Free Study Material from

All Lab Experiments

Analog Systems & Applications

Chapter - 7, 8

7. OPAMP and Its Applications

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Chapter 7

~~Chapter 6~~

OPAMP and its applications

Operational Amplifiers (Black Box approach): Characteristics of an Ideal and Practical Op-Amp. (IC 741) Open-loop and Closed-loop Gain. Frequency Response. CMRR. Slew Rate and concept of Virtual ground. **(4 Lectures)**

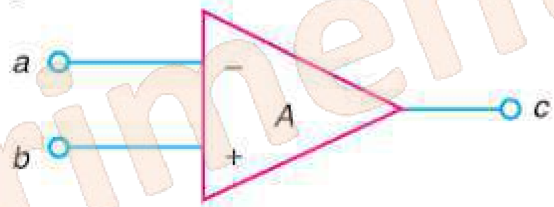
Applications of Op-Amps: (1) Inverting and non-inverting amplifiers, (2) Adder, (3) Subtractor, (4) Differentiator, (5) Integrator, (6) Log amplifier, (7) Comparator and Zero crossing detector (8) Wein bridge oscillator. **(9 Lectures)**

Q: Define OPAMP. draw its symbol.

An operational amplifier is a high gain direct coupled amplifier with high input impedance and low output impedance to which feedback is added to regulate overall response.

Circuit Symbol of an *OPAMP*

Fig. 65.1 shows the circuit symbol of an *OP* AMP.



Terminals *a* and *b* are the input terminals. The terminal *c* is the output terminal. Terminal *a* (marked '−') is called the *inverting input terminal*. The negative sign indicates that a signal applied at the terminal *a* will appear at the terminal *c* with a polarity opposite to that at the terminal *a*. Terminal *b* (marked '+') is the *noninverting input terminal*. This means that the output signal at *c* is always of the same polarity as that of the signal applied at the terminal *b*.

Q:what are the characteristics of OP-AMP.

Ans:

An ideal operational amplifier has the following characteristics.

1. Infinite input impedance *i.e.*, $Z_i = \infty$
2. Zero output impedance $Z_0 = 0$
3. Infinite voltage gain $A = -\infty$

   Even a feeble differential input signal gets amplified to a large extent.

4. Infinite bandwidth $B_w = \infty$

   The voltage gain of the amplifier is constant at all frequencies of the input signals.

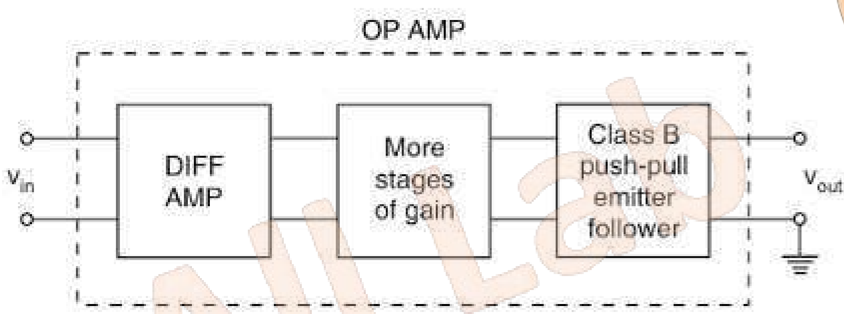
5. Perfect balance $V_0 = 0$ when $V_1 = V_2$.

   Any signal, common to both the inputs, is rejected at the output.

6. Zero drift, *i.e.*, characteristics do not change with temperature.
7. Common mode rejection ratio should tend to ∞.
8. Slew rate should tend to ∞.

Q:Give the block diagram of OPAMP.

Ans:



A typical op-amp is made up of three types of amplifier circuit: a *differential amplifier*, a *voltage amplifier*, and a *push-pull amplifier*.

The input stage is a diff amp, followed by more stages of gain, and a class B push-pull emitter follower.

(*i*) Because a diff amp is the first stage, it determines the input characteristics of the op amp. The differential amplifier can accept two input signals and amplifies the difference between these two input signals.

(*ii*) The voltage amplifier is usually a class A amplifier that provides additional op-amp gain. Some differential amplifier can accept two input signals and amplifies the difference between these two input signals.

(*ii*) The voltage amplifier is usually a class A amplifier that provides additional op-amp gain. Some op-amps may have more than one voltage amplifier stage.

