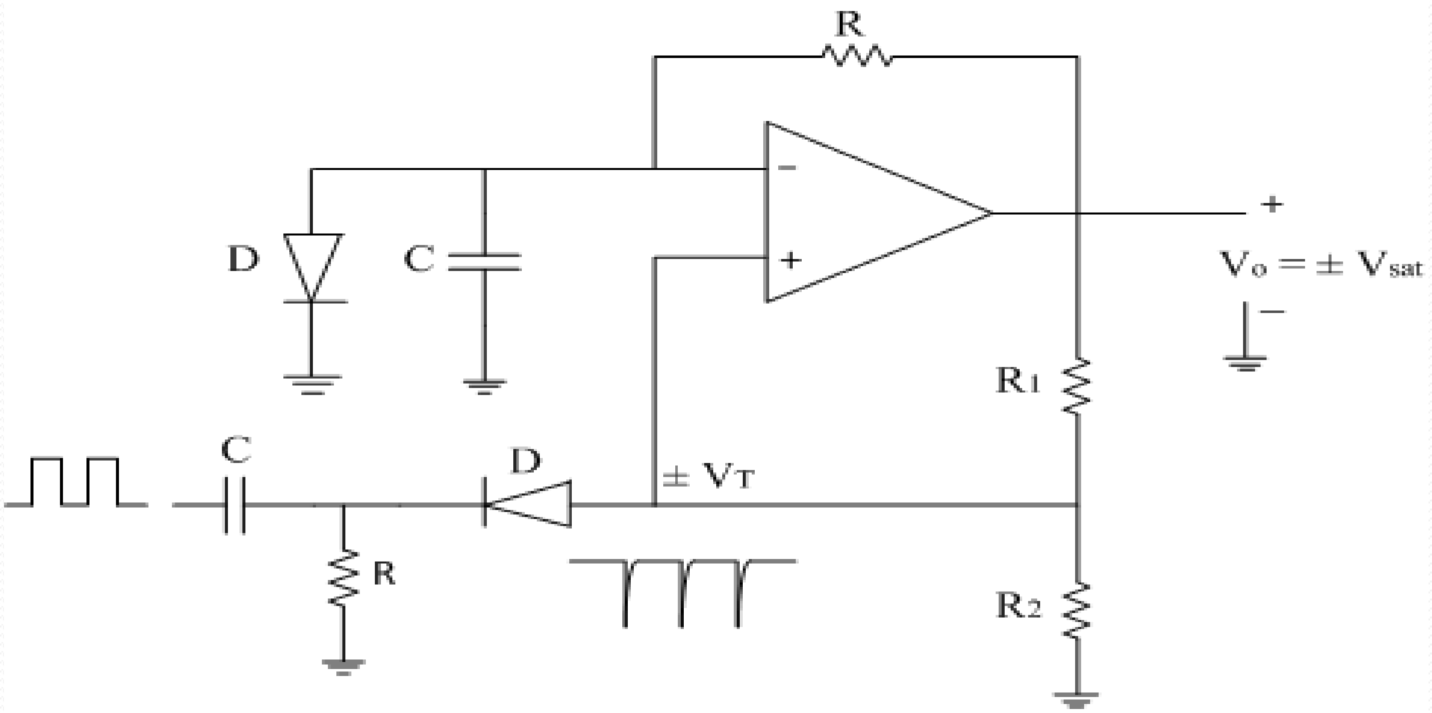
- The period of the output waveform is determined by the RC time constant
- Time period :$T=2RC\ln(\frac{1+\beta}{1-\beta})$
- The frequency is determined by the time it takes the capacitor to charge from –βVsat to +βVsat and vice versa.The voltage across the capacitor as a function of time is given by,
- $Vc(t)=Vf+(Vi-Vf)e^{\frac{-t}{RC}}$

Continued….

- Final value, V_f=+Vsat and initial value, V_i=-βVsat
- $V_c(t)$=Vsat-vsat(1+β) $e^{\frac{-t}{RC}}$
- At t=T_1, voltage across the capacitor reaches βVsat and switching takes place
- βVsat =Vsat-vsat(1+β) $e^{\frac{-t}{RC}}$
- $T_1=RC\ln(\frac{1+\beta}{1-\beta})$ half of the period
- $T=2T_1=2RC\ln(\frac{1+\beta}{1-\beta})$

MONOSTABLE MULTIVIBRATOR USING OPAMP

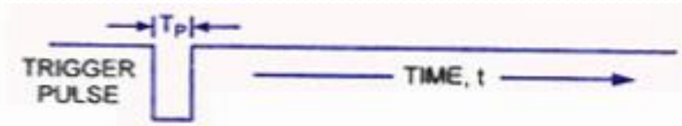
- One stable state and the other quasi stable



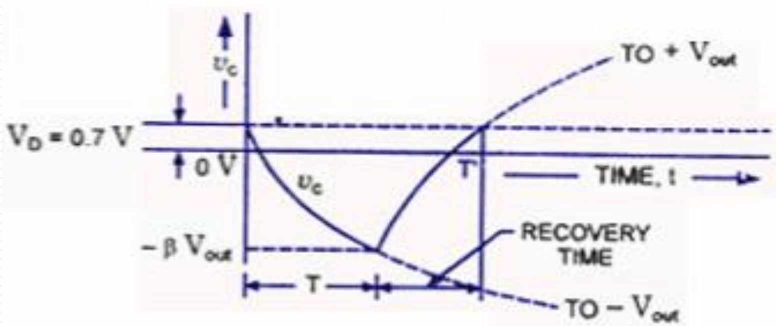
- If Diode clamps the capacitor voltage to 0.7Vwhen the o/p is at +Vsat
- A pulse signal when passed through the differentiator RC and Diode provides negative going trigger to the + input terminal.
- Assume Vo=+Vsat.Diode conducts and capacitor gets clamped to 0.7V
- Voltage at non inverting terminal is +βVsat –V1
- If effective voltage is less than 0.7V,o/p switches from +Vsat to-Vsat.

Working continued….

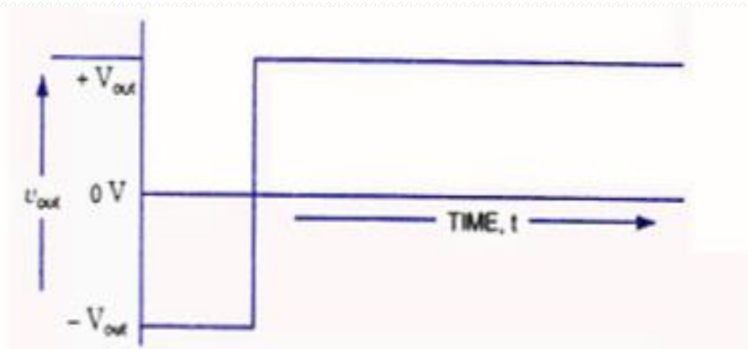
- Then the diode will be reverse biased and capacitor charges exponentally to –Vsat through resistance R
- Voltage at the non inverting terminal be –βVsat.When the capacitor voltage becomes slightly more negative than –βVsat,o/p switches to +Vsat.



(b) Negative Trigger Pulse



(c) Waveform of v_c



PULSEWIDTH

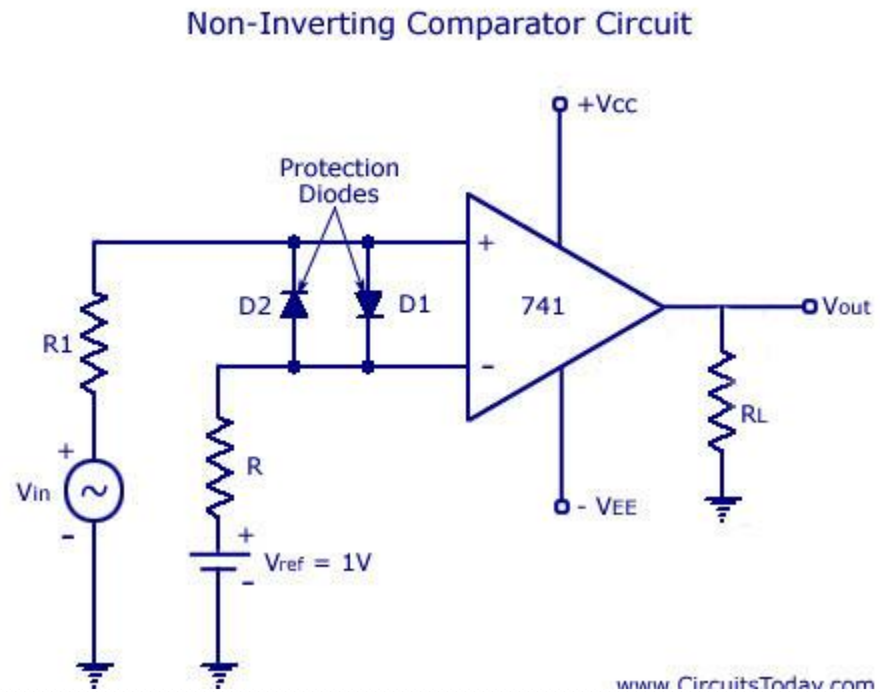
- $Vc(t)=Vf+(Vi-Vf)\ e^{\frac{-t}{RC}}$
- As Vf=-Vsat, Vi=Vd
- $Vc(t)=-Vsat+(Vd+Vsat)\ e^{\frac{-t}{RC}}$
- At t=T, Vc(t)=−βVsat
- $-\beta Vsat=-Vsat+(Vd+Vsat)\ e^{\frac{-t}{RC}}$
- $e^{\frac{t}{RC}}=\frac{Vd+Vsat}{-\beta Vsat+Vsat}=\frac{Vsat(1+Vd/Vsat)}{Vsat(1-\beta)}$
- $T=RC\ \ln\frac{(1+Vd/Vsat)}{(1-\beta)}$ where $\beta=\frac{R2}{R1+R2}$
- If Vsat>>Vd and R1=R2 so that β=0.5 then
- T=0.69 RC

