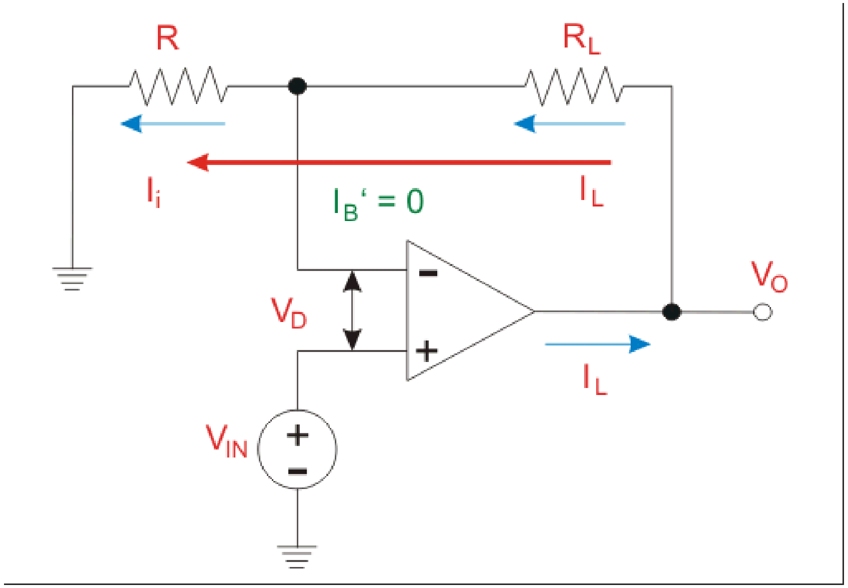
MODULE 3-ANALOG INTEGRATED CIRCUITS

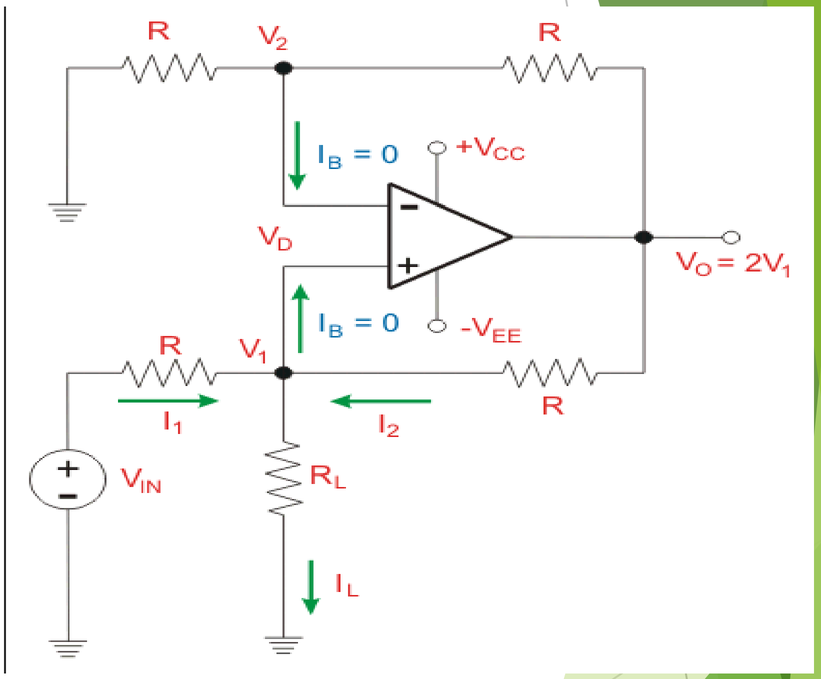
CREDITS-4

COURSE CODE: EC 204

VOLTAGE TO CURRENT CONVERTER

- Called Transconductance amplifier
- By application of voltage essential current is sustained throughout the circuit
- Convert voltage to a proportional o/p current.
- (a)With floating load
- (b)With grounded load





- R_L is floating(not linked to the ground) **Vin=IL*R**(Ib=0) ie.**IL=Vin/R**(Vi--→IL)
- Same current flows thru signal source and load.So this load current is provided back.
- Ii=IL

Continued….

- one end of the load is always grounded.
- connection between the input voltage and load current.
- Opamp is in non inverting mode and gain=1+R/R=2
- I1+i2=iL or (Vin-V1)/R+(V0-V1)/R=iL
- O/p voltage ,V0=2V1---------2
- (Vin-2V1+V0)/2=iL*R--------1
- Substitute 2 in 1
- As input impedance of non inverting amplifier is very high ,it draws very little current from the source.
- the current I_L is related to the voltage, V_{IN} and R.

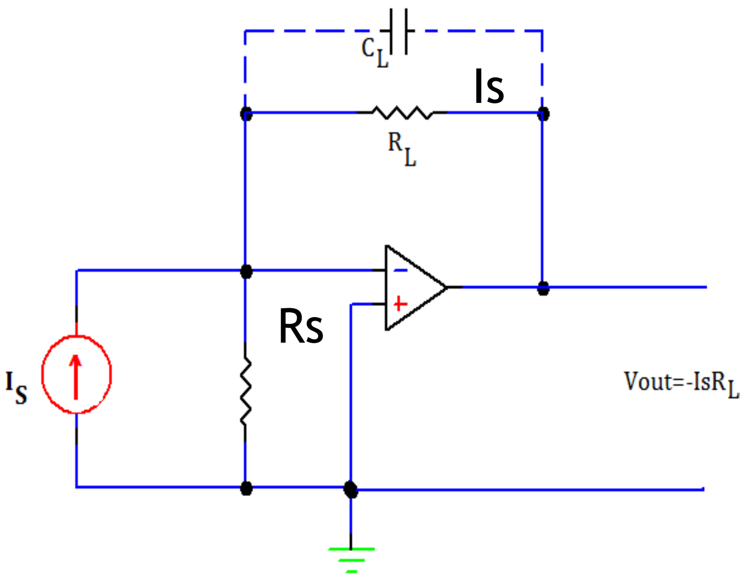
I_L=Vin/R

- Applications:
- For low voltage dc and ac voltmeter
- Testing LED
- Zener diode tester
- Testing diodes