(*iii*) A push-pull class B amplifier is used for the output stage.

Q:Define CMRR.

Ans:

It is defined as the ratio between the differential gain, A_d to the common mode gain, A_c

$$CMRR = \rho = \frac{A_d}{A_c} = \frac{\text{Differential–mode gain}}{\text{Common–mode gain}}.$$

Alternately, *CMR* may be expressed in decibels as

$$CMR = 20 \log CMRR = 20 \log A_d - 20 \log A_c.$$

CMRR is infinity for a differential amplifier.

Q:define Slew rate.

Ans: slew rate is defined as the change of voltage or current, or any other electrical quantity, per unit of time. Expressed in SI units, the unit of measurement is volts/second or amperes/second

$$\mathrm{SR} = \max\left(\left|\frac{dv_{\mathrm{out}}(t)}{dt}\right|\right)$$

where $v_{\mathrm{out}}(t)$ is the output produced by the amplifier as a function of time t.

Q:Draw the circuit diagram of an inverting amplifier and derive the expression for voltage gain.

Ans:

If only one input is applied to the inverting input terminal, then it is called inverting amplifier. Fig 39.11 shows the circuit of an inverting amplifier.

The differential input resistance R_1 is infinite for an ideal *OP-AMP*. But for a practical amplifier it must be much larger than output resistance R_0. So we can assume that $I_0 = I_1$. It means that an extremely negligible amount of current flows in the *OP-AMP*. We may write

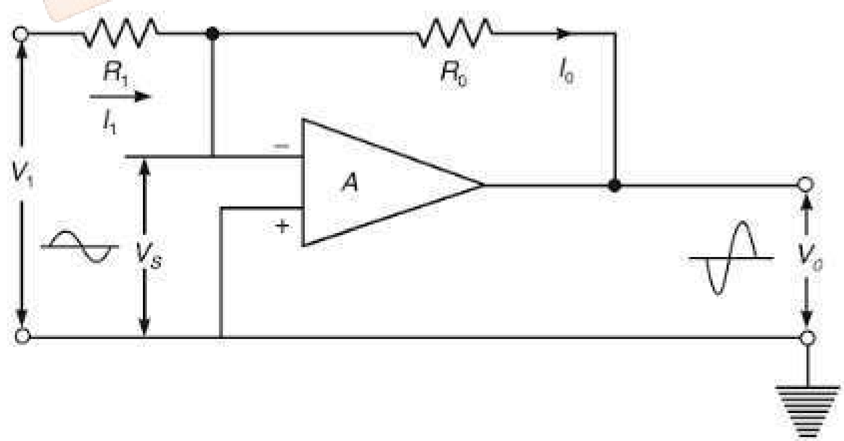
$$I_1 = \frac{V_1 - V_s}{R_1}$$

$$I_0 = \frac{V_s - V_0}{R_0}$$

Neglecting the current entering into the *OP–AMP*, we may write

$$I_1 = I_0$$

$$\frac{V_1 - V_s}{R_1} = \frac{V_s - V_0}{R_0}$$



On rearranging
$$\frac{V_0}{R_0} = -\frac{V_1}{R_1} + \frac{V_s}{R_1} + \frac{V_s}{R_0}$$

Again
$$V_0 = -AV_s \text{ or } V_s = -\frac{V_0}{A}$$

$$\frac{V_0}{R_0} = -\frac{V_1}{R_1} - \frac{V_0}{A}\left(\frac{1}{R_0} + \frac{1}{R_1}\right)$$

Neglecting the second term,

$$\frac{V_0}{R_0} = -\frac{V_1}{R_1}$$

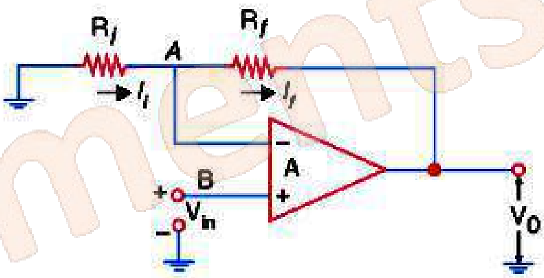
or voltage gain,
$$\frac{V_0}{V_1} = -\frac{R_0}{R_1}$$

Thus the resulting amplification is entirely determined by feedback return *i.e.*, by resistors R_0 and R_1. The negative sign in the voltage gain equation indicates a 180° phase shift.