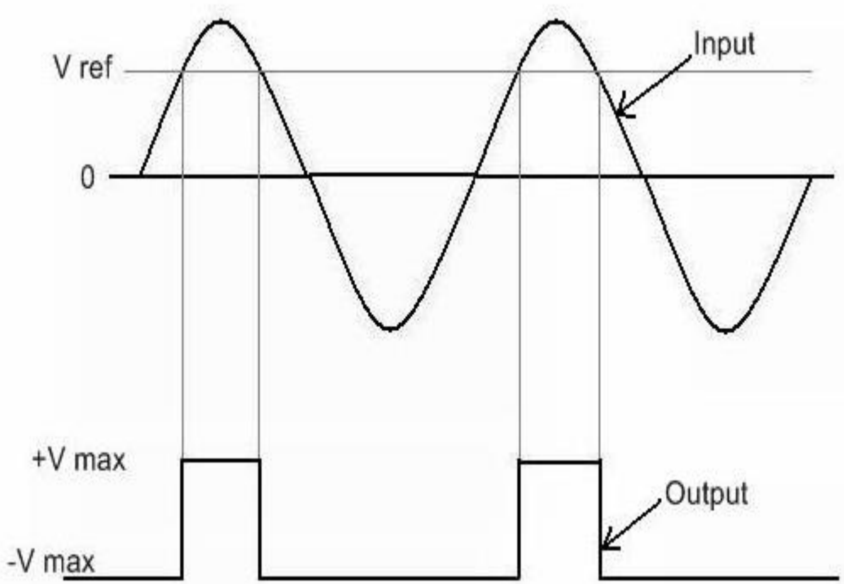
COMPARATORS

- Compares a signal voltage applied at one input of an opamp with a known reference voltage
- A reference voltage ,Vref is applied

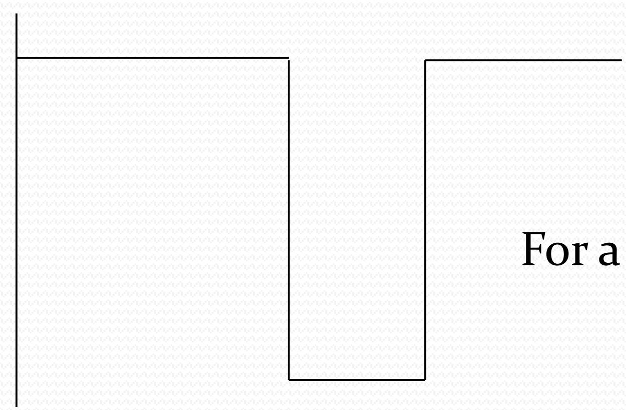
To –ve input and input is applied to +ve i/p.

- When Vi<Vref o/p voltage is –Vsat
- When Vi>Vref,o/p voltage is +Vsat





For a +ve Vref



For a –ve Vref

Continued……..

- Vref is applied to the + input and Vin is
- Applied to the – input.
- When Vi<Vref o/p voltage is +Vsat
- When Vi>Vref,o/p voltage is -Vsat

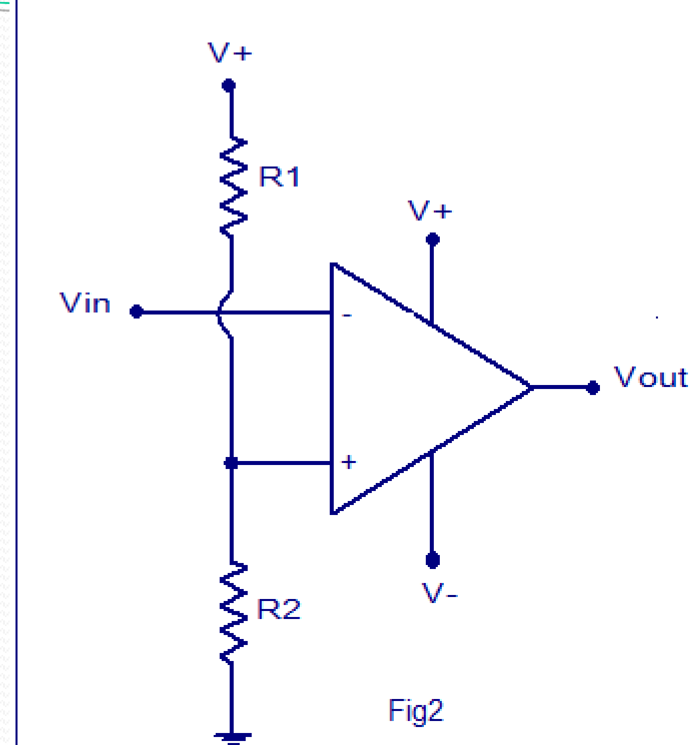
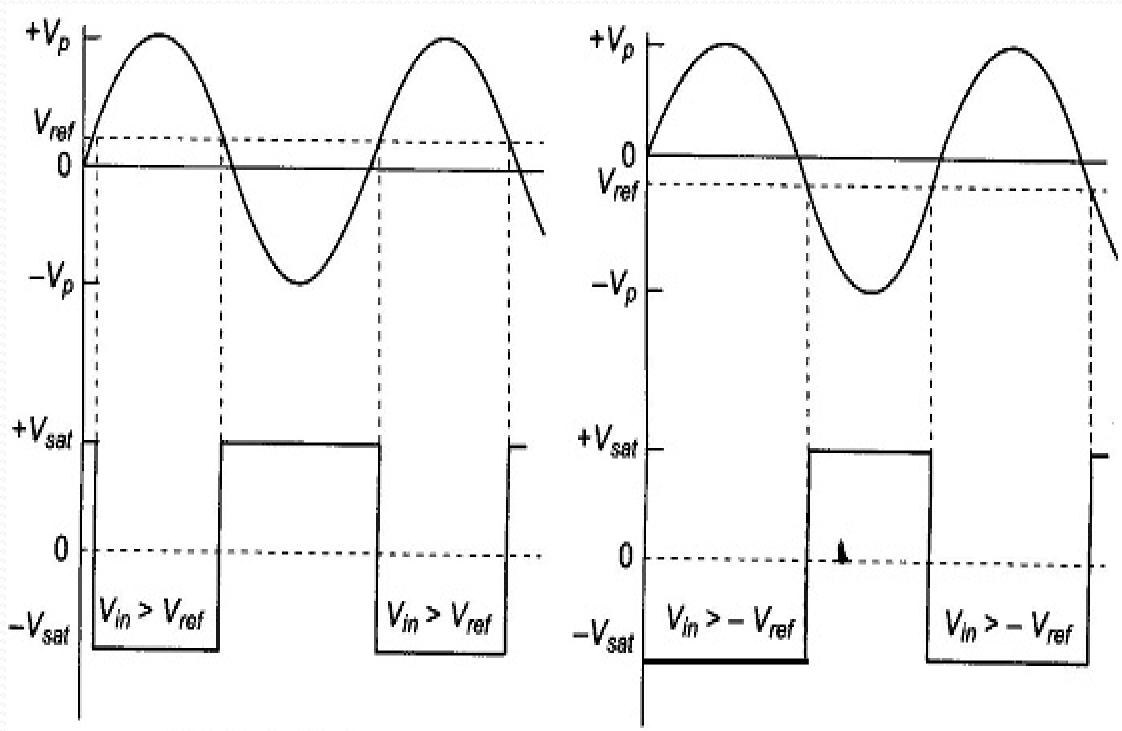


