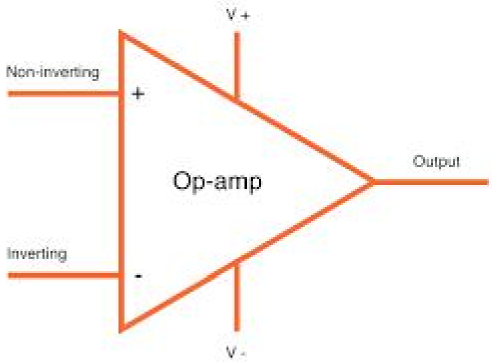
Unit-III
Operational Amplifiers & Its Applications

Introduction

The op amp is one of the basic building blocks of linear design. In its classic form it consists of two input terminals, one of which inverts the phase of the signal, the other preserves the phase, and an output terminal. This ignores the power supply terminals, which are obviously required for operation.



The name “op amp” is the standard abbreviation for operational amplifier.

Voltage Feedback (VFB) Model

The classic model of the voltage feedback op amp incorporates the following characteristics:

1.) Infinite input impedance

2) Infinite bandwidth

3) Infinite gain

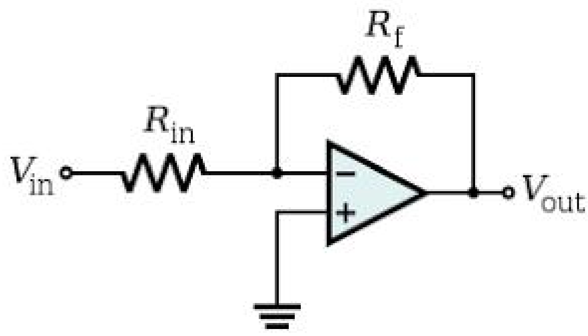
4) Zero output impedance

5) Zero power consumption

Inverting and Non-inverting Configurations:

There are two basic ways to configure the voltage feedback op amp as an amplifier.With this circuit, the output is out of phase with the input. The gain of this circuit is determined by the ratio of the resistors used and is given by:

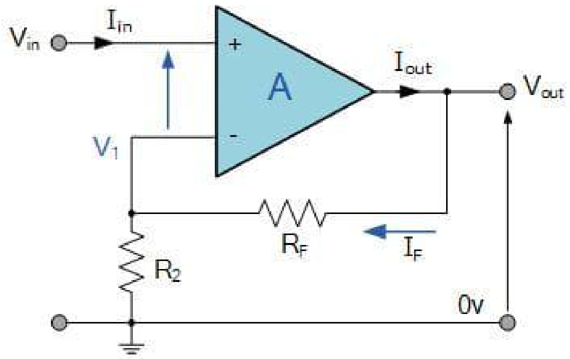
$$A = -\frac{R_f}{R_i}$$



Inverting Op-Amp

Below shows what is know as the non-inverting configuration. With this circuit the output is in phase with the input. The gain of the circuit is also determined by the ratio of the resistors used and is given by:

$$A = 1 + \frac{R_f}{R_i}$$



Non-Inverting Op-Amp

Slew Rate:

The slew rate of an amplifier is the maximum rate of change of voltage at its output. It is expressed in V/s (or, more probably, V/µs). Op amps may have different slew rates during positive- and negative going transitions, due to circuit design, but for this analysis.we shall assume that good fast op amps have reasonably symmetrical slew rates.

If we consider a sine wave with a p-p amplitude of 2 Vp and frequency f, the expression for the output voltage is:

$$v(t) = v_p \sin 2\pi f t$$

This has a maximum slew rate:

$$\frac{dv}{dt} = 2\pi f V_p$$

Differentiator:

The input signal to the differentiator is applied to the capacitor. The capacitor blocks any DC content so there is no current flow to the amplifier summing point, X resulting in zero output voltage. The capacitor only allows AC type input voltage changes to pass through and whose frequency is dependant on the rate of change of the input signal.

At low frequencies the reactance of the capacitor is “High” resulting in a low gain (Rƒ/Xc) and low output voltage from the op-amp. At higher frequencies the reactance of the capacitor is much lower resulting in a higher gain and higher output voltage from the differentiator amplifier.

However, at high frequencies an op-amp differentiator circuit becomes unstable and will start to oscillate. This is due mainly to the first-order effect, which determines the frequency response of the op-amp circuit causing a second-order response which, at high frequencies gives an output voltage far higher than what would be expected. To avoid this the high frequency gain of the circuit needs to be reduced by adding an additional small value capacitor across the feedback resistor Rƒ.