CURRENT TO VOLTAGE CONVERTER

- Called Transresistance amplifier
- Conversion of light energy to o/p current.Current through these devices can be converted to voltage(such as in photo cell,photo diode,photo voltaic cell)
- Thus amount of light incident

on the photo device can be measured



- Negative terminal is at virtual ground
- No current flows thru Rs and current

 Is flows thru load resistor R_L

- o/p voltage=-Is*RL
- Depending on the bias current,

measurable lowest current is found out.(Ib=3nA) for 741 IC

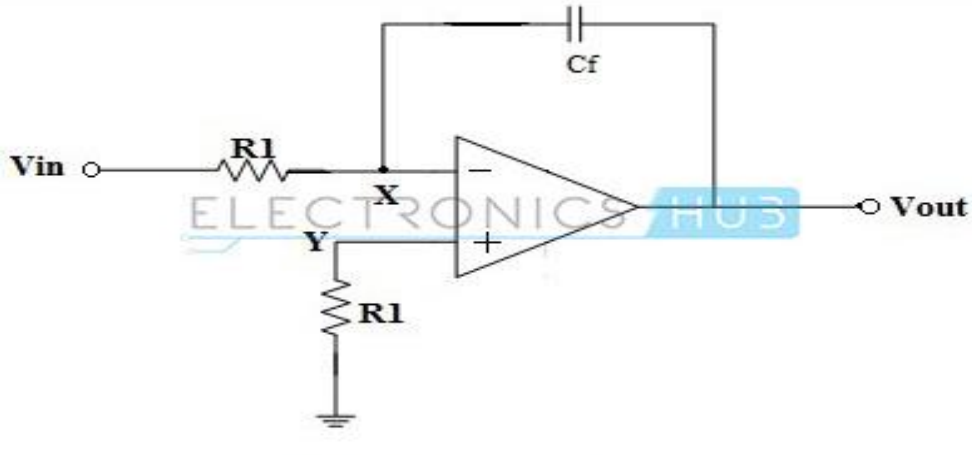
- C_L is to reduce high frequency noise and possibility of oscillations.

Virtual Ground

- In opamps the term virtual ground means that the voltage at that particular node is almost equal to ground voltage (0V). It is not physically connected to ground. This concept is very useful in analysis of opamp circuits and it will make a lot of calculations very simple.
- concept is valid only when negative feedback is applied to opamp like in inverting ampliers.

Virtual Ground	Real Ground
Virtual Ground is a concept that made for easy explantaion and calculation purposes.	Real Ground is a terminal which is physically connected to ground or earth which acts as the reference point for the entire circuit.
Voltage is **approximately** Zero	Voltage is Zero
Not able to sink infinite current	It is an infinite current sink
Not electrically connected to Ground	Electrically connected to Ground

INTEGRATOR

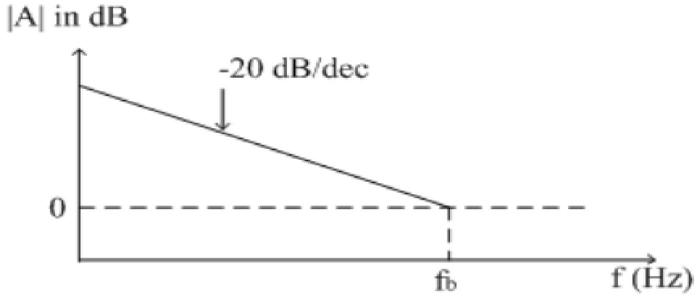


An Ideal Op-amp Integrator

- Vin-0/R1 +Cf dV0/dt=0
- dV0/dt=(-1/R1Cf) Vi
- Integrate both sides,

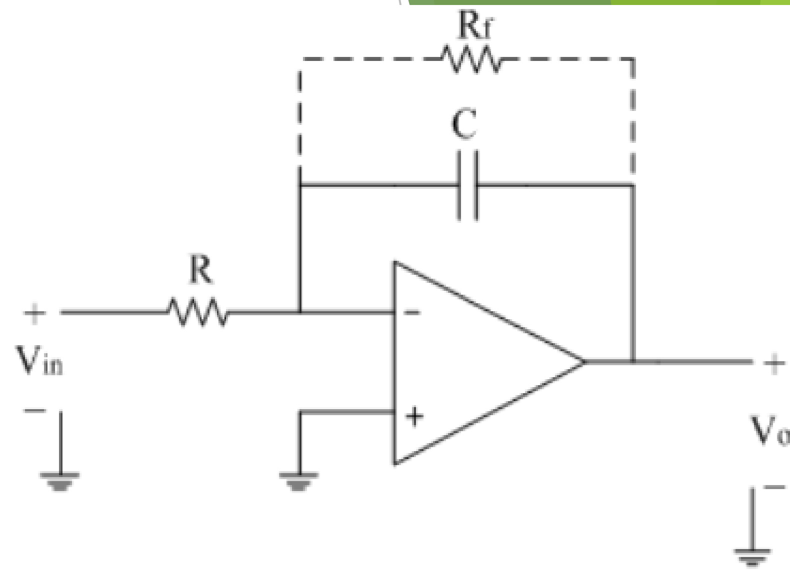
$$V_{out} = -\frac{1}{R1C1}\int_0^t Vin\,dt$$

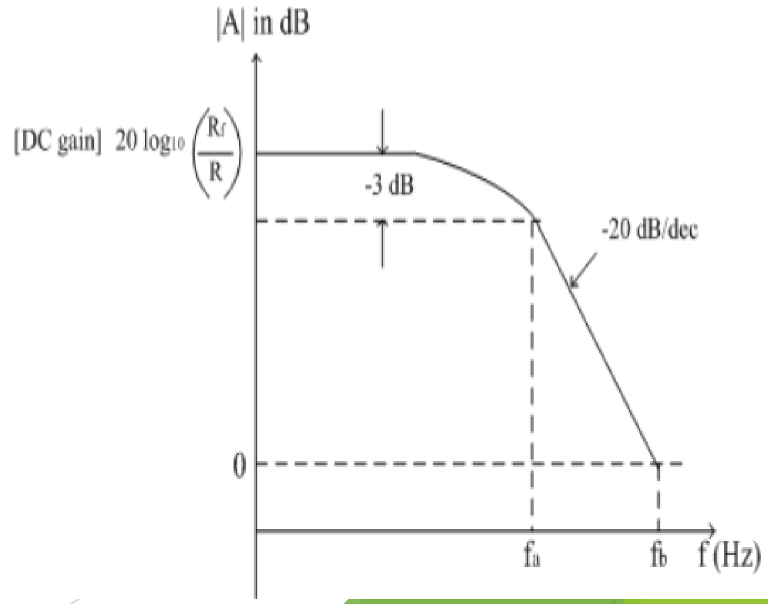
- Thus o/p voltage is proportional to the time integral of the input.(inverting integrator.)
- R1 at the non inverting side,to minimize the effect of input bias current.
- V0(s)=-1/sR1Cf Vi(s)
- |A|=1/wR1Cf (w=2*π*f)
- Gain is inversely proportional to f
- At w=0,A=infiniity /(At dc,Cf =open circuit so open loop gain becomes infinity)
- This problem of infinite gain will be solved by practical integrator circuit(lossy integrator)