Q:Draw the circuit diagram of an inverting amplifier and derive the expression for voltage gain.

Ans:

Fig. 65.13 shows the circuit diagram of an ideal op- amp in the non-inverting mode. The input signal is applied to the non- inverting input terminal (+). The feed back is applied to the inverting input terminal (–) through R_f. The resistors R_f and R_i form the feed back voltage divider circuit.



To find the voltage gain

The node B is at potential V_{in}. Hence the potential of point A is the same as that of B which is V_{in}.

Applying KCL,

$$\frac{0 - V_{in}}{R_i} = \frac{V_{in} - V_0}{R_f}$$

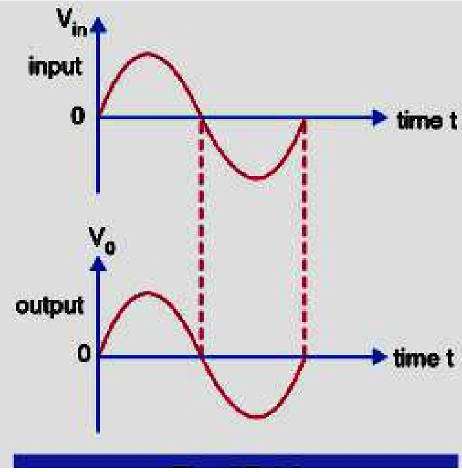
$$\therefore \quad -\frac{V_{in}}{R_f} - \frac{V_{in}}{R_i} = -\frac{V_0}{R_f}$$

$$\therefore \quad V_{in}\left[\frac{1}{R_i} + \frac{1}{R_f}\right] = \frac{V_0}{R_f}$$

$$V_0 = V_{in}\left[\frac{R_f}{R_i} + 1\right]$$

$$\therefore \quad \frac{V_0}{V_{in}} = 1 + \frac{R_f}{R_i}$$

The output voltage is in phase with the input voltage

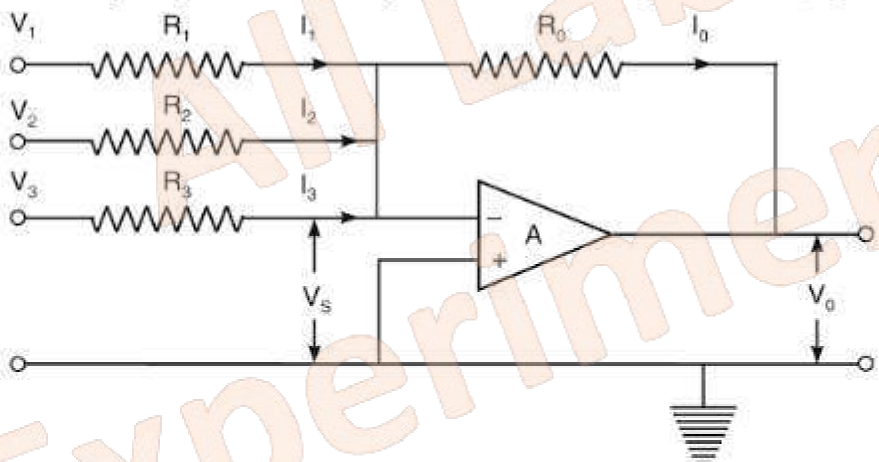


Q:Draw the circuit diagram of Adder using op-amp and derive the expression for output voltage.

Ans:

An adder is a circuit whose output is proportional to the algebraic sum of the input voltages.

Consider an inverting amplifier with 3 inputs at the inverting terminal.



The inverting terminal is virtually grounded by the feedback resistor R_0.

So the sum of the currents through R_1, R_2, R_3 is equal to the current through R_0.

$$I_0 = I_1 + I_2 + I_3 \qquad \text{...(1)}$$

$$\frac{V_s - V_0}{R_0} = \frac{V_1 - V_s}{R_1} + \frac{V_2 - V_s}{R_2} + \frac{V_3 - V_s}{R_3}$$

or
$$-\frac{V_0}{R_0} = \frac{V_1}{R_1} + \frac{V_2}{R_2} + \frac{V_3}{R_3} - V_s\left(\frac{1}{R_0} + \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}\right) \qquad \text{...(2)}$$

We have $V_0 = -AV_s$.