Fig2

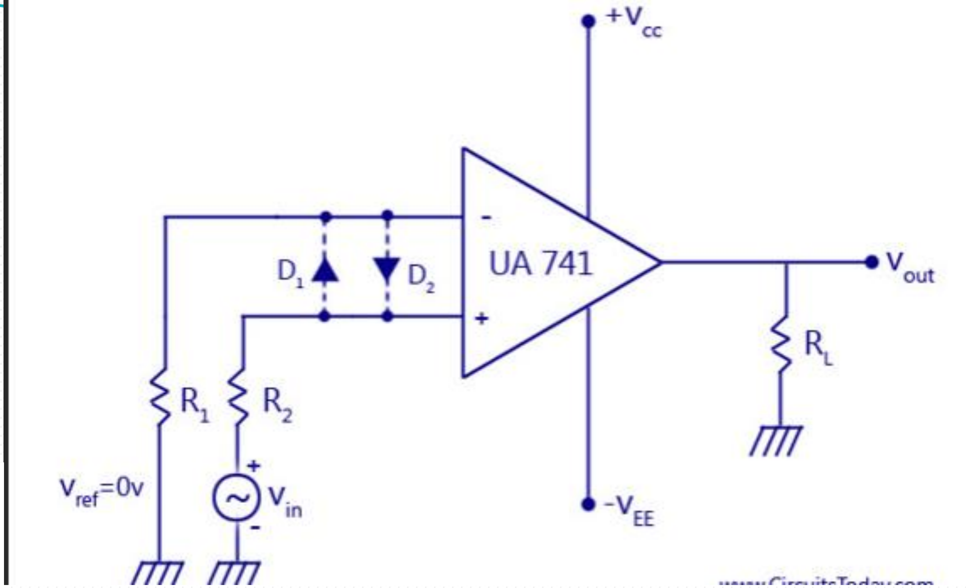


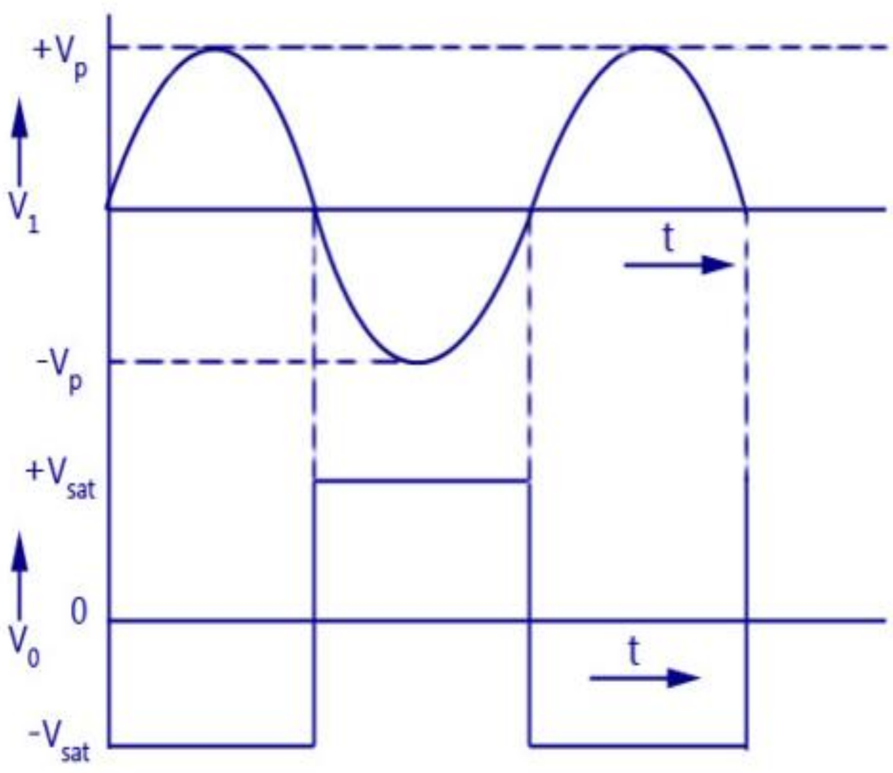
(i) If V_{ref} is Positive

(ii) If V_{ref} is Negative

Zero Crossing Detector

- Vref is set to zero
- Sine to square wave generator
- Vin is applied to inverting i/p





TRIANGULAR WAVE GENERATOR

- Integrating a square wave

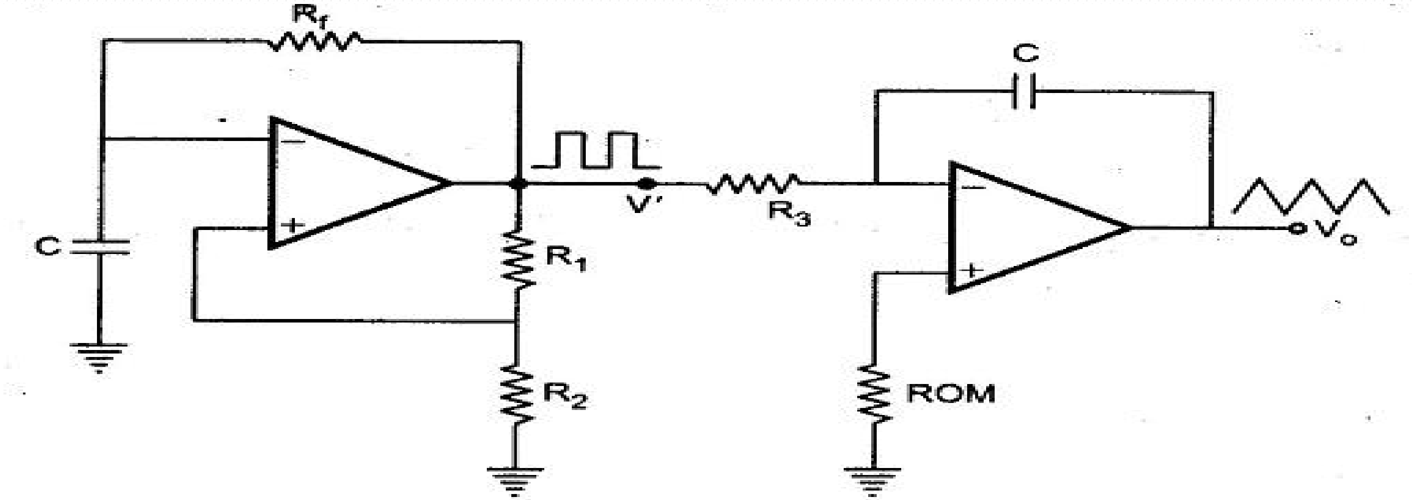
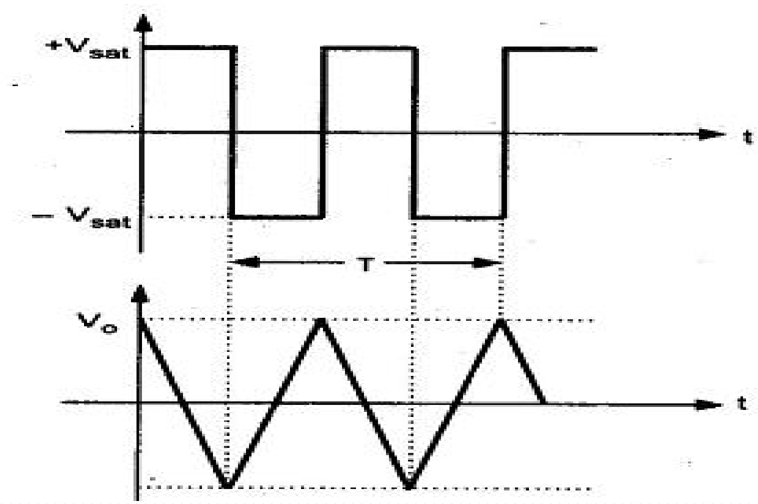
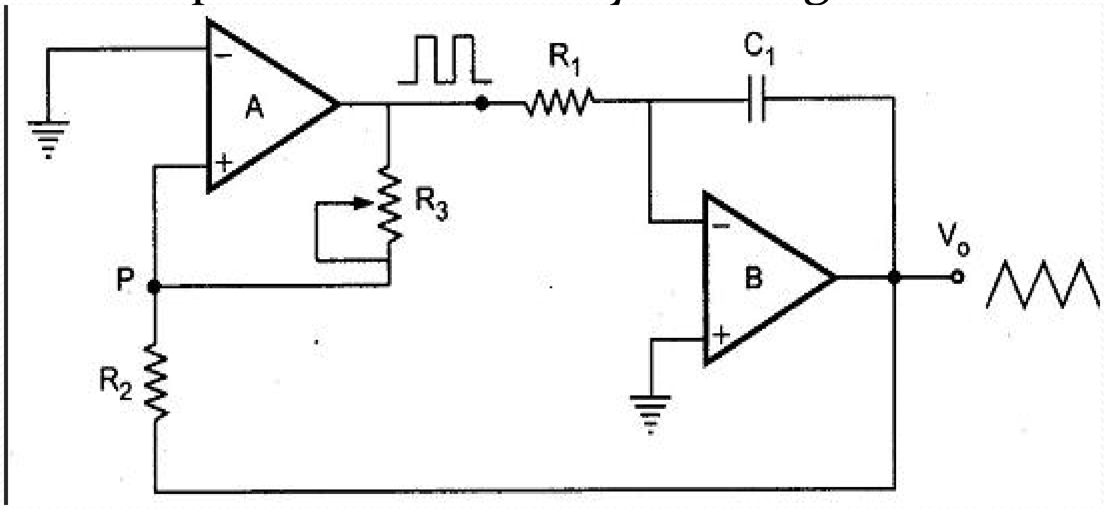


Fig. 2.85 Triangular wave generator



Alternate circuit

- Using lesser number of components
- Two level comparator followed by an integrator