PRACTICAL INTEGRATOR(LOSSY INTEGRATOR)

- Cf is shunted by a resistor,Rf
- Power dissipation is different for Rf||C
- Vin(s)/R+sCfVo(s)+Vo(s)/Rf=0
- Vo(s)=(-1/(sRCf+R/Rf))Vi(s)
- If Rf is large,lossy integrator will be equal to ideal integrator.
- |A|=|Vo/Vi|=(Rf/R)/sqrt(1+(wRCf)^2)
- At low frequencies,gain is constant at Rf/R.
- Break frequency,fa is the frequency at which gain is 1/sqrt(2)
- By solving fa=1/(2πRfCf)
- If f<fa ,circuit is like inverting amplifier





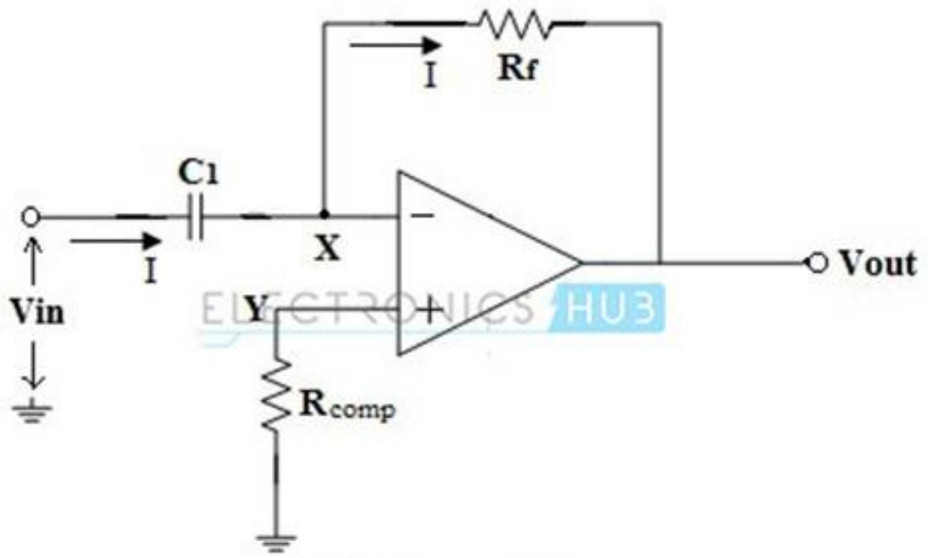
DIFFERENTIATOR

- Mathematical operation
- Output is the derivative of input
- Node X is at virtual ground
- Current through capacitor is

  I=C1d/dt(Vin)+Vo/Rf=0-------1
- No current into the opamp
- Vo=-RfC1dVin/dt
- Thus the name differentiator
- -ve sign indicates a 180 degree phase shift of the o/p waveform wrt i/p signal.
- Take Laplace Transform on both sides,

Vo(s)=-RfC1sVin(s)

- |A|=|-jwRfC1|=wRfC1=2πfRfC1=f/fa where fa=1/2πRfC1
- At f=fa,|A|=1 ie.0dB
- Gain increases at a rate of +20dB/decade
- At high frequency, it becomes unstable and break into oscillation.
- Input impedance decreases with increase in frequency and circuit is sensitive to high frequency noise.



PRACTICAL DIFFERENTIATOR

- Eliminates problem of instability and high frequency noise

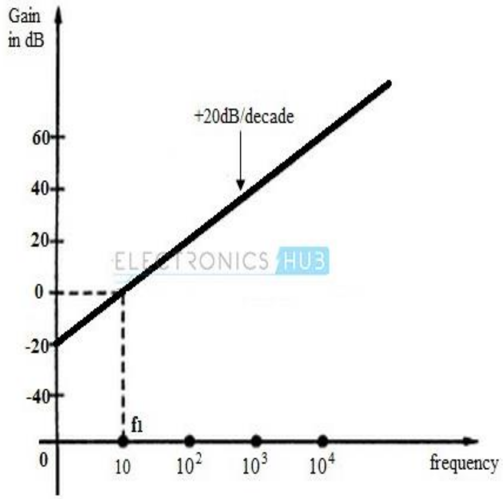


Fig: Frequency Response of Ideal Differentiator

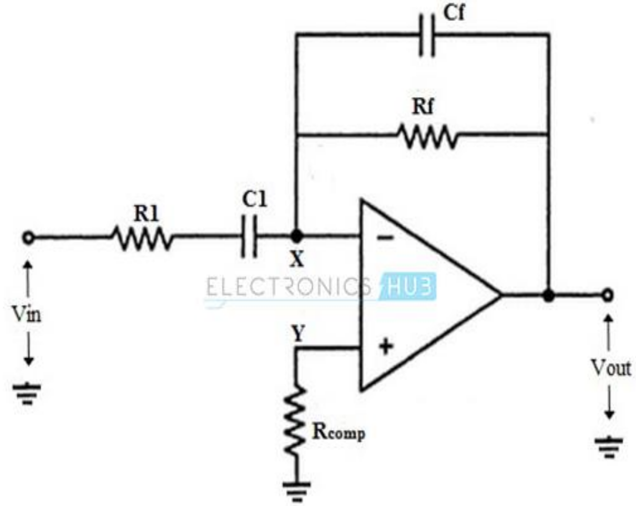


Fig: A Practical Op-amp Differentiator Circuit

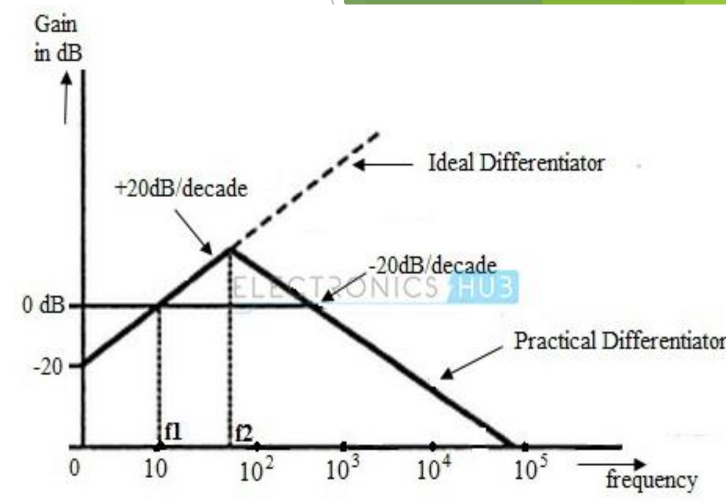


Fig: Frequency Response of Practical Differentiator

- Zf=Rf||Cf   Zi=R1 +C1
- Vo(s)/Vi(s)=sRfC1/(1+sRfCf)(1+sR1C1)
- For RfCf=R1C1,Vo(s)/Vi(s)=-sRfC1/(1+j(f/fb))^2

where fb=1/2πR1C1

Gain increases at +20dB/decade for frequency f<fb and decreases at -20dB/decade for f>fb

