JEPPIAAR INSTITUTE OF TECHNOLOGY

"Self-Belief | Self Discipline | Self Respect"

DEPARTMENT

OF

ELECTRICAL AND ELECTRONICS ENGINEERING

LECTURE NOTES

EE8451 – LINEAR INTEGRATED CIRCUITS AND APPLICATIONS

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UNIT III APPLICATIONS OF OPAMP 9

Instrumentation amplifier and its applications for transducer Bridge, Log and Antilog Amplifiers- Analog multiplier & Divider, first and second order active filters, comparators, multivibrators, waveform generators, clippers, clampers, peak detector, S/H circuit, D/A converter (R- 2R ladder and weighted resistor types), A/D converters using opamps.

Instrumentation Amplifier:

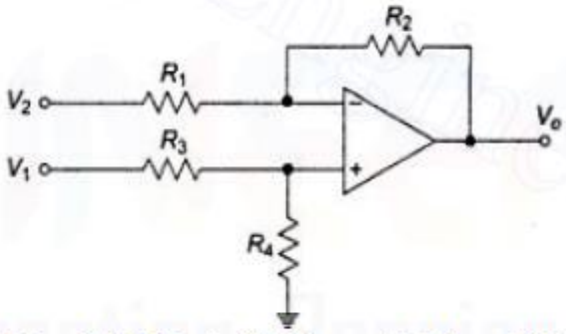

Fig. 2.18 Basic Differential Amplifier

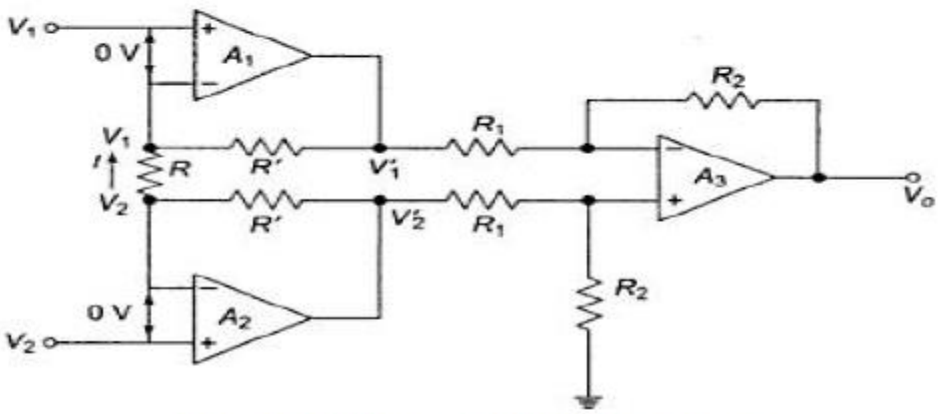

Fig. 2.19 Instrumentation Amplifier

Current flowing in resistor R is I= $(V_1-V_2)/R$ and it flow through R' in the direction shown, Voltage

at non-inverting terminal op-amp A3 is $R_2V_1'/(R_1+R_2)$. By superposition theorem,

$V_o= (R_2/R_1)V_1+(1+R_2/R_1)(R_2V_2/(R_1+R_2)=R_2/R_1(V_1'-V_2')$;

$V_1'= R'I+V_1=R'/R(V_1-V_2)+V_1$

$V_2'= R'I+V_1=R'/R(V_1-V_2)+V_2$;

$V0= (R_2/R_1)[(2R'/R(V_2-V1)+ (V_2-V1)]= (R_2/R_1)[(1+2R'/R)(V_2-V1)$

In a number of industrial and consumer applications, one is required to measure and control physical quantities. Some typical examples are measurement and control of temperature, humidity, light intensity, water flow etc. these physical quantities are usually measured with help of transducers. The output of transducer has to be amplified so that it can drive the indicator or display system. This function is performed by an instrumentation amplifier. The important features of an instrumentation amplifier are

1. High gain accuracy
2. High CMRR
3. High gain stability with low temperature coefficient
4. Low output impedance

There are specially designed op-amps such as μA725 to meet the above stated requirements of a good instrumentation amplifier. Monolithic (single chip) instrumentation amplifier are also available commercially such as AD521, AD524, AD620, AD624 by Analog Devices, LM363.XX (XX -->10,100,500) by National Semiconductor and INA101, 104, 3626, 3629 by Burr Brown. In the circuit of figure 6(a), source V1 sees an input impedance = R3+R4 (=101K) and the impedance seen by source V2 is only R1 (1K). This low impedance may load the signal source

heavily. Therefore, high resistance buffer is used preceding each input to avoid this loading effect as shown in figure