$$-\frac{V_0}{R_0} = \left(\frac{V_1}{R_1}+\frac{V_2}{R_2}+\frac{V_3}{R_3}\right)+\frac{V_0}{A}\left(\frac{1}{R_0}+\frac{1}{R_1}+\frac{1}{R_2}+\frac{1}{R_3}\right) \quad \text{... (3)}$$

Since the value of A is very large, the second term on the R.H.S. is neglected as compared with the first term. Eq. (3) becomes

$$-\frac{V_0}{R_0} = \frac{V_1}{R_1}+\frac{V_2}{R_2}+\frac{V_3}{R_3} \quad \text{...(4)}$$

If $R_0 = R_1 = R_2 = R_3$, we get

$$V_0 = -(V_1+V_2+V_3) \quad \text{...(5)}$$

output voltage = – (sum of the input voltages).

Q:Draw the circuit diagram of Subtractor using op-amp and derive the expression for output voltage.

Ans:

The function of a subtracter is to provide an output proportional to or equal to the difference of two input signals.

We have to apply the inputs at the inverting and non-inverting terminals (Fig. 39.16).

Both inverting and non-inverting operations take place simultaneously.

The output can be derived using the superposition theorem.

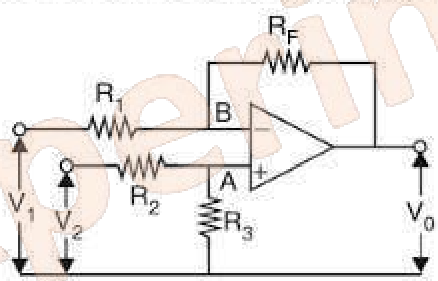


Fig. 39.16

Thus the resultant output,

$$v_0 = v_{01} + v_{02} \quad \text{...(1)}$$

Here, v_{01} and v_{02} are the outputs due to v_1 and v_2 inputs respectively.

Output v_{01} : The output v_{01} due to v_1 alone with the other input earthed is the same as that of inverting circuit.

$$v_{01} = -(R_F/R_1)v_1 \qquad ...(2)$$

Output v_{02} : The output v_{02} due to v_2 alone with the other input earthed is the same as that of non-inverting circuit.

$$v_{02} = (1 + R_F/R_1)v_A$$

Here,

$$v_A = R_3 v_2 /(R_2 + R_3)$$

$$v_{02} = \left(1+\frac{R_F}{R_1}\right)\frac{R_3}{R_2 + R_3}v_2 \qquad ...(3)$$

The resultant

$$v_0 = -\frac{R_F}{R_1}v_1 + \left(1+\frac{R_F}{R_1}\right)\left(\frac{R_3}{R_2 + R_3}\right)v_2 \qquad ...(4)$$

For $R_2 = R_1$ and $R_3 = R_F$, we get

$$v_0 = -\frac{R_F}{R_1}v_1 + \left(1+\frac{R_F}{R_1}\right)\left(\frac{R_F}{R_1 + R_F}\right)v_2$$

$$= (R_F/R_1)(v_2 - v_1) \qquad ...(5)$$

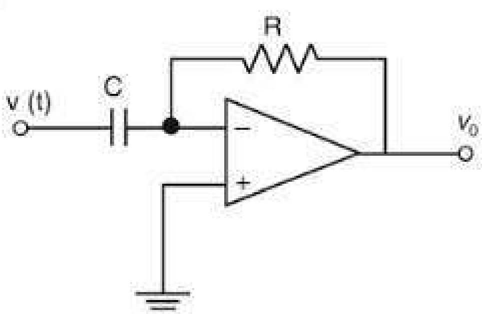
Further, if $R_F = R_1$, then,

$$v_0 = (v_2 - v_1) \qquad ...(6)$$

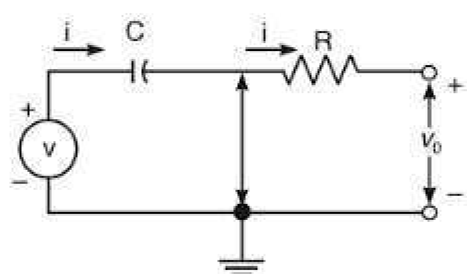
Output voltage = difference of the two input voltages

Q: explain OPAMP as differentiator.

The input signal source of voltage $v(t)$ is connected to the inverting input terminal through a capacitor C. The non-inverting input terminal is earth-connected. Negative feedback is given through a resistance R.



(a)



(b)

Let $v(t)$ be the signal voltage given as the input, which drives varying current through the capacitance C.