Rcomp –to reduce the i/p bias current

LOG AND ANTILOG AMPLIFIERS

- Some functions like ln x,log x and sinh x-antilog amp
- Log amp-to compress the dynamic range of a signal
- LOG AMPLIFIER
- electronic circuit that produces a voltage at the output that is proportional to the logarithm of the voltage applied to the resistor connected to its inverting terminal
- A grounded base transistor is placed in the feedback path and collector is at virtual ground. So voltage current relationship is that of a diode
- Ie=Is(e^(qVe/kT)-1)
- Ic=Ie so Ic=Is(e^(qVe/kT)-1)
- Is-emitter saturation current.10^-13
- k-Boltzmann 's constant
- T-absolute temperature in Kelvin
- Ic/Is=(e^(qVe/kT)-1)
- As Ic>>Is so Ic/Is=(e^(qVe/kT)
- Take natural log on both sides,Ve=kT/q ln(Ic/Is)
- Ic=Vin/R and Ve=-Vo Thus Vo=-kT/q ln((Vin/RIs)=-kT/q ln(Vin/Vref)

Where Vref=R*Is

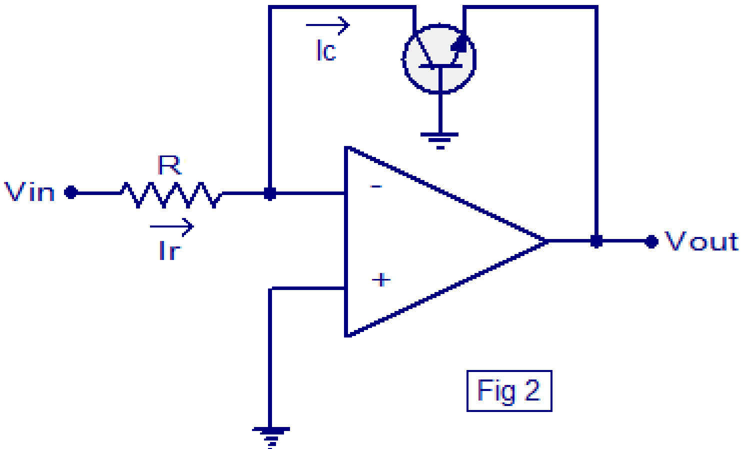
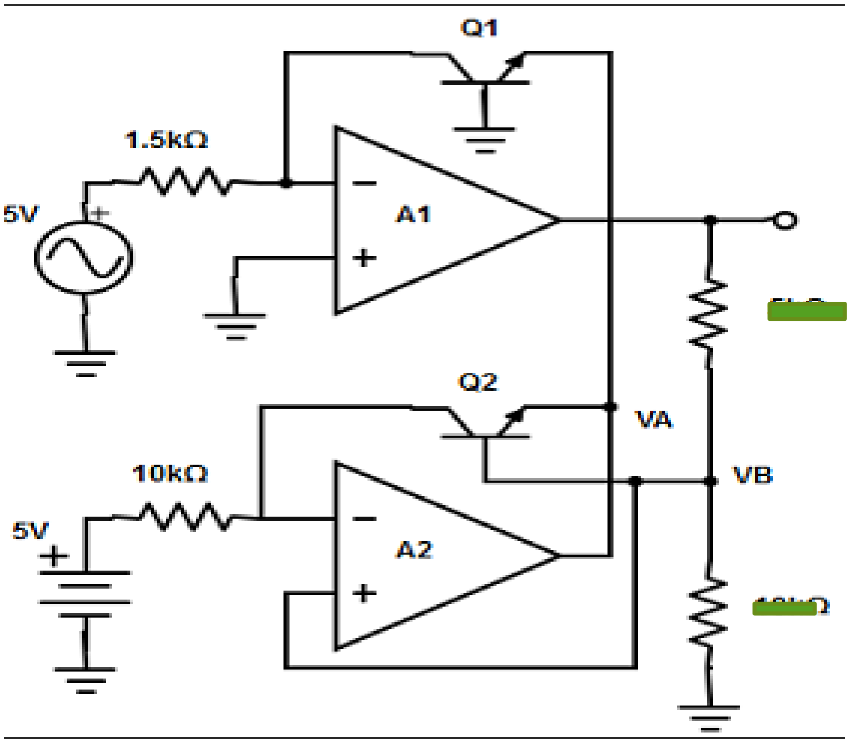


Fig 2

Limitation

- The emitter saturation current, Is varies from transistor to transistor and with temperature.Thus a stable reference voltage Vref cannot be obtained.



log amp using two opamps

$$V_o=(1+R_2/R_{tc})\ kT/q\ \ln(V_{in}/V_{ref})$$

<u>ANTILOG AMPLIFIER</u>

- electronic circuit that produces a voltage at the output that is proportional to the anti-logarithm of the voltage that is applied to the diode connected to its inverting terminal.

Continued….

- Input is fed into the temperature compensating voltage divider R2 and Rtc and to the base of Q2.
- Output is fed back to the inverting input of A1thru R1
- Base emitter voltage of two transistors:-

Vq1(b-e)=(kT/q)ln(Vo/R1*Is)

Vq2(b-e)=(kT/q)ln(Vref/R1*Is)

- Base of Q1 is grounded VA=-Vq1(b-e)

  =-(kT/q)ln(Vo/R1*Is)
- Base voltage of Q2,V_B=Vi(Rtc/(R2+Rtc))
- Emitter voltage of Q2, Vq2(e)=V_B + Vq2(b-e)

  =Vi(Rtc/(R2+Rtc))+(kT/q)ln(Vref/R1*Is)
- This is VA=Vq2(e)
- -(kT/q)ln(Vo/R1*Is)= Vi(Rtc/(R2+Rtc))+(kT/q)ln(Vref/R1*Is)
- Vi(Rtc/(R2+Rtc))=-(kT/q)[ln(Vo/(R1*Is))-ln(Vref/(R1*Is))]
- -(q/kT)[Rtc/(R2+Rtc)]Vi=ln(Vo/Vref)
- Change natural log into $\log_{10}$
- Log X=0.4343 lnX
- -0.4343*(q/kT)[Rtc/(R2+Rtc)]Vi=0.4343*ln(Vo/Vref)
- -K’Vi=log (Vo/Vref)