The op-amp A1 and A2 have differential input voltage as zero. For V1=V2, that is, under common mode condition, the voltage across R will be zero. As no current flows through R and R‘ the non-inverting amplifier. A1 acts as voltage follower, so its output V2‘=V2. Similarly op-amp A2 acts as voltage follower having output V1‘=V1. However, if V1≠V2, current flows in R and R‘, and (V2‘-V1‘)>(V2- V1). Therefore, this circuit has differential gain and CMRR more compared to the single opamp circuit of figure 2.10. The difference gain of this instrumentation amplifier R, however should never be made zero, as this will make the gain infinity. To avoid such a situation, in a practical circuit, a fixed resistance in series with a potentiometer is used in place of R. Figure (c) shows a differential instrumentation amplifier using Transducer Bridge. The circuit uses a resistive transducer whose resistance changes as a function of the physical quantity to be measured. The bridge is initially balanced by a dc supply voltage Vdc so that V1=V2. As the physical quantity changes, the resistance RT of the transducer also changes, causing an unbalance in the bridge (V1≠V2). This differential voltage now gets amplified by the three opamp differential instrumentation amplifier.

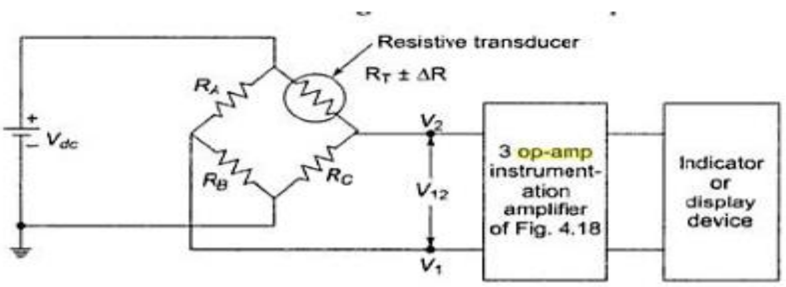

Fig.2.20 Instrumentation bridge using transducer Bridge

$R_B(V_{dc})/(R_B+R_A)= R_C V_{dc}/(R_C+R_T)$

Applications of instrumentation amplifier with the transducer bridge,

- temperature indicator,
- temperature controller and
- light intensity meter.

LOG AMPLIFIER:

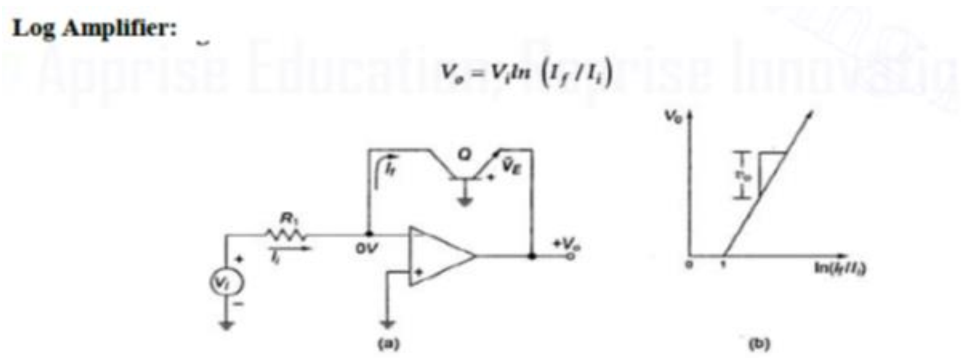

Fig 2.28 Fundamental log-amp Circuit and its characteristics

There are several applications of log and antilog amplifiers.
Antilog computation may require functions such as ln x, log x or sin hx.

Uses:
Direct dB display on a digital Voltmeter and Spectrum analyzer. Log-amp can also be used to compress the dynamic range of a signal. A grounded base transistor is placed in the feedback path. Since the collector is placed in the feedback path. Since the collector is held at virtual ground and the base is also grounded, the transistor‘s voltage-current relationship becomes that of a diode and is given by,

$I_E = I_S[e^{\frac{qV_{BE}}{kT}} - 1]$ and since $I_c = I_E$ for a grounded base transistor $I_C = I_S\ e^{kT}$

Is-emitter saturation current $\approx 10^{-13}$ A

k=Boltzmann's constant

T=absolute temperature (in ^{o} K)

$$V_o = -\frac{kT}{q} ln\left(\frac{V_i}{R_1 I_S}\right) = -\frac{kT}{q} ln\left(\frac{V_i}{V_R}\right)$$

where Vref =R1Is

The output voltage is thus proportional to the logarithm of input voltage.