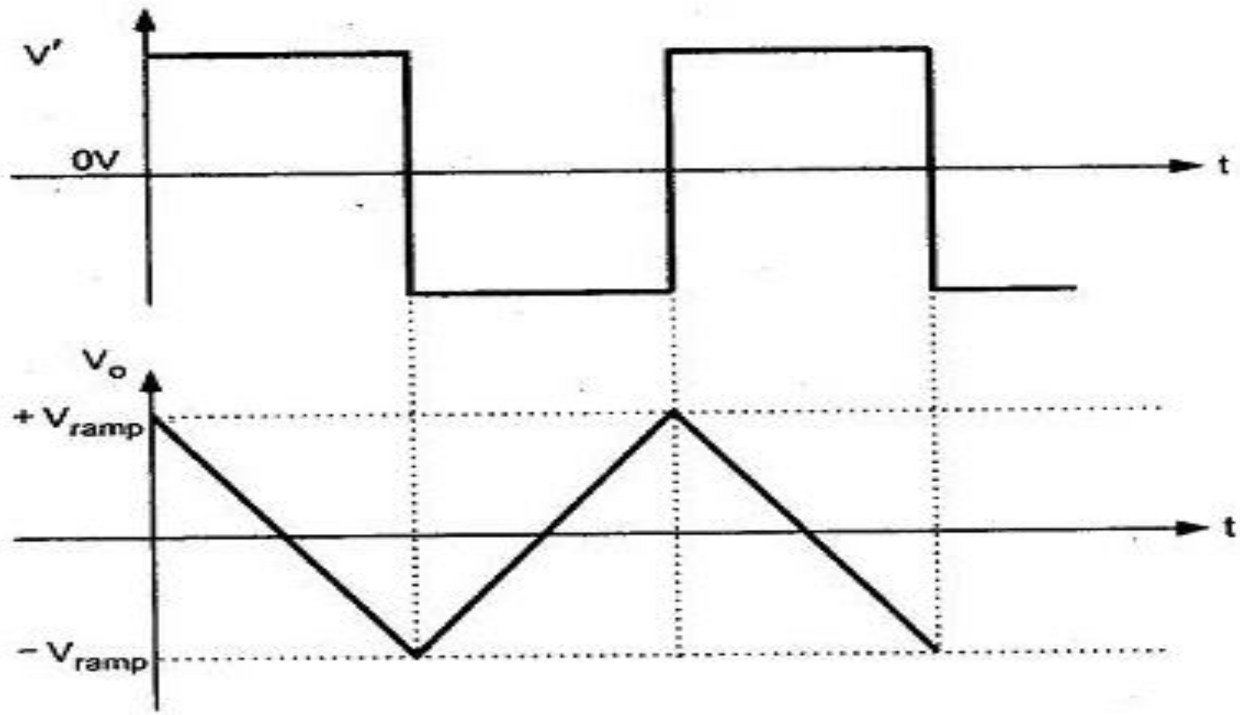


- o/p of comparator A is a square wave of amplitude +/-Vsat and is applied to –ve input terminal of the integrator B producing a triangular wave.
- Triangular wave is fed back as input to the comparator A through a voltage divider R2R3
- Assume o/p of A is at +Vsat.o/p of integrator is –ve going ramp
- One end of the voltage divider is at +Vsat and other end at the negative going ramp of B.
- At time t=t1,when the negative going ramp attains a value of

–Vramp,effective voltage at P becomes slightly less than 0V.This switches o/p of A from +Vsat to –Vsat.

Continued……

- When o/p is at –Vsat,o/p of B increases to +Vramp
- At time t=t2,when the positive going ramp attains a value of +Vramp, effective voltage at P becomes slightly above 0V.This switches o/p of A from -Vsat to +Vsat.Cycle repeats and forms a triangular waveform.
- Amplitude of the triangular wave depends upon RC value of the integrator B and o/p voltage level of A



FREQUENCY:

Effective voltage at P when the o/p of A is at +Vsat

$$-V_{ramp}+\frac{R2}{R2+R3}(+V_{sat}-(-V_{ramp}))$$

At t=t1,voltage at point P=0

$$-V_{ramp}+\frac{R2}{R2+R3}(+V_{sat}-(-V_{ramp}))=0$$

$$-V_{ramp}+V_{ramp}\left(\frac{R2}{R2+R3}\right)+V_{sat}\left(\frac{R2}{R2+R3}\right)=0$$

$$-V_{ramp}\left(\frac{R3}{R2+R3}\right)=-V_{sat}\left(\frac{R2}{R2+R3}\right)$$

$$-V_{ramp}=-V_{sat}\left(\frac{R2}{R3}\right)\text{---------------------}1$$

Effective voltage at P when the o/p of A is at –Vsat

$$V_{ramp}=V_{sat}\left(\frac{R2}{R3}\right)\text{---------------------}\ 2$$

Peak to peak amplitude of the triangular wave, Vo(p-p)= $2V_{sat}\left(\frac{R2}{R3}\right)$--A

The time taken by the output to swing from – Vramp to +Vramp (or from + Vramp to –Vramp) is equal to half the time period T/2.

Time can be calculated from the integrator o/p equation,

$$V_o(p\text{-}p)=\frac{-1}{R1C1}\int_0^{T/2}(-V_{sat})\,dt$$

$$=\frac{V_{sat}}{R1C1}(T/2) \quad \text{or } T=2R1C1\frac{V_o(p-p)}{V_{sat}}\text{-----B}$$

Continued….

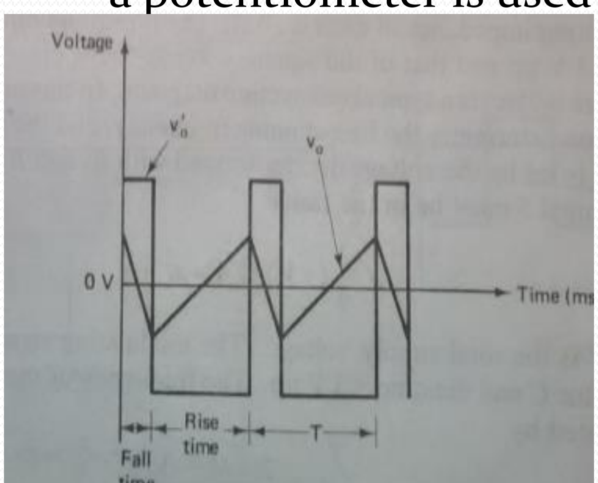
- Substitute A in B

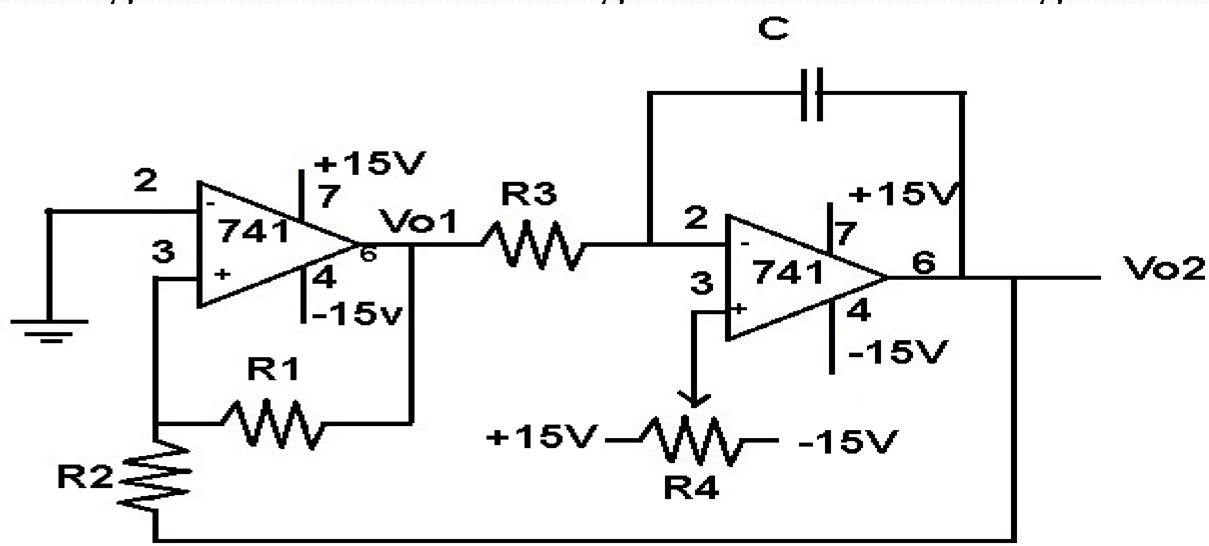
$$T=\frac{4R1R2C1}{R3}$$

- Frequency of oscillation, $f=\frac{1}{T}=\frac{R3}{4R1R2C1}$

SAWTOOTH WAVEFORM GENERATOR:

- Sawtooth waveform can be also generated by an asymmetrical astable multivibrator followed by an integrator.
- The rise time of triangular wave is always equal to its fall of time.tr=tf
- For saw tooth generator, rise time may be much higher than its fall of time.tr>tf
- The triangular wave generator can be converted in to a saw tooth wave generator by injecting a variable dc voltage into the non-inverting terminal of the integrator.
- a potentiometer is used





FREQUENCY

$$f=\left(\frac{1}{RC}\right)\frac{Vi}{Vref}$$

1.Design a sawtooth wave generator for 10V peak and frequency of 200Hz.Assume Vi=2V and Vref=10V

Ans:Let R=10KΩ C=0.1μF

F= $\frac{1}{10*10^3*0.1*10^{-6}}$ (2/10) =200

2.Determine period, frequency ,peak value of square wave, peak value of triangular wave. Assume R1=100KΩ,R2=10KΩ,R3=20KΩ,C1=0.01μF,Vsat=+/-14V