We see from the equivalent circuit of Fig. 39.15 (*b*) that

$$i = C\frac{dv(t)}{dt} \quad ...(1)$$

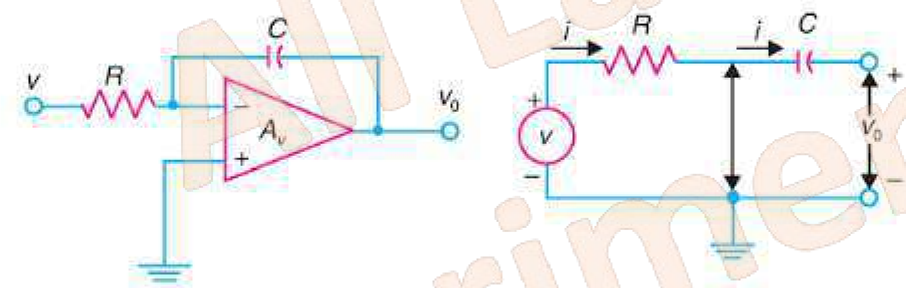
$$v_0 = -Ri = -RC\frac{d}{dt}v(t) \quad ...(2)$$

Hence, the output voltage is proportional to the differential of the input voltage.

Q:explain OPAMP as integrator.

Ans: the circuit shown below produces an output voltage that is proportional to the time integral of input voltage .hence this circuit is known as integrator.

The input signal source of voltage $v(t)$ is connected to the inverting input terminal through resistance R. The negative feedback is given using a capacitor C. The non-inverting terminal is earth-connected



(*a*) Operational integrator. (*b*) Equivalent circuit

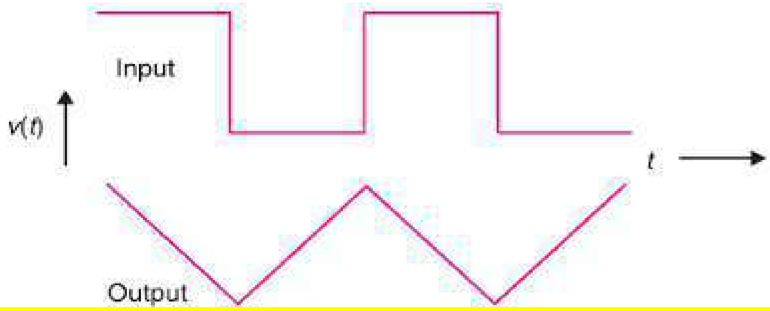
the double-headed arrow represents a virtual ground. Hence $i = v/R$.

$$v_0 = -\frac{1}{C}\int i\,dt = -\frac{1}{RC}\int v\,dt$$

The amplifier therefore provides an output voltage proportional to the integral of the input voltage.

Case I. If the input voltage is a constant, $v = V$, then the output will be a ramp, $V_0 = -Vt/RC$. Such an integrator makes an excellent sweep circuit for a cathode-ray-tube oscilloscope, and is called a *Miller integrator*, or *Miller sweep*.

Case II. If the input voltage is a square wave, then the output will be a triangle wave



Q:Draw the circuit diagram for OPAMP as logarithmic amplifier.

Principle. A logarithmic amplifier has an output voltage which is proportional to the logarithm of the input voltage, *i.e.*,

$$v_0 \propto \log_e v_i.$$

The linear OPAMP can be combined with a nonlinear element such as a diode or transistor to achieve this. The output gets greatly compressed. Therefore the response of a meter across the output will be like that of a decibel meter.

(*i*) Fig. 39.17 shows the circuit of a logarithmic amplifier using a diode.

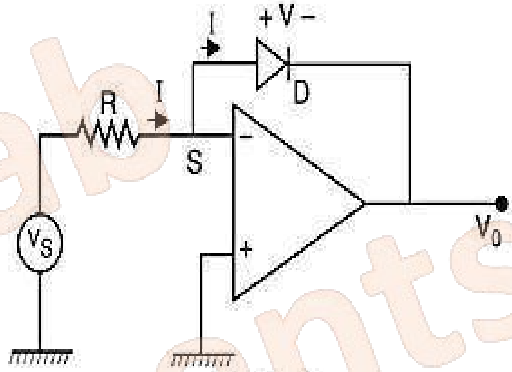
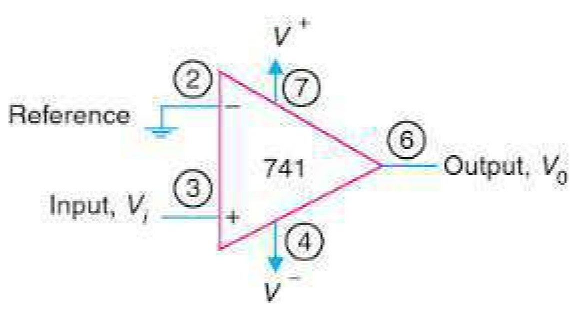