Although the circuit gives natural log (ln), one can find log10, by proper scaling

Log10X=0.4343 ln X

The circuit has one problem. The emitter saturation current Is varies from transistor to transistor and with temperature. Thus a stable reference voltage V ref cannot be obtained. This is eliminated by the circuit given below

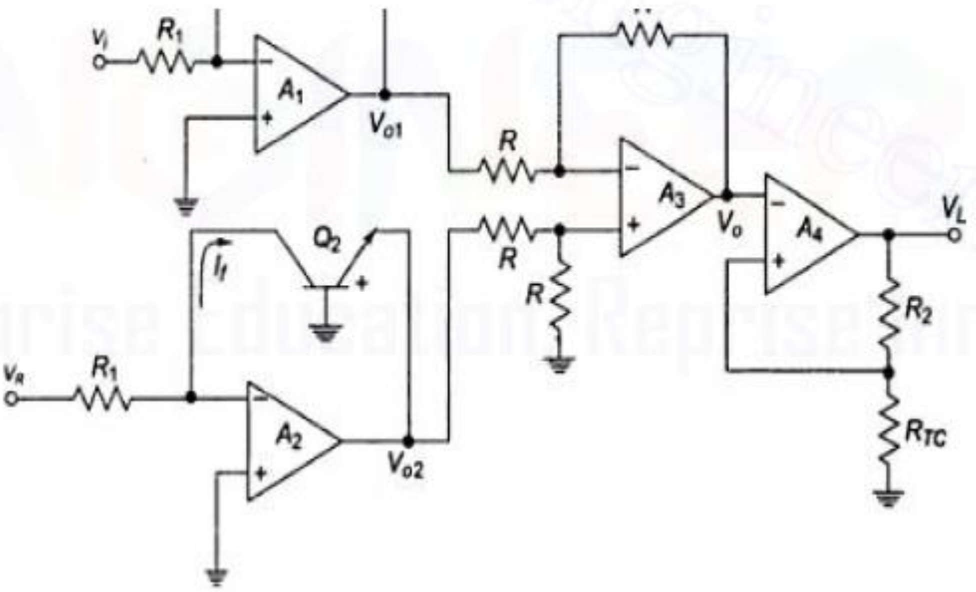

Fig. 2.29 Logarithmic amplifier with compensation of emitter saturation current

The input is applied to one log-amp, while a reference voltage is applied to one log-amp, while a reference voltage is applied to another log-amp. The two transistors are integrated close together in the same silicon wafer. This provides a close match of saturation currents and ensures good thermal tracking.

Assume IS1=IS2=IS

Thus the reference level is now set with a single external voltage source. Its dependence on device and temperature has been removed. The voltage V_o is still dependent upon temperature and is directly proportional to T. This is compensated by the last op-amp stage A4 which provides a non-inverting gain of (1+R2/RTC). Temperature compensated output voltage V_L

$$V_L = \left(1 + \frac{R_2}{R_{TC}}\right)\frac{kT}{q}\,ln\left(\frac{V_i}{V_R}\right)$$

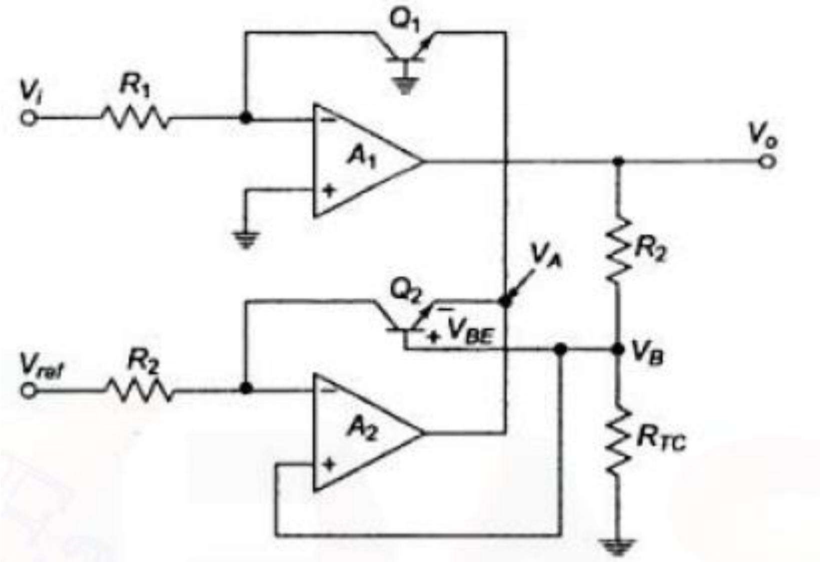

Fig.2.30 Logarithmic amplifier using two op amps

Where RTC is a temperature-sensitive resistance with a positive coefficient of temperature (sensor) so that the slope of the equation becomes constant as the temperature changes.