Ans:T=$\frac{4R1R2C1}{R3}$ =2ms

f=1/T=500Hz

Peak value=+14V and -14 V

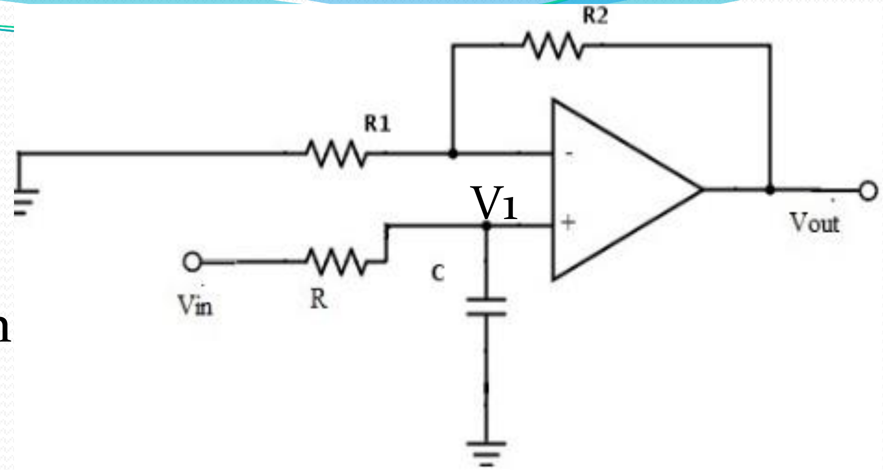
Vramp=Vsat($\frac{R2}{R3}$)=7V

Active Filters

- Simplest way-Filter is made by using passive components(R,L,C)-which works for high frequencies.
- Active filters-opamp as active element + RLC as passive elements
- **Advantages:**
  - Increased current gain
  - No inductors-so reduction in size,weight and cost.
  - Reduction in parasitic capacitance.
  - Small cost
  - Rapid,stable and econonmical design of filters.
  - Easily tunable due to flexibility in gain and frequency adjustments.
  - High i/p impedance and low o/p impedance for opamp.So no loading effect and no need of buffer amplifier while cascading
  - Can realize rational function using active network
  - Eliminates passivity and reciprocity of RLC network
- **Limitations:**
  - High frequency response is limited by the gain-BW product and slew rate leading to lower BW
  - Large sensitivity(variation of filter parameter with supply voltage, temperature due to variation in gain of opamp, frequency response)
  - Requires dual polarity dc power supply.

FIRST ORDER LOWPASS FILTER

- Single RC network connected to the +terminal of non inverting opamp
- R1 and Rf determine the gain of the filter in pass band.



Voltage across the capacitor C (s-domain

$V1(s)=\frac{\frac{1}{sC}}{\frac{1}{sC}+R}Vin(s)$ [Vin*Xc/R+Xc=V1]

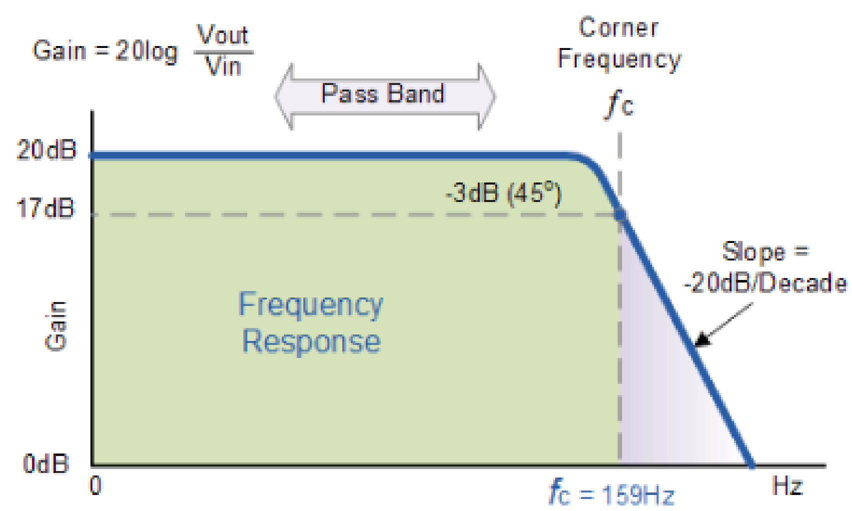
$\frac{V1(s)}{Vin(s)} = \frac{1}{RCs+1}$-------1

Closed loop gain A=[(1+Rf/R1)]=$\frac{Vo(s)}{V1(s)}$--2

Overall TF=$\frac{A}{RCs+1}$-----------3

Let wh=$\frac{1}{RC}$

Overall TF=$\frac{Awh}{s+wh}$ $------------- -Tr$



Put s=jw in 3

$H(jw)=\frac{A}{RCjw+1}=\frac{A}{1+j\frac{w}{wh}}=\frac{A}{1+j\frac{f}{fh}}$ where $f=\frac{1}{2\pi RC}$ and $f=\frac{w}{2\pi}$

Continued………

- At very low frequency, f<<fh, |H(jw)|≈A(pass band)
- At f=fh, $|H(jw)|=\frac{A}{\sqrt{2}}$=0.707A(-3db down)
- At f>>fh, |H(jw)|<<A ≈0(gain decreases at a rate of -20dB/decade-stop band)
- $A(s)=\frac{1}{s+1}=\frac{1}{jw+1}=\frac{1}{\sqrt{1+w2}}$;A(dB)=20log 1-20log$\sqrt{1+w2}$;when w=1 0-20log$\sqrt{2}$=-3dB

LOW PASS FILTER DESIGN:

1.Choose the value of high cut off frequency, fh

2.Select the value of capacitor C such that its value ≤ 1μF

3.When the values fh and C are known, the value of R can be calculated by using

$fh=\frac{1}{2\pi RC}$

4.Finally select the values of Ri and Rf depending on the desired pass band gain by using A=1+(Rf/R1)

1.Design a first order LPF at a cut-off frequency of 2KHz with a gain of 2.

Ans:fh=2KHz,A=2

LetC=0.01μF , $f=\frac{1}{2\pi RC}$,$R=\frac{1}{2\pi fC}=\frac{1}{2\pi*2*10^3*0.01*10^{-6}}$=7.95kΩ

A=1+(Rf/R1)=2; Rf=R1=10kΩ

SECOND ORDER LOWPASS FILTER(SALLEN-KEY)

- For 2^{nd} order,-20log$\sqrt{1+(\frac{w}{w0})^4}$=-20log$(\frac{w}{w0})^2$=-40dB/dec
- Consists of 2 RC pairs and

Has a roll off rate of -40dB/decade

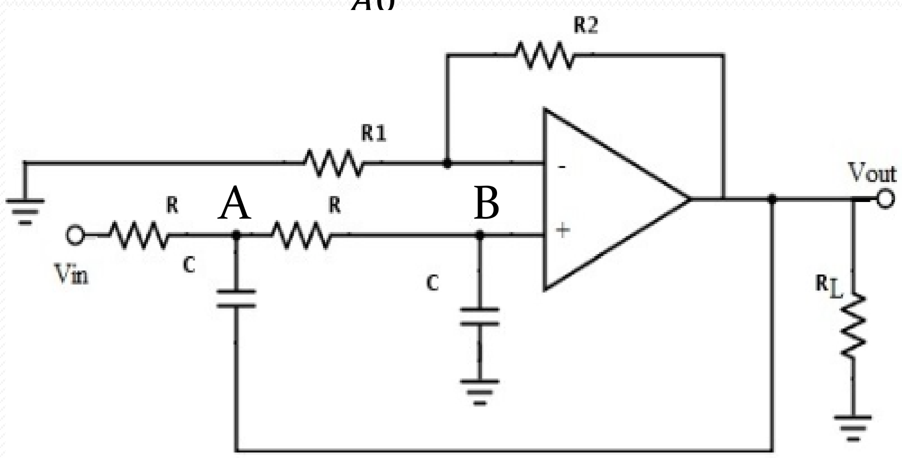
Due to virtual ground concept Vout≈Vb

Apply KCL to node A

$$ViY1 = Va(Y1+Y2+Y3) - VoY3 - VbY2$$

$$ViY1 \quad = Va(Y1+Y2+Y3) - VoY3 - Vo\frac{Y2}{A0} \quad \text{(as Vb*Ao=Vo)------1}$$

Apply KCL to node B



$VaY2 = Vb(Y2+Y4) = \frac{V0}{A0}(Y2+Y4)$

$Va = Vo\frac{Y2+Y4}{A0Y2}$------2

Substitute 2 in 1 Gen:equation

$$\frac{Vo}{Vi} = \frac{AoY1Y2}{Y1Y2+Y4(Y1+Y2+Y3)+Y2Y3(1-Ao)}$$

To make a LPF,Y1=Y2=1/R,Y3=Y4=sC

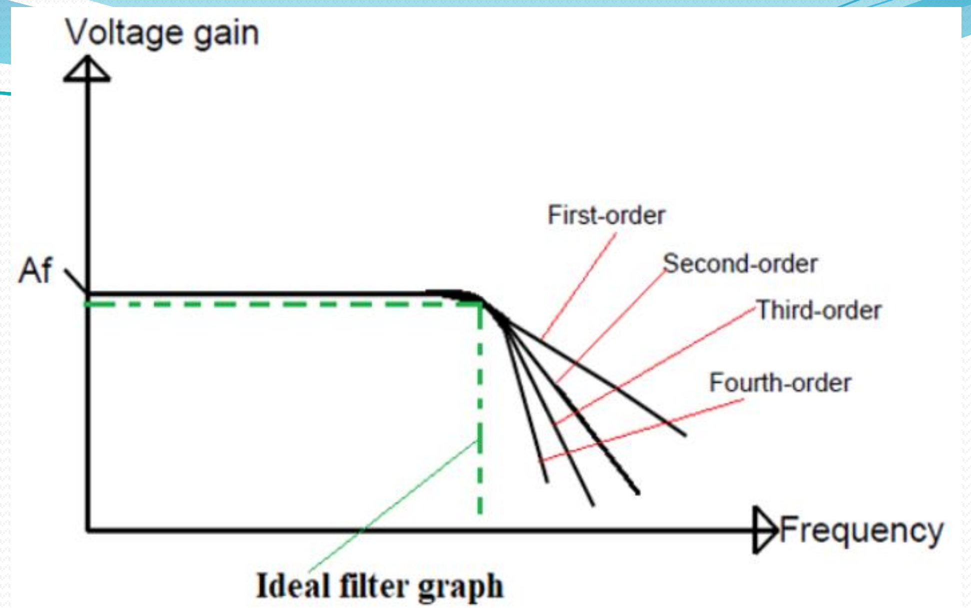
---3

Continued.....