Vo=Vref(10^-K’Vi) where K’=0.4343(q/kT)[Rtc/(R2+Rtc)]

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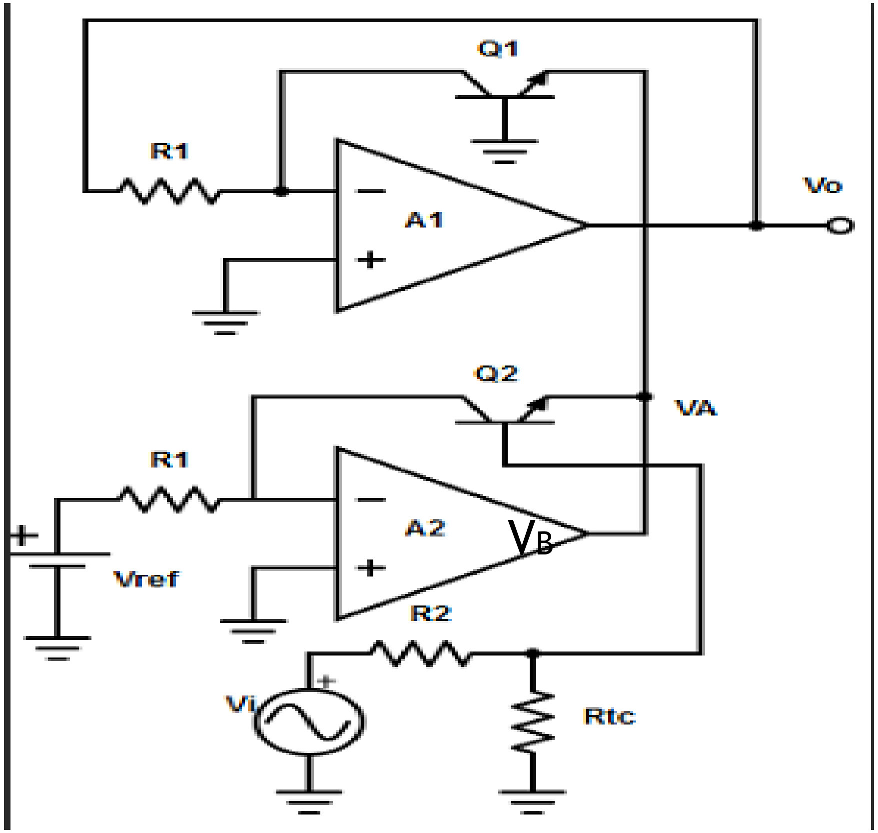
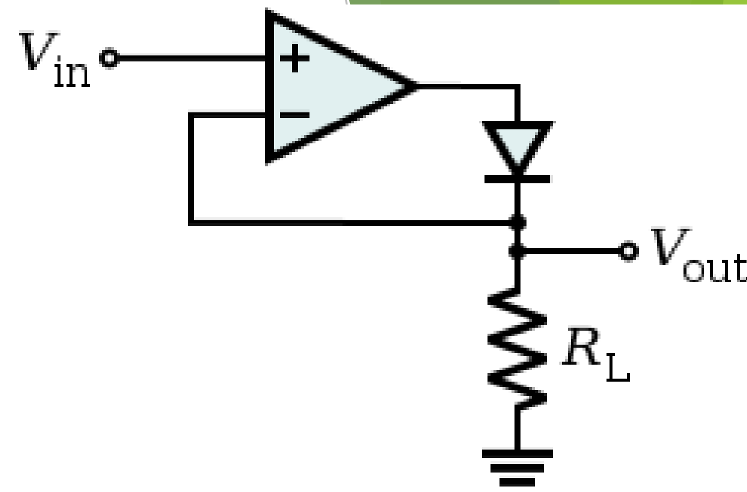


- An increase of input by one volt causes the o/p to decrease by a decade

PRECISION RECTIFIER

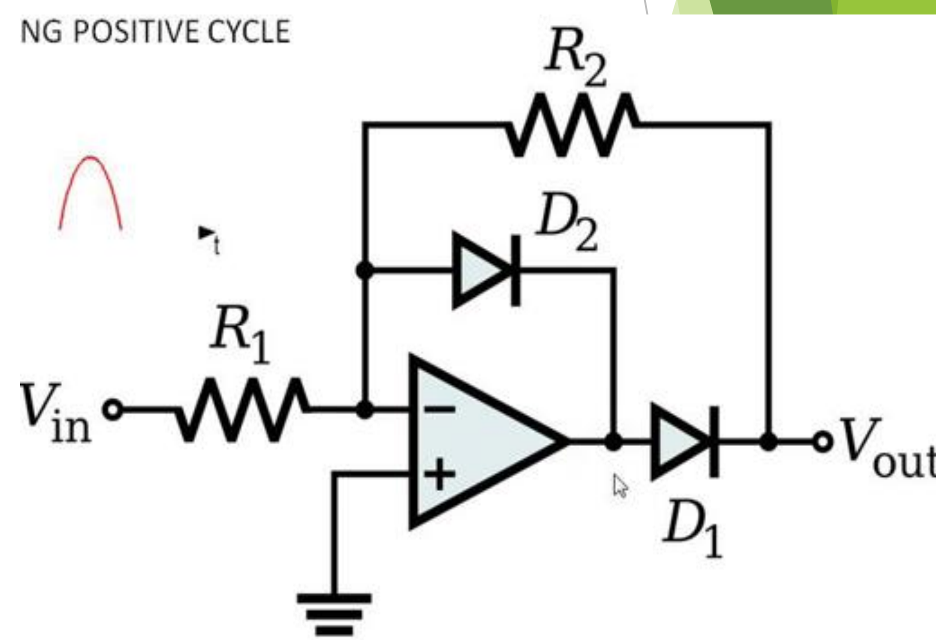


- To rectify voltages below cut in voltage of the diode.
- Place a diode in the feedback loop of an opamp.
- Functions as a **Non inverting precision halfwave rectifier.**
- When Vi is positive,opamp o/p is also positive.Vo=Vi
- When Vi is negative,opamp o/p is also negative and Diode becomes reverse biased and Vo=0.

Here cut in voltage becomes Vr/Aol=0.7/10^4=70uV

Conduction begins from a low voltage.