2.12 Antilog Amplifier

A circuit to convert logarithmically encoded signal to real signals. Transistor in inverting input converts input voltage into logarithmically varying currents

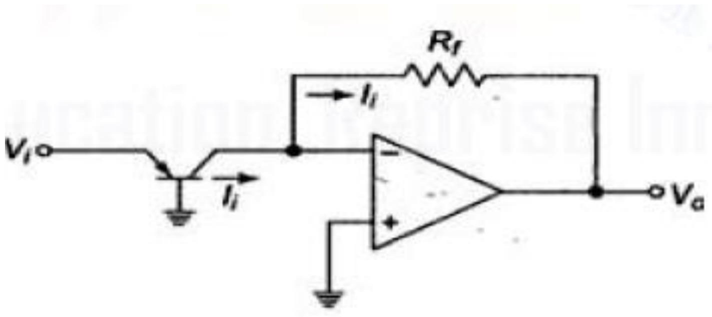

Fig. 2.31 Antilog amplifier

$$I_i = I_c = I_s\left(e^{\frac{\eta V_{BE}}{kT}}\right) \text{ and } V_0 = R_f\, I_s\left(e^{\frac{\eta V_{BE}}{kT}}\right)$$

The circuit is shown in figure below. The input V_i for the antilog-amp is fed into the temperature compensating voltage divider R2 and R_{TC} and then to the base of Q2. The output of A2 is fed back to R1 at the inverting input of op amp A_1. The non-inverting inputs are grounded

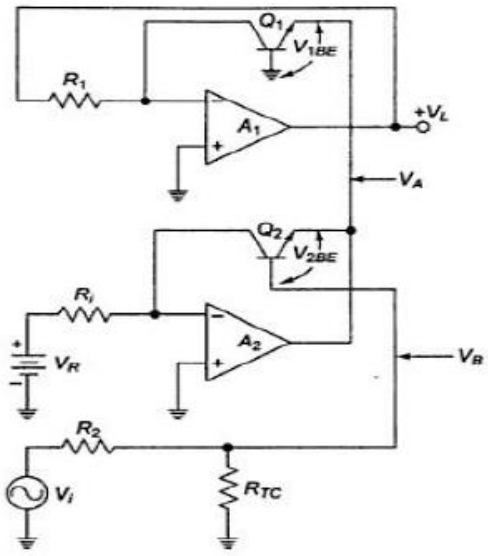

Fig 2.32 Antilog amplifier

$V_{1BE} = \frac{kT}{q}\ln[\frac{V_L}{R_1 I_S}]$ and $V_{2BE} = \frac{kT}{q}\ln[\frac{V_B}{R_1 I_S}]$ and $V_A = -V_{1BE}$ and $V_B = R_{TC}/(R_2+R_{TC})\, V_i$

$V_{Q2E} = V_B + V_{2BE} = R_{TC}/(R_2+R_{TC})\, V_i - \frac{kT}{q}\ln[\frac{V_B}{R_1 I_S}]$

$V_{Q2E} = V_A$

Therefore,

$$-\frac{kT}{q}ln\left(\frac{V_L}{R_1 I_S}\right) = \frac{R_{TC}}{R_2+R_{TC}}V_i + \frac{kT}{q}ln\left(\frac{V_R}{R_1 I_S}\right)$$

Rearranging, we get

$$\frac{R_{TC}}{R_2+R_{TC}}V_i = -\frac{kT}{q}ln\left(\frac{V_L}{R_1 I_S}\right) - \frac{kT}{q}ln\left(\frac{V_R}{R_1 I_S}\right)$$

$$= -\frac{kT}{q}ln\left(\frac{V_L}{V_R}\right)$$

We know that $\log_{10} x = 0.4343\, ln\, x$.

Therefore, $-0.4343\left(\frac{q}{kT}\right)\left(\frac{R_{TC}}{R_2+R_{TC}}\right)V_i = 0.4343\, ln\left(\frac{V_L}{V_R}\right)$

$-0.4343\left(\frac{q}{kT}\right)\left(\frac{R_{TC}}{R_2+R_{TC}}\right)V_i = \log_{10}\left(\frac{V_L}{V_R}\right)$

$-KV_i = \log\left(\frac{V_L}{V_R}\right)$

$K = 0.4343\left(\frac{q}{kT}\right)\left(\frac{R_{TC}}{R_2+R_{TC}}\right)$

$V_L = V_R 10^{-KV_i}$

The output Vo of the antilog- amp is fed back to the inverting input of A1 through the resistor R_1. Hence an increase of input by one volt causes the output to decrease by a decade.

Analog Multipliers:

A multiple produces an output V0 which is proportional to the product of two inputs Vxand Vy. V0 = KVxVy where K is the scaling factor = (1/10) V-1.

There are various methods available for performing analog multiplication. Four of such techniques, namely,

1. Logarithmic summing technique
2. Pulse height/width modulation Technique
3. Variable trans conductance Technique
4. Multiplication using Gilbert cell and
5. Multiplication using variable trans conductance technique.