Fig. 39.17

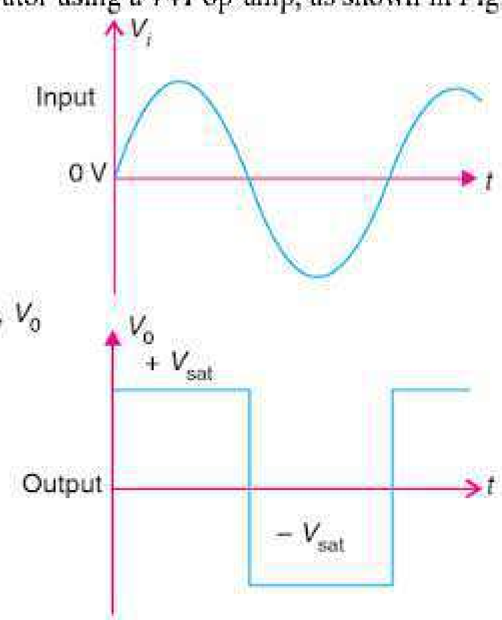
Q:Draw the circuit diagram for OPAMP as comparator.

A comparator is a circuit with two inputs. It is used to compare a voltage in one input with a fixed reference voltage at the other input.

We can examine the operation of a comparator using a 741 op-amp, as shown in Fig. 65.12.

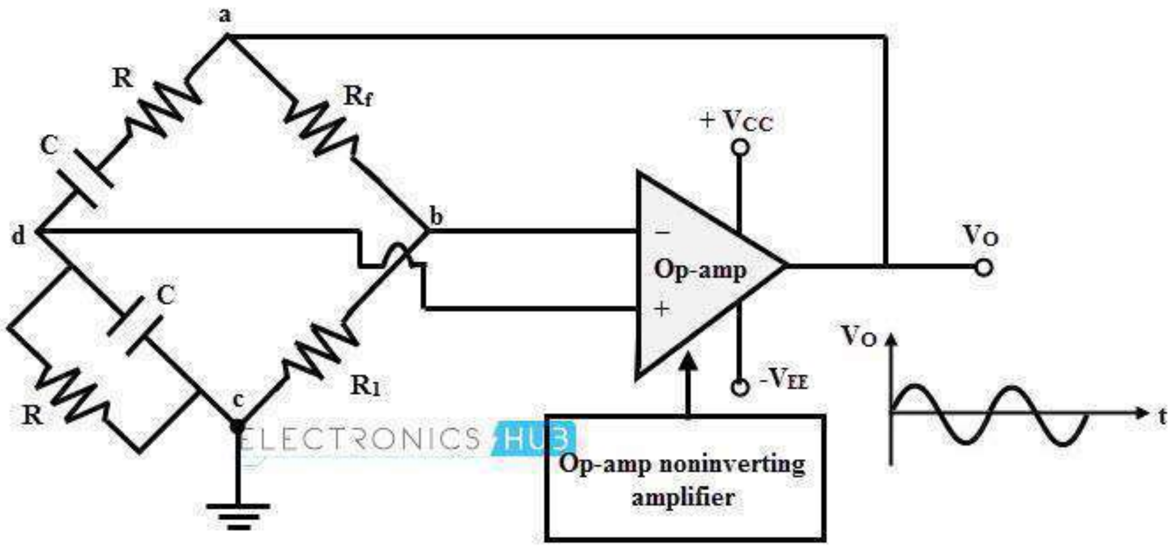


(*a*)



(*b*)

Q:Draw the circuit diagram of Wien's bridge oscillator. And derive the expression for frequency of oscillations.
Ans:A practical circuit oscillator uses opamp and RC bridge circuit,with the oscillator frequency set by the R and C components.