- From 3, $H(s)=\frac{Ao}{(sCR)^2+sCR(3-Ao)+1}$------------------4
- H(o)=Ao and H(∞)=0 Thus LPF is clear
- TF of 2nd order LPF, $H(s)=\frac{Aowh^2}{s^2+\propto whs+wh^2}$-----------5 where Ao=gain, wh=upper cut off frequency, ∝=damping coefficient
- Compare 4 and 5 $\frac{Aowh^2}{s^2+\propto whs+wh^2}=\frac{Ao}{(sCR)^2+sCR(3-Ao)+1}$
- $wh=\frac{1}{RC}$ ∝=3-Ao
- Value of the damping coefficient can be determined by the value of Ao
- Put s=jw in 5
- Thus normalized frequency $s=j(\frac{w}{wh})$
- In dB, $|H(jw)|=20\log\frac{Ao}{\sqrt{(1-\frac{w^2}{wh^2})^2+\left(\propto\frac{w}{wh}\right)^{\wedge}2}}$
- Heavily damped filter, ∝>1.7, response is stable
- When ∝ decreases, response exhibits overshoot and ripple at early stage
- If ∝ is reduced too much, filter becomes oscillatory
- For ∝=1.414, flattest pass band occurs-**BUTTERWORTH FILTER** Eg:Audio filters
- For ∝=1.06-Chebyshev filters and ∝ =1.73-Bessel filters

Continued….

- $|H(jw)|$ in dB=20log$\frac{Ao}{\sqrt{1+(\frac{w}{wh})^4}}$
- For nth order, $|H(jw)|=\frac{1}{\sqrt{1+(\frac{w}{wh})^{2n}}}$



n (order)	Normalized Denominator Polynomials in Factored Form
1	$(1+s)$
2	$(1+1.414s+s^2)$
3	$(1+s)(1+s+s^2)$
4	$(1+0.765s+s^2)(1+1.848s+s^2)$
5	$(1+s)(1+0.618s+s^2)(1+1.618s+s^2)$
6	$(1+0.518s+s^2)(1+1.414s+s^2)(1+1.932s+s^2)$
7	$(1+s)(1+0.445s+s^2)(1+1.247s+s^2)(1+1.802s+s^2)$
8	$(1+0.390s+s^2)(1+1.111s+s^2)(1+1.663s+s^2)(1+1.962s+s^2)$
9	$(1+s)(1+0.347s+s^2)(1+s+s^2)(1+1.532s+s^2)(1+1.879s+s^2)$
10	$(1+0.313s+s^2)(1+0.908s+s^2)(1+1.414s+s^2)(1+1.782s+s^2)(1+1.975s+s^2)$

- Design a second order Butterworth LPF having upper cut off frequency 1 KHz

fh=$\frac{1}{2*\pi*RC}$;∝=3-Ao

Let C=0.1μF R=$\frac{1}{2*\pi*fhC}$=$\frac{1}{2*\pi*1000*0.1*10^{-6}}$=1.6KΩ

As butterworth filter for order ,n=2 then ∝=1.414

Ao=3- ∝=3-1.414=1.586

TF =$\frac{1.586}{s^2+1.414s+1}$ (denominator from the table)

Ao=1+$\frac{Rf}{Ri}$=1.586

So Rf=0.586Ri Let Rf=5.86KΩ and Ri=10KΩ

Draw the circuit and mark the component values

- Design a fourth order butterworth LPF having upper cut off frequency 1kHz

fh=$\frac{1}{2*\pi*RC}$;∝=3-Ao

Let C=0.1μF R=$\frac{1}{2*\pi*fhC}$=$\frac{1}{2*\pi*1000*0.1*10^{-6}}$=1.6KΩ

∝1=0.765 , ∝2=1.848 two damping factors

Ao1=3- ∝1=3-0.765=2.235

Ao2= 3 −∝2=3-1.848=1.152

TF=$\frac{2.235}{s^2+0.765s+1}$. $\frac{1.152}{s^2+1.848s+1}$

Ao1=1+$\frac{Rf}{Ri}$=2.235 so Rf=1.235Ri Let Rf=12.35K Ω and Ri=10K Ω

Ao2=1+$\frac{Rf}{Ri}$=1.152 so Rf=0.152Ri Let Rf=15.2K Ω and Ri=100K Ω

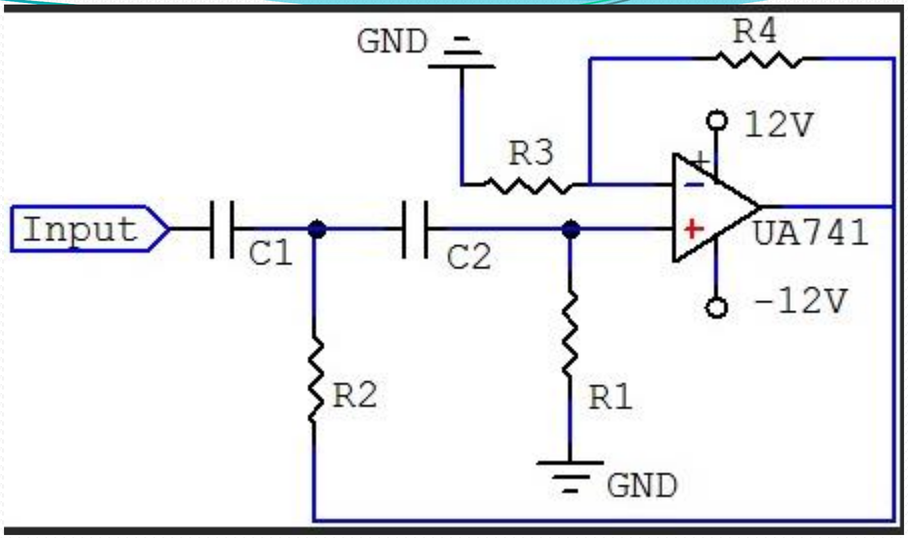
Draw two second order LPF cascaded with R and C for both

Ist stage Rf=12.35K Ω and Ri=10K Ω

2^{nd} stage Rf=15.2K Ω and Ri=100K Ω

HIGH PASS ACTIVE FILTER

- Interchanging R and C in LPF
- $\frac{Vo}{Vi}=\frac{AoY1Y2}{Y1Y2+Y4(Y1+Y2+Y3)+Y2Y3(1-Ao)}$



Put Y1=Y2=sC,Y3=Y4=1/R

H(s)=$\frac{Aos^2}{s^2+(3-Ao)wls+wl^2}$

where wl=$\frac{1}{RC}$

H(0)=0 and H(∞)=Ao Thus HPF is clear

|H(jw)| =$\frac{Ao}{\sqrt{1+(\frac{fl}{f})^4}}$

For nth order,|H(jw)|=$\frac{1}{\sqrt{1+(\frac{fl}{f})^{2n}}}$

- Design a second order Butterworth HPF having lower cut off frequency 1 KHz

fl=$\frac{1}{2*\pi*RC}$;∝=3-Ao

Let C=0.1μF R=$\frac{1}{2*\pi*fhC}$=$\frac{1}{2*\pi*1000*0.1*10^{-6}}$=1.6K'Ω

As butterworth filter for order ,n=2 then ∝=1.414

Ao=3- ∝=3-1.414=1.586

TF =$\frac{1.586}{s^2+1.414s+1}$ (denominator from the table)

Ao=1+$\frac{Rf}{Ri}$=1.586

So Rf=0.586Ri Let Rf=5.86K'Ω and Ri=10K'Ω

BAND PASS FILTER

- Depending on figure of merit and quality factor,there are two types :Narrow(Q>10) and Wide BPF(Q<10)
- $Q = \frac{fo}{BW} = \frac{fo}{fh - fl}$ and $fo = \sqrt{fhfl}$ where fo-central frequency
- **NARROW BANDPASS FILTER:**

➢ Important parameters are upper and lower cut off frequencies,Band width,central frequency,gain Ao and selectivity Q