An actual multiplier has its output voltage V0 defined by

$$V_0 = \frac{(V_x+\phi_x)(V_y+\phi_y)}{10(1+\varepsilon)}+\phi_0$$

where φx and φy are the offsets associated with signals Vx and Vy, ε is the error signal associated with K and φ0 is the offset voltage of the multiplier output.

Terminologies associated voltage of the multiplier characteristics:

- ✓ Accuracy:

This specifies the derivation of the actual output from the ideal output, for any combination of X and Y inputs falling within the permissible operating range of the multiplier.

- ✓ Linearity:

This defines the accuracy of the multiplier. The Linearity Error can be defined as the maximum absolute derivation of the error surface. This linearity error imposes a lower limit on the multiplier accuracy.

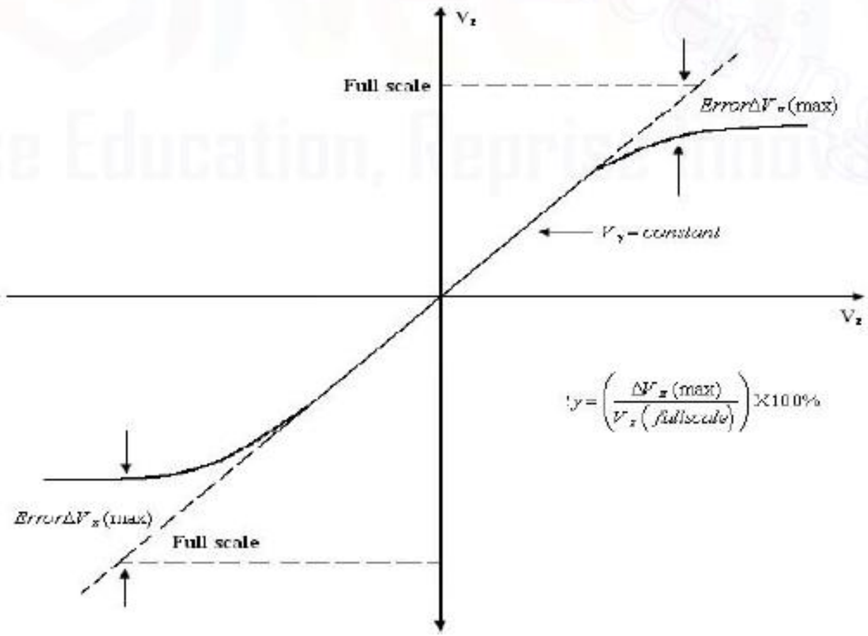

Fig.3.1 Linearity of the multiplier

The figure shows the response of the output as a function of one input voltage Vx when the other Vy is assumed constant. It represents the maximum percentage derivation from the ideal straight line output. An error surface is formed by plotting the output for different combinations of X and Y inputs.

- ✓ Square law accuracy:

The Square – law curve is obtained with the X and Y inputs connected together and applied with the same input signal. The maximum derivation of the output voltage from an ideal square –law curve expresses the squaring mode accuracy.

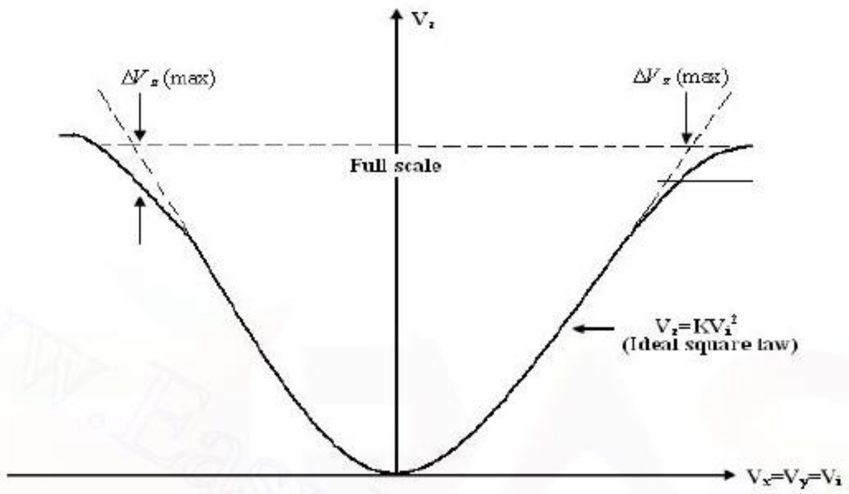

Fig. 3.2 squaring mode accuracy

- ✓ Bandwidth:

The Bandwidth indicates the operating capability of an analog multiplier at higher frequency values. Small signal 3 dB bandwidth defines the frequency f0 at which the output reduces by 3dB from its low frequency value for a constant input voltage. This is identified individually for the X and Y input channels normally.