- **Inverting Precision Half wave rectifier:**
- When Vi >0,opamp o/p becomes negative
- D2 conducts and D1 reverse biased,Vo=0
- No current flows thru R2
- When Vi<0,opamp o/p becomes positive
- D1 conducts and D2 reverse biased
- So circuit acts like an inverting amplifier
- Gain=R2/R1
- Advantages:
- half wave rectifier
- non saturating

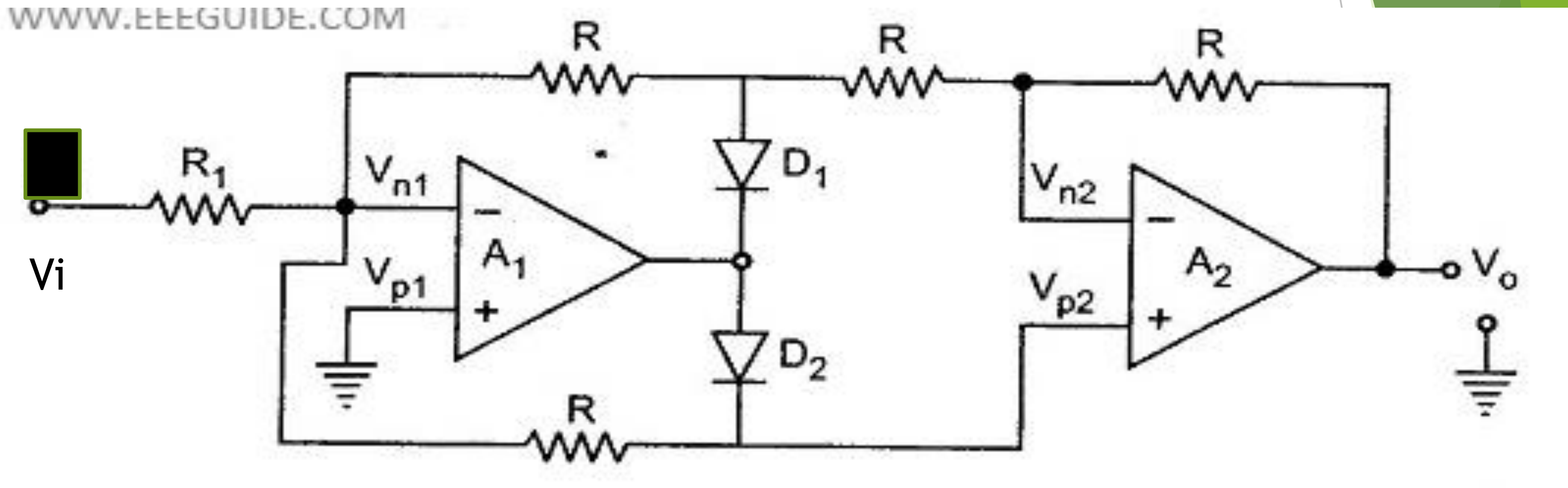


FULL WAVE RECTIFIER

- Accepts ac signal either negative or positive,the o/p is obtained as

Positive. It is called absolute value circuit.

- When Vi>0,A1=negative
- D1-FB,D2-RB and no current flows through resistance R connected between V_{n1} and V_{p2}
- A1 and A2 act as inverter giving positive o/p.Vo=Vi



- When Vi<0,A1 is positive
- D1-RB,D2-FB
- Eqwt circuit is as shown:

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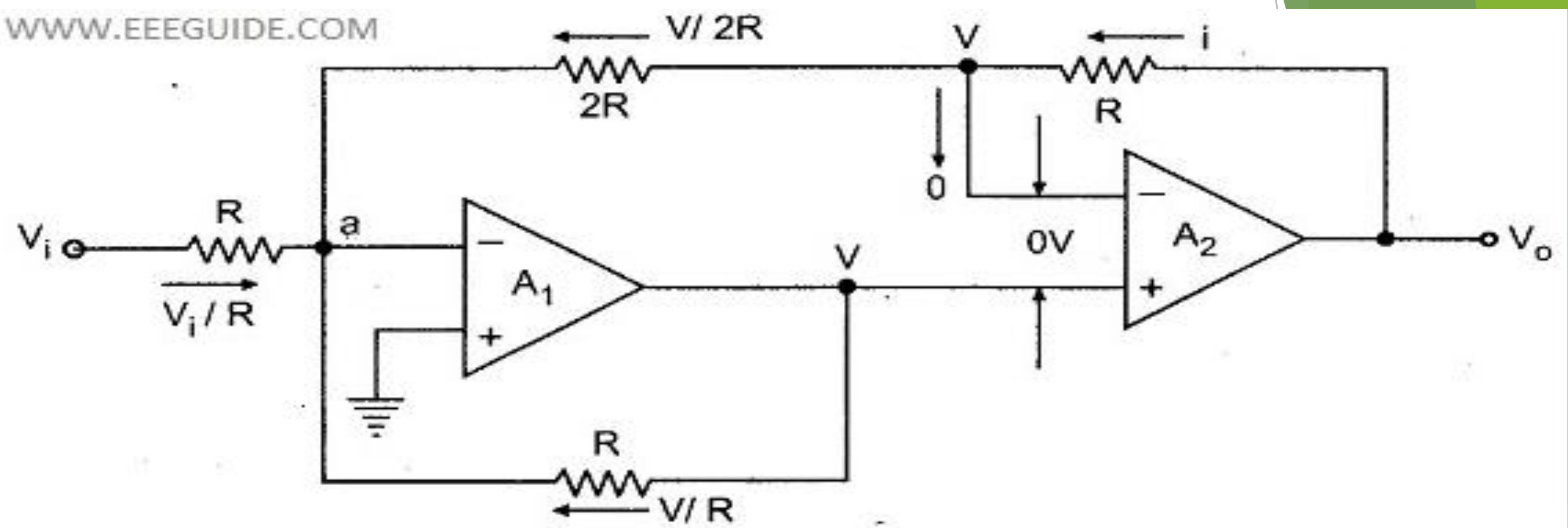
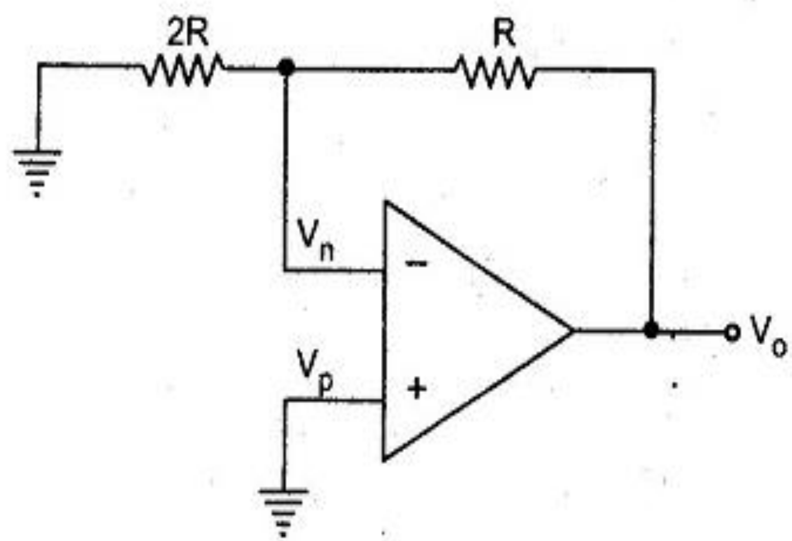
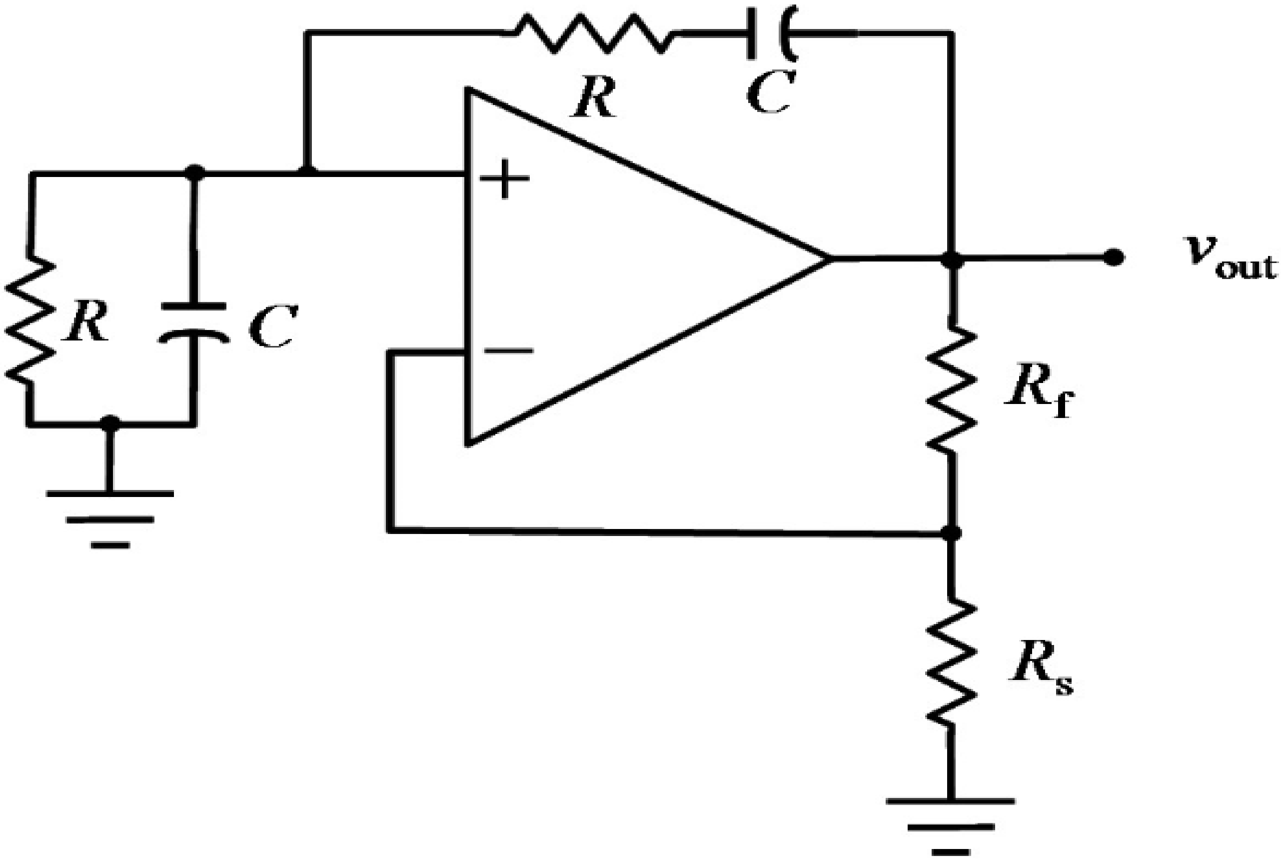




- Vi/R +V/2R +V/R =0
- V=-2/3 Vi
- Vo=(1+R/2R)(-2/3Vi)=-Vi
- As Vi is negative ,Vo is also negative
- Vo=-Vi

WEIN BRIDGE OSCILLATOR

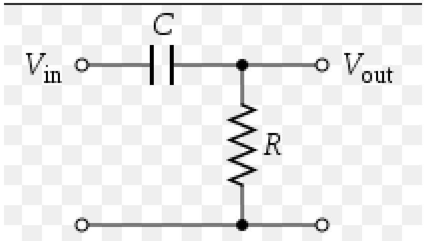


- AF oscillator
- Feedback circuit is a tank circuit which generates weak oscillations and it is amplified using an opamp.
- Here it works as a non inverting amplifier.
- Series impedance is denoted by Zs and Parallel impedance is denoted by Zp

Continued....