Frequency of Oscillation

Neglecting loading effects of the op-amp input and output impedances, the analysis of the bridge circuit results in

$$\frac{R_3}{R_4} = \frac{R_1}{R_2} + \frac{C_2}{C_1} \qquad ...(1)$$

and

$$f_0 = \frac{1}{2\pi\sqrt{R_1 C_1 R_2 C_2}} \qquad ...(2)$$

If $R_1 = R_2 = R$ and $C_1 = C_2 = C$, the oscillator frequency is

$$f_0 = \frac{1}{2\pi RC} \qquad ...(3)$$

and

$$\frac{R_3}{R_4} = 2 \qquad ...(4)$$

Thus, a ratio of R_3 to R_4 greater than 2 will provide sufficient loop gain for the circuit to oscillate at the frequency calculated using Eq. (3).

Chapter 8

~~Chapter 7~~

conversion

Conversion: D/A Resistive networks (Weighted and R-2R Ladder). Accuracy and Resolution. **(3 Lectures)**

Q: what is digital to analog converter?

Ans:

Digital to analog converter is used to convert digital quantity into analog quantity. DAC converter produces an output current of voltage proportional to digital quantity (binary word) applied to its input. Today microcomputers are widely used for industrial control. The output of the microcomputer is a digital quantity. In many applications the digital output of the microcomputer has to be converted into analog quantity which is used for the control of relay, small motor, actuator e.t.c. In communication system digital transmission is faster and convenient but the digital signals have to be converted back to analog signals at the receiving terminal. DAC converters are also used as a part of the circuitry of several ADC converters.

Q: Derive the expression for voltage in binary weighted resistor DAC.

Ans:

A binary weighted resistor ladder D/A converter is shown in figure 1

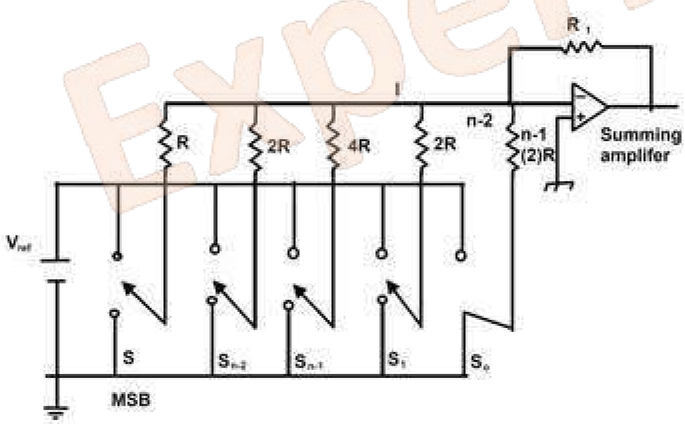


Figure 1: A Binary weighted D/A Converter

Figure 1: Binary Weighted DAC

The behavior of the circuit may be analyzed easily by using "**Millman's theorem**". It state that "***the voltage appearing at any node in a resistive network is equal to the summation of the current entering the node (assuming the node voltage is zero) divided by the summation of the conductance connected to the mode***".

Mathematically we can write

$$V_o = \frac{\frac{V_1}{R} + \frac{V_2}{2R} + \frac{V_3}{4R} + \cdots \frac{V_n}{(2^{n-1})R}}{\left[\frac{1}{R} + \frac{1}{2R} + \frac{1}{4R} + \cdots \frac{1}{(2^{n-1})R}\right]}$$

Assume that the resistor R_1, R_2, R_3 .... R_n are binary weighted resistors, thus

$R_1 = R$

$R_2 = 2R$

$R_3 = 4R$

....

....

....

$R_n = (2^{n-1})\ R$

$$V_o = \frac{\frac{V_1}{R_1} + \frac{V_2}{R_2} + \frac{V_3}{R_3}}{\left[\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}\right]}$$

Q: Define accuracy and resolution of a D/A converter.

Ans: Accuracy can be defined as the amount of uncertainty in a measurement with respect to an absolute standard. Accuracy specifications usually contain the effect of errors due to gain and offset parameters. Offset errors can be given as a unit of measurement such as volts or ohms and are independent of the magnitude of the input signal being measured.

Resolution is the ratio between the maximum signal measured to the smallest part that can be resolved - usually with an analog-to-digital (A/D) converter.
It is the degree to which a change can be theoretically detected, usually expressed as a number of bits. This relates the number of bits of resolution to the actual voltage measurements.