The transconductance bandwidth represents the frequency at which the transconductance of the multiplier drops by 3dB of its low frequency value. This characteristic defines the application frequency ranges when used for phase detection or AM detection.

- ✓ Quadrant:

The quadrant defines the applicability of the circuit for bipolar signals at its inputs. First – quadrant device accepts only positive input signals, the two quadrant device accepts one bipolar signal and one unipolar signal and the four quadrant device accepts two bipolar signals.

- ✓ Logarithmic summing Technique:

This technique uses the relationship lnVx + lnVy =ln(VxVy) As shown in figure the input voltages Vx and Vy are converted to their logarithmic equivalent, which are then added together by a summer. An antilogarithmic converter produces the output voltage of the summer. The output is given by,

Vz = ln-1 (ln(Vx Vy)) = Vx Vy .

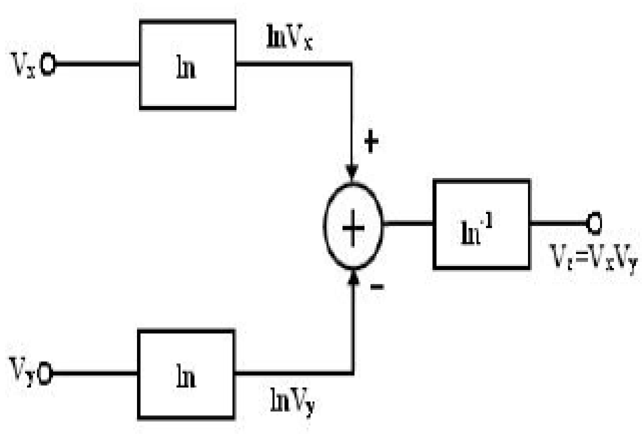

Fig. 3.3 logarithmic summing method

The relationship between I0 and VBE of the transistor is given by IC = I0e(VBE /VT) .It is found that the transistor follows the relationship very accurately in the range of 10nA to 100mA. Logarithmic multiplier has low accuracy and high temperature instability. This method is applicable only to positive values of Vx and Vy.

Limitation: this type of multiplier is restricted to one quadrant operation only.

✓ Pulse Height/ Width Modulation Technique:

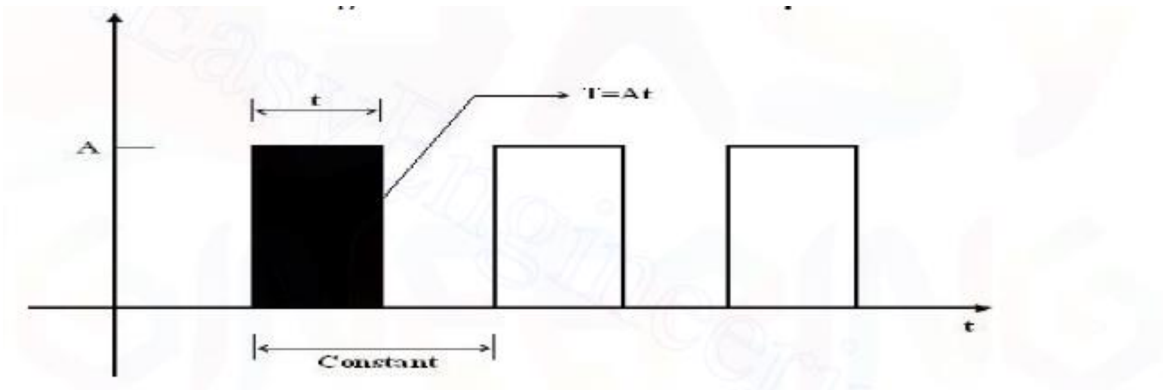

Fig.3.4 Pulse Height/ Width Modulation Technique

In this method, the pulse width of a pulse train is made proportional to one input voltage and the pulse amplitude is made proportional to the second input voltage. Therefore, Vx =Kx A,Vy =Ky t, and Vz =Kz T where Kx, Ky, Kz are scaling factors. In figure A is the amplitude of thepulse, t is the pulse width and T is the area of the pulse. Therefore,

$$V_z = K_z T = \frac{V_x V_y}{k_x k_y}$$

The modulated pulse train is passed through an integrated circuit. Therefore, the input of the integrator is proportional to the area of pulse, which in turn is proportional to the product of two input voltages.