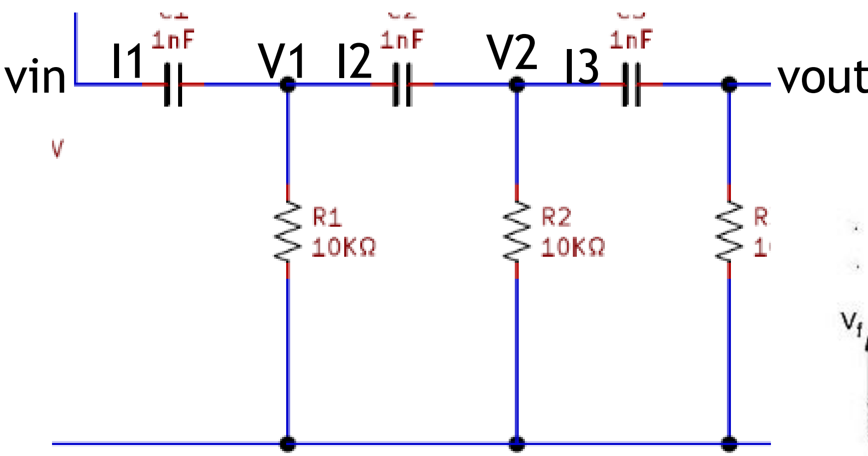
- Zs=R+Xc= R+$\frac{1}{jwC}$--------------1
- Zp=RXc/R+Xc=$\frac{\text{R}}{\text{jwC}}$/R+$\frac{1}{jwC}$=$\frac{R}{1+jwRC}$-------2
- Vf=βVo   β=$\frac{Vf}{Vo}$
- β=$\frac{Zp}{Zs+Zp} = \frac{R}{1+jwRC}$/[(R+$\frac{1}{jwC}$) + $\frac{R}{1+jwRC}$]
- [$\frac{R}{1+jwRC}$]/[$\frac{jwRC+1}{jwC}$+$\frac{R}{1+jwRC}$] =[$\frac{R}{1+jwRC}$]/$\frac{(1+jwRC)^2+jwRC}{jwC(1+jwRC)}$
- [$\frac{R}{1+jwRC}$]X$\frac{jwC(1+jwRC)}{(1+jwRC)^2+jwRC}$=$\frac{jwRC}{(1+jwRC)^2+jwRC}$=$\frac{jwRC}{1+3jwRC-(wRC)^2}$
- To ensure phase shift of O degree by the feedback network
- 1-$(wRC)^2$=0(Equate real part to zero)
- W=$\frac{1}{RC}$ f=$\frac{1}{2\pi RC}$
- Equate imaginary part to 0
- feedback gain =1/3
- Aβ=1   then A=3; If A<3 damped oscillations ;A>3 growing oscillation

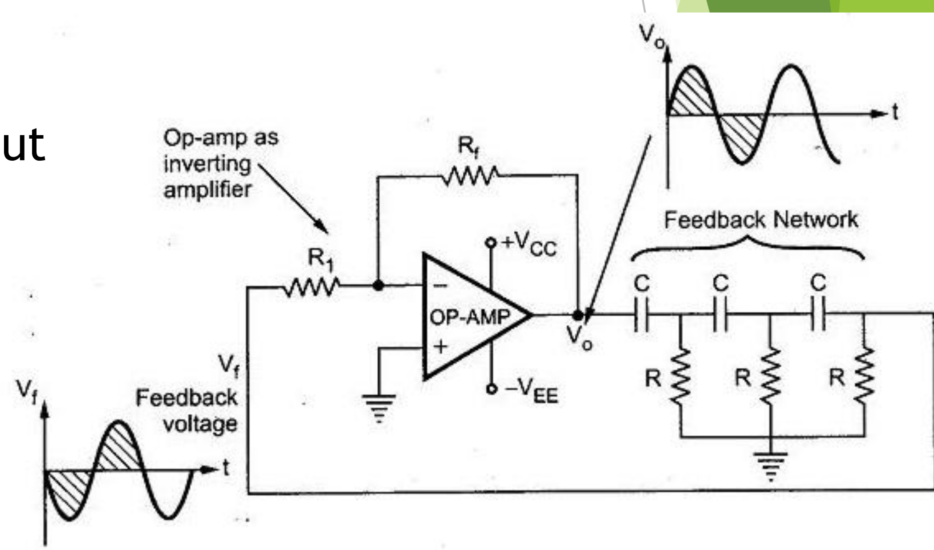
RC PHASE SHIFT OSCILLATOR

- Amplifiers with positive feedback
- |Aβ|=1   angle(Aβ)=0
- 

$$\frac{Vo}{Vin}=\frac{R}{R-jXc} = 1/(1-j\frac{Xc}{R})$$

- $\Phi = 0 - \tan^{-1}\left(-\frac{1}{wRC}\right) = \tan^{-1}\left(\frac{1}{wRC}\right) = \tan^{-1}\left(\frac{Xc}{R}\right)$
- If R=0, Φ=90degree(ideal) ;60degree(practical)





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- At node V2:

$$V2=I3Xc+Vo=(\frac{V0}{R}Xc)+Vo=\frac{Vo}{jwRC}+Vo=Vo(1+\frac{1}{jwRC})\text{-------}1$$

At node V2 apply KCL,

$$I2=\frac{V2}{R}+I3=\frac{Vo}{R}\,(1+\frac{1}{jwRC})+\frac{V0}{R}=\frac{V0}{R}(2+\frac{1}{jwRC})\text{----}2$$

- At node V1:

$$V1=V2+I2Xc\;=Vo(1+\frac{1}{jwRC})+\frac{V0}{jwCR}(2+\frac{1}{jwRC})$$

$$V1=\;Vo(1+\frac{3}{jwRC}-\frac{1}{(wRC)^2})\text{-------------}3$$

At node V1 apply KCL,

$$I1=\frac{V1}{R}+I2=\frac{Vo}{R}(1+\frac{3}{jwRC}-\frac{1}{(wRC)^2})+\frac{V0}{R}(2+\frac{1}{jwRC})$$

$$=\frac{Vo}{R}(3+\frac{4}{jwRC}-\frac{1}{(wRC)^2})\text{-----------------}4$$

At Vin:

$$Vin=V1+I1Xc=Vo(1+\frac{3}{jwRC}-\frac{1}{(wRC)^2})+\frac{Vo}{jwRC}(3+\frac{4}{jwRC}-\frac{1}{(wRC)^2})$$

$$=Vo[1+\frac{6}{jwRC}\text{-}\frac{5}{(wRC)^2}\text{-}\frac{1}{j(wRC)^3}]$$

Continued…….

- Equate imaginary part to zero:

$\frac{6}{wRC}$-$\frac{1}{(wRC)^3}$=0 $(wRC)^2 = \frac{1}{6}$ w=$\frac{1}{\sqrt{6}}$*$\frac{1}{RC}$

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

Questions:

1. With the help of circuit diagram and relevant equations, explain the disadvantages of a differentiator. How are the disadvantages removed in a practical differentiator?
2. With the help of circuit diagrams and graphs, explain the working of a Full wave Precision rectifier.
3. With the help of a circuit diagram, derive the equation for load current IL, for a V to I converter with grounded load and deduce the condition for its ideal current converter
4. Derive the equation for frequency of oscillation (f0) of a Wein Bridge oscillator. Design a Wein Bridge oscillator for f0 = 1KHz.
5. Draw the circuit of a log amplifier with temperature compensation and derive the equation for its output voltage

Continued….

6. Derive the equation for output voltage of an integrator. Why is it called a lossy integrator?

7. Prove that the input voltage is converted into corresponding output current in a voltage to current converter with floating load

8. How to realize Wein-Bridge oscillator using op. amp.? Derive the condition of oscillation and frequency of oscillation for the circuit

9. Design a fullwave rectifier to rectify an ac signal of 0.2V peak-to-peak. Explain its principle of operation.