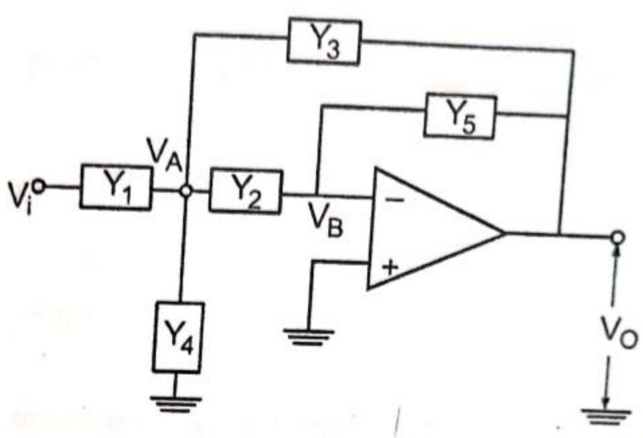


Fig.3.39 Band pass configuration

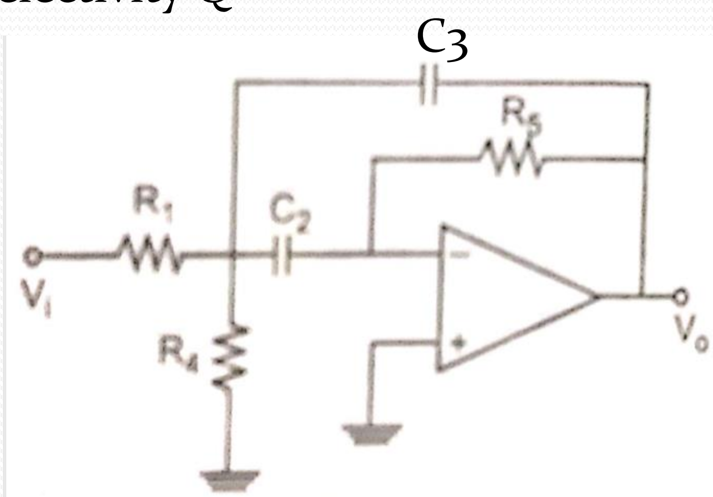


Fig.3.40 Second order band pass filter

- Y1=G1;Y2=sC2=Y3=sC3;Y4=G4;Y5=G5-----A
- Apply KCL at node A,

(Vi-Va)Y1=(Va-0)Y4+(Va-Vb)Y2+(Va-Vo)Y3

Vb=0(virtual ground)

ViY1+VoY3=Va(Y1+Y2+Y3+Y4)---------1

Continued..........

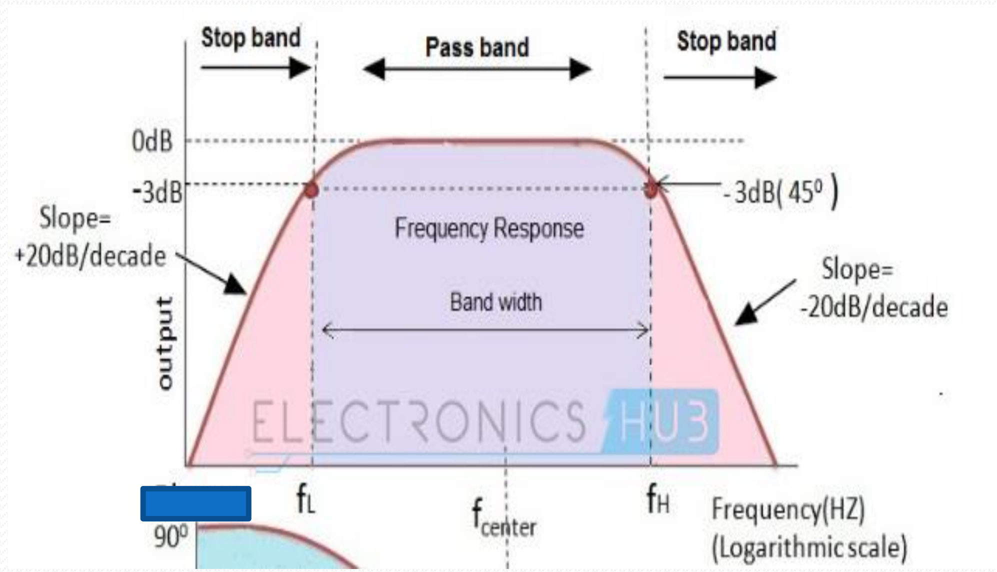
- Apply KCL at node B

$(Va-Vb)Y2=(Vb-Vo)Y5 \qquad Vb=0$

$VaY2=-VoY5 \qquad Va=-Vo\frac{Y5}{Y2}$ ------------2

Put Va in eqn 1

$ViY1+VoY3=-Vo\frac{Y5}{Y2}(Y1+Y2+Y3+Y4)$



$ViY1=-Vo[\frac{Y5Y1}{Y2}+\frac{Y5Y2}{Y2}+\frac{Y5Y3}{Y2}+\frac{Y5Y4}{Y2}+\frac{Y3Y2}{Y2}]$

$ViY1=-Vo[\frac{Y5Y1}{Y2}+\frac{Y5Y2}{Y2}+\frac{Y5Y3}{Y2}+\frac{Y5Y4}{Y2}+\frac{Y3Y2}{Y2}]$

$ViY1=-Vo[\frac{Y5Y1+Y5Y2+Y5Y3+Y5Y4+Y3Y2}{Y2}]$

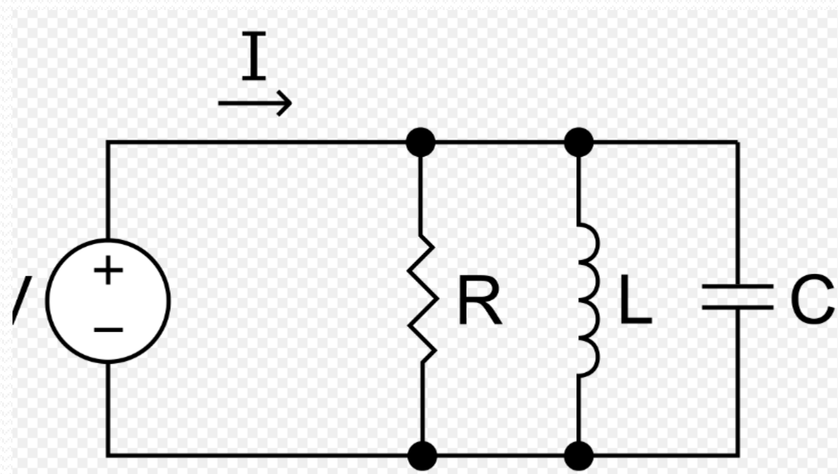
$Vo/Vi=\frac{Y1Y2}{Y5Y1+Y5Y2+Y5Y3+Y5Y4+Y3Y2}$ --------------3

Acc to eqn A

$Vo/Vi=\frac{-sG1C2}{s^2C2C3+G1G5+sC2G5+sC3G5+G4G5}$

$Vo/Vi=\frac{-G1}{sC3+\frac{[C2+C3]G5}{C2}+\frac{G5[G1+G4]}{sC2}}$ ---------4

TF is equivalent to parallel RLC circuit



$Vo/Vi=\frac{-G\prime}{sC+\frac{1}{sL}+G}$ ----------5

Continued.....

- Compare 4 and 5,

$G' = G_1$

$L = \dfrac{C2}{G5(G1+G4)}$

$C = C_3$

Resonance frequency for an RLC circuit, $wo^2 = \frac{1}{LC}$

$wo^2 = \frac{G5(G1+G4)}{C2C3}$-----6

At resonance, sL=1/sC

Then eqn 5 is Vo/Vi at w=wo, $\frac{-G\prime}{G} = -\frac{G1}{G5(C2+C3)/C2} = \frac{-\left(\frac{G1}{G5}\right)C2}{C2+C3}$

G5=1/R5;G1=1/R1 $= \frac{-(R5/R1)C2}{c2+C3}$

Q factor at resonance $Qo = \frac{woL}{R} = \text{woRC} = \frac{woC}{G} = \frac{woC2C3}{G5(C2+C3)}$------------7

$BW = fh - fl = \frac{f0}{Q0} = \frac{w0}{2\pi Q0} = \frac{1}{2\pi RC} = \frac{G}{2\pi C}$

$BW = \frac{G5(C2+C3)}{2\pi C2C3}$ ---------------8

$fo = \sqrt{fhfl}$

Continued…..

- At resonant frequency $C_2=C_3=C$
- $|Vo/Vi|=\frac{\left(-\frac{R5}{R1}\right)C}{C+C}=\frac{(-R5)}{2R1}=-Ao$----------9
- $wo^2=\frac{G5(G1+G4)}{C^2}$----------10
- $BW=\frac{G5(C2+C3)}{2\pi C2C3}=\frac{G5*2C}{2\pi C^2}=\frac{G5}{\pi C}=\frac{1}{\pi R5C}$-----------11 damping factor, $\alpha=\frac{1}{Q}$

DESIGN OF THE FILTER:

Step 1:Choose $C_1=C_2=C$

Step 2:Resistors Calculation: $R_1=\frac{Q}{2\pi fc*C*Af}$

$R_2=\frac{Q}{2\pi fc*(2Q^2-Af)}$

$R_3=\frac{Q}{\pi fc*C}$

Step 3:Gain at fc: $Af=\frac{R3}{2R1}$ Condn: $Af<2Q^2$

Step 4:For a multiple feedback filter, center frequency ,fc-new frequency fc'
Without changing gain or BW.Repalce R2 by R2'

$R_2'=\left(\frac{fc}{fc'}\right)^2 R_2$

Problems:

1.Design a narrow band pass filter fc=3KHz,Q=30,Af=20

Ans: Assume C1=C2=C=0.1μF

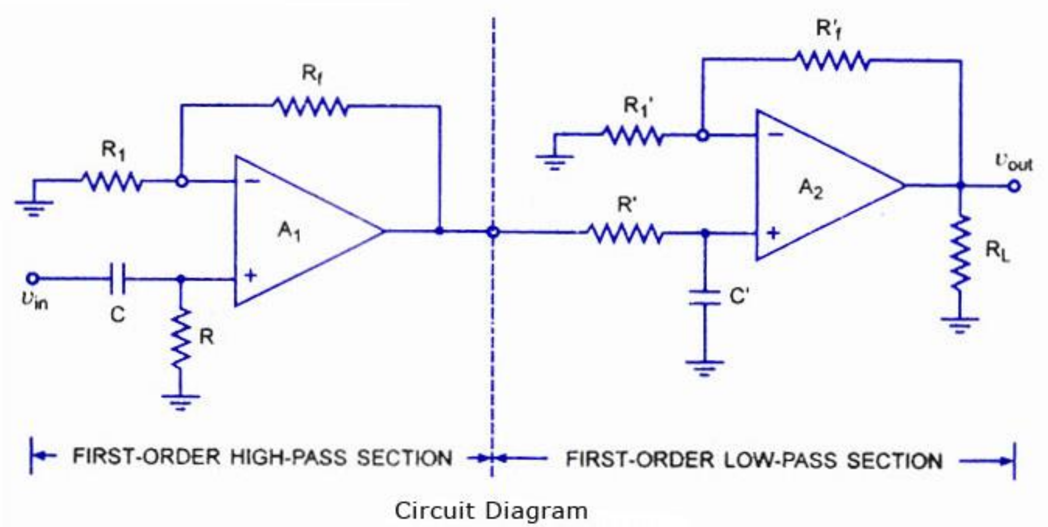
$$R1=\frac{Q}{2\pi fc*C*Af}=\frac{30}{2\pi*3*10^3*0.1*10^{-6}*20}=796\Omega$$

$$R2=\frac{Q}{2\pi fc*(2Q^2-Af)}=\frac{30}{2\pi*3*10^3*(2*30^2-20)}=9\Omega$$

$$R3=\frac{Q}{\pi fc*C}=\frac{Q}{\pi*3*10^3*0.1*10^{-6}}=32\Omega$$

$$Af=\frac{R3}{2R1}$$

WIDE BAND PASS FILTER:



Wide Band Pass Filter

Continued….

- Cascading HPF and LPF
- If HPF and LPF are of first order, BPF will have a roll off rate-20dB/dec
- $|Vo/Vi| = \frac{Ao(\frac{f}{fl})}{\sqrt{\left[1+\left(\frac{f}{fl}\right)^2\right]\left[1+\left(\frac{f}{fh}\right)^2\right]}}$ where $fl = \frac{1}{2\pi RC}$ and $fh = \frac{1}{2\pi R'C'}$

2.Design a wide band pass filter having fl=400Hz,fh=2KHz and pass band gain of 4.Find value of Q

Ans:Ao=1+Rf/Ri=2 so Rf=Ri=10KΩ

For LPF,fh=2KHz=$\frac{1}{2\pi R'C'}$ Let C'=0.01μF ,R'=7.9K Ω Gain=2

For HPF,fl=400Hz=$\frac{1}{2\pi RC}$ Let C=0.01μF ,R=39.8K Ω Gain=2

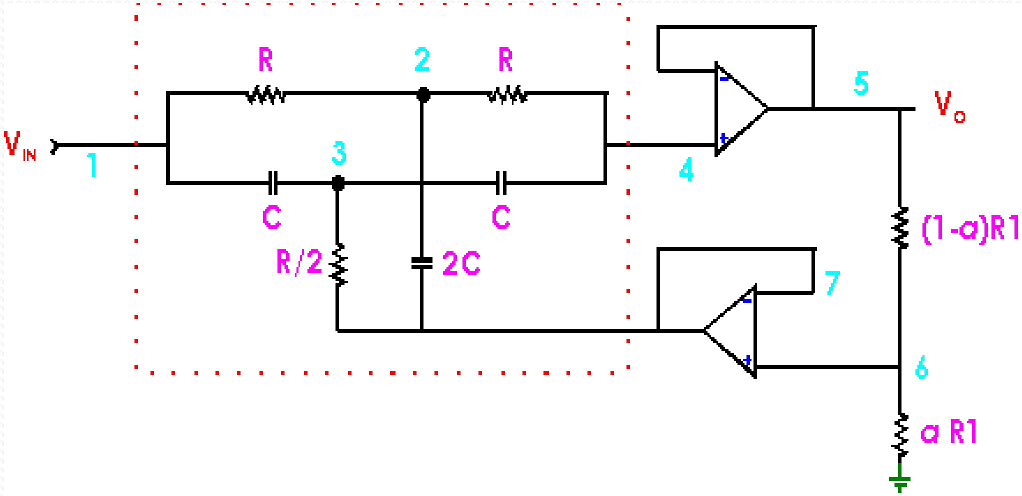
$fo = \sqrt{fhfl} = \sqrt{2000 * 400} = 894.4$

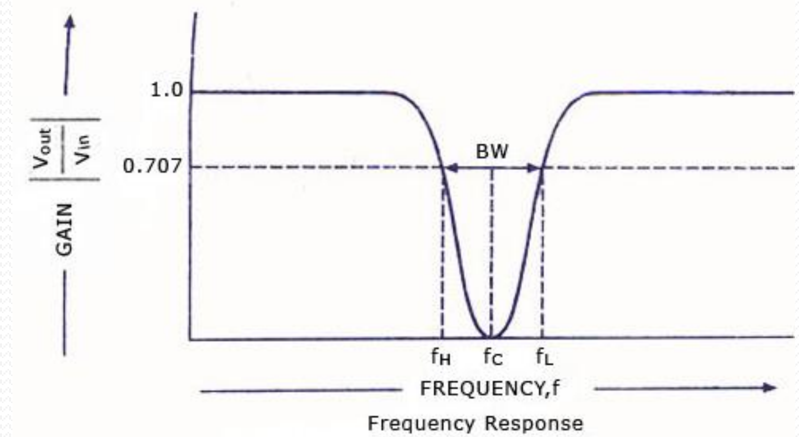
$Q = \frac{fo}{BW} = \frac{fo}{fh-fl} = \frac{894.4}{1800} = 0.56$

For wide band pass filter,Q is very low,Q<10

BAND REJECT FILTER

- Band stop /band elimination can be narrow/wide band
- Narrow band reject filter is called Notch filter(rejection of single frequency)
- Obtained by subtracting band pass filter o/p from its input





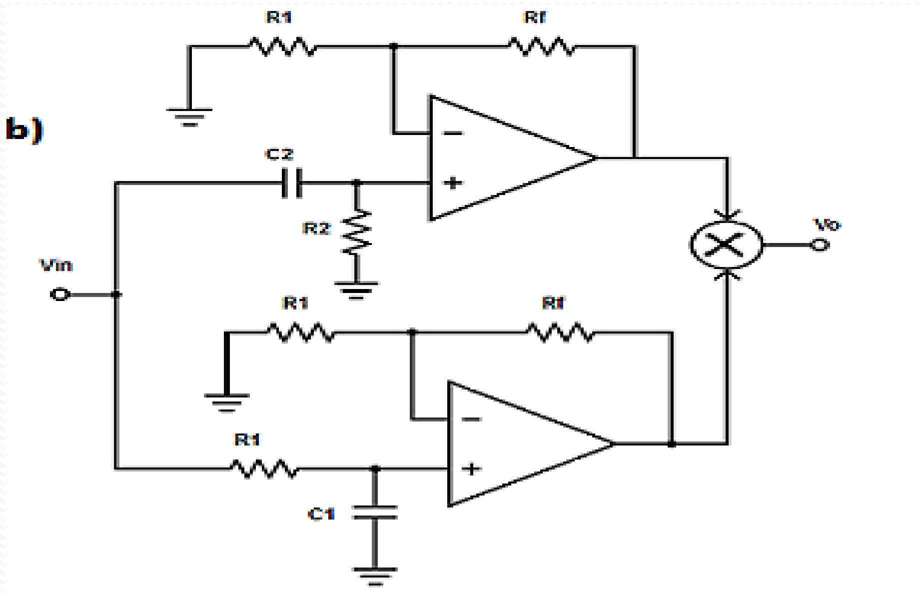
- fo=$\frac{1}{2\pi RC}$
- Design a 50Hz active notch filter

Ans:fo=$\frac{1}{2\pi RC}$=50Hz Let C=0.1μF R=31.8K Ω

For R/2 take two resistors of 31.8K Ω in parallel and for2C take two 0.1μF capacitors in parallel to make twin –T notch filter as shown above

Continued.....

- Wide band reject filter (Q<10)made using a LPF,HPF and summer
- fl>fh and pass band gain of LPF and HPF should be same



3.Design a wide band reject filter having fh=400Hz and fl=2KHzhaving pass band gain of 2

For HPF,fl=2KHz=$\frac{1}{2\pi R2C2}$ $Let\ C2 =$ 0.1μF,R2=795Ω

For LPF,fh=400Hz=$\frac{1}{2\pi R1C1}$ $Let\ C1 =$ 0.1μF,R1=3978 Ω

Ao=1+Rf/Ri=2 Rf=Ri=10KΩ

Questions:

1. Design a second order Butterworth Low Pass Filter with fH= 2KHz

2Design a first order wide bandpass filter with fH= 2KHz and fL= 500 Hz

3. Design a Notch filter to eliminate power supply hum (50 Hz).

4. Design a Schmitt Trigger with hysteresis width, Vh= 2V.

Assume Vsat= ± 14V

5. Design a circuit to generate 1KHz triangular wave with 5V peak.

6.Design a first order low pass filter at a cut-off frequency of 2kHz with a pass band gain of 3

7. Derive the design equations for a second order Butterworth active low pass filter

8. What is a zero crossing detector?

9. Derive the equation for frequency of oscillation for a square-triangular waveform generator.

10. Derive the equation for the transfer function of a first order wide Band Pass filter.