Comparator

A comparator compares a signal voltage on one input of an op-amp with a known voltage called a reference voltage on the other input. Comparators are used in circuits such as,

✓ Digital Interfacing

✓ Schmitt Trigger

✓ Discriminator

✓ Voltage level detector and oscillators

2.13.1 Non-inverting Comparator:

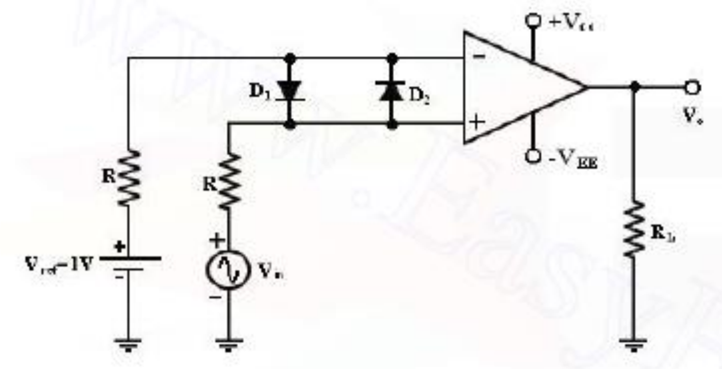

Fig. 2.33 non-inverting comparator circuit

A fixed reference voltage V_{ref} of 1 V is applied to the negative terminal and time varying signal voltage Vin is applied to the positive terminal.

When Vin is less than Vref the output becomes V0 at –Vsat

[Vin < Vref => V0 (-Vsat)].

When Vin is greater than Vref, the (+) input becomes positive, the V0 goes to +Vsat.

[Vin > Vref => V0 (+Vsat)].

Thus the V0 changes from one saturation level to another.

The diodes D1 and D2 protect the op-amp from damage due to the excessive input voltage Vin. Because of these diodes, the difference input voltage Vid of the op-amp diodes are called clamp diodes.

The resistance R in series with Vin is used to limit the current through D1 and D2. To reduce offset problems, a resistance Rcomp = R is connected between the (-ve) input and Vref.

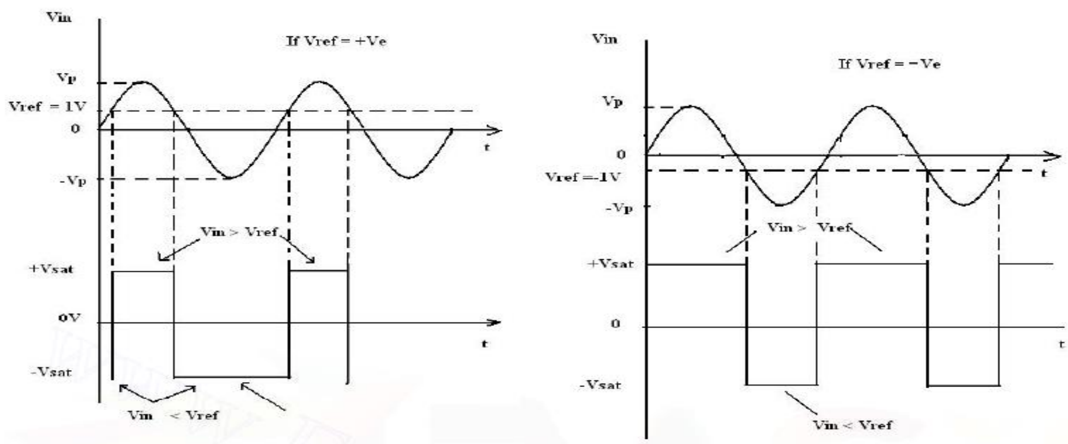

Fig. 2.34 Input and Output Waveforms of non-inverting comparator

2.13.2 Inverting Comparator:

This fig shows an inverting comparator in which the reference voltage Vref is applied to the (+) input terminal and Vin is applied to the (-) input terminal.

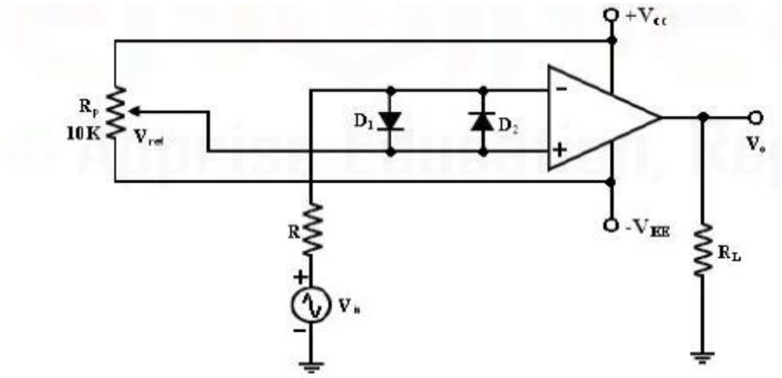

Fig. 2.35 Inverting comparator circuit

In this circuit Vref is obtained by using a 10K potentiometer that forms a voltage divider with DC supply volt +Vcc and -1 and the wiper connected to the input. As the wiper is moved towards +Vcc, Vref becomes more positive. Thus a Vref of a desired amplitude and polarity can be got by simply adjusting the 10k potentiometer.

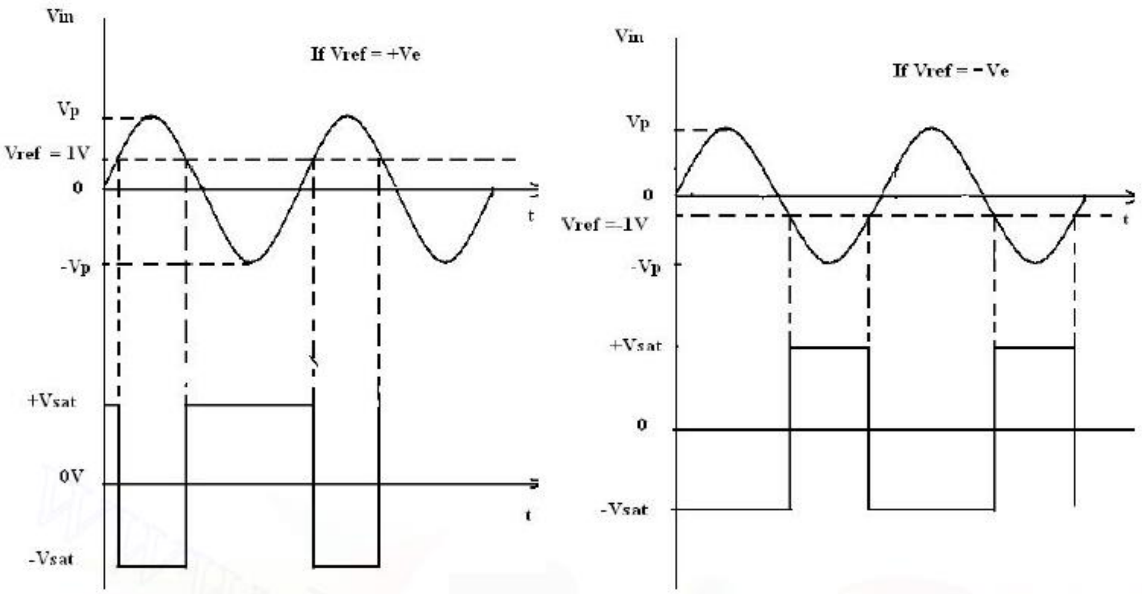

Fig. 2.36 Input and Output Waveforms of non-inverting comparator

Applications:

- ✓ **Zero Crossing Detector: [Sine wave to Square wave converter]**

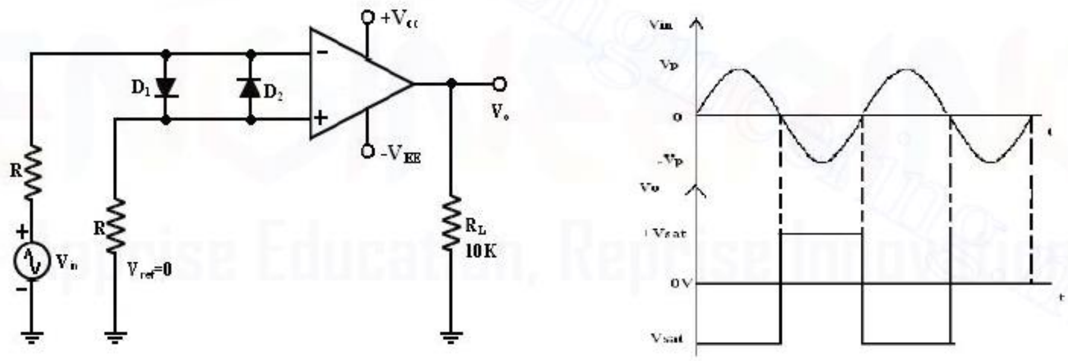

Fig. 2.37 Zero crossing detector circuit and input-output waveforms

One of the applications of comparator is the zero crossing detector or ―sine wave to Square wave Converter. The basic comparator can be used as a zero crossing detector by setting Vref is set to Zero. This Fig shows when in what direction an input signal Vin crosses zero volts. (i.e.) the o/p V0 is driven into negative saturation when the input the signal Vin passes through zero in positive direction. Similarly, when Vin passes through Zero in negative direction the output V0 switches and saturates positively.

✓ Drawbacks of Zero- crossing detector:

In some applications, the input Vin may be a slowly changing waveform, (i.e) a low frequency signal. It will take Vin more time to cross 0V, therefore V0 may not switch quickly from one saturation voltage to the other. Because of the noise at the op-amp‘s input terminals the output V0 may fluctuate between 2 saturations voltages +Vsat and –Vsat. Both of these problems can be cured with the use of regenerative or positive feedback that cause the output V0 to change faster and eliminate any false output transitions due to noise signals at the input Inverting comparator with positive feedback. This is known as Schmitt Trigger.