Since the node voltage of the operational amplifier at its inverting input terminal is zero, the current, i flowing through the capacitor will be given as:

$$I_{In} = I_F \ and \ I_F = -\frac{V_{out}}{R_F}$$

The charge on the capacitor equals Capacitance times Voltage across the capacitor

$$Q = C \times V_{In}$$

Thus the rate of change of this charge is:

$$\frac{dQ}{dt} = C\frac{dV_{In}}{dt}$$

but dQ/dt is the capacitor current, *i*

$$I_{In} = I_F = C\frac{dV_{In}}{dt}$$

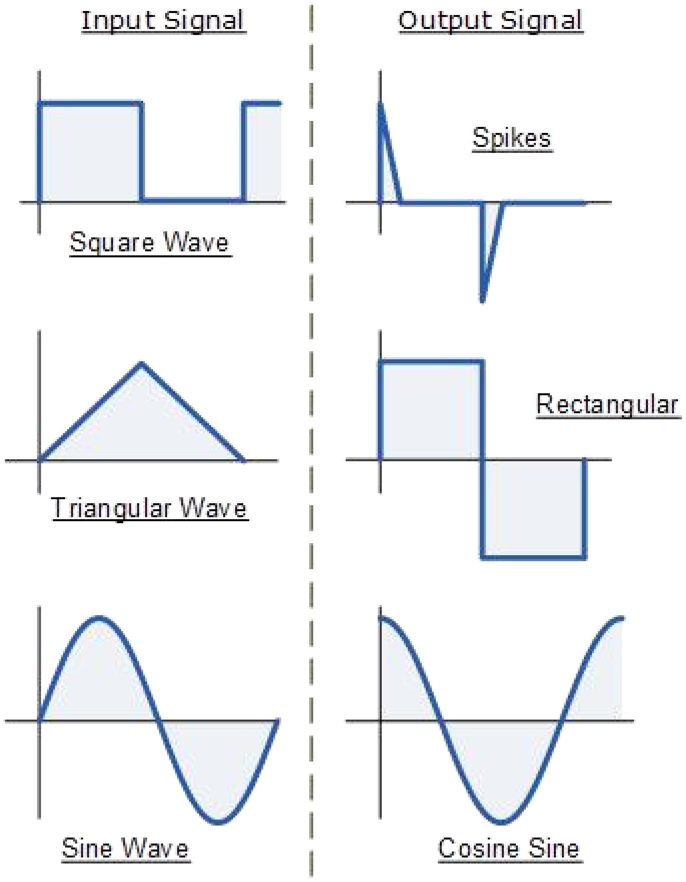
$$-\frac{V_{out}}{R_F} = C\frac{dV_{In}}{dt}$$

from which we have an ideal voltage output for the op-amp differentiator is given as:

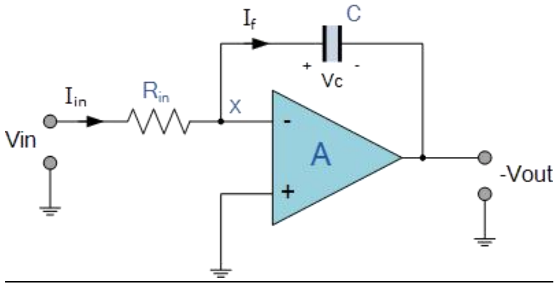
$$-\frac{V_{out}}{R_F} = C\frac{dV_{In}}{dt}$$

Therefore, the output voltage Vout is a constant –Rƒ*C times the derivative of the input voltage Vin with respect to time. The minus sign (–) indicates a 180º phase shift because the input signal is connected to the inverting input terminal of the operational amplifier.

If we apply a constantly changing signal such as a Square-wave, Triangular or Sine-wave type signal to the input of a differentiator amplifier circuit the resultant output signal will be changed and whose final shape is dependant upon the RC time constant of the Resistor/Capacitor combination.



Integrator:



We know from first principals that the voltage on the plates of a capacitor is equal to the charge on the capacitor divided by its capacitance giving Q/C. Then the voltage across the capacitor is output Vout therefore: -Vout = Q/C. If the capacitor is charging and discharging, the rate of charge of voltage across the capacitor is given as:

$$V_c = \frac{Q}{C} \; , V_c = V_x - V_{out} = 0 - V_{out}$$

$$-\frac{dv_{out}}{dt} = \frac{dQ}{Cdt}$$

But dQ/dt is electric current and since the node voltage of the integrating op-amp at its inverting input terminal is zero, X = 0, the input current I(in) flowing through the input resistor, Rin is given as:

$$I_{in} = \frac{V_{in} - 0}{R_{in}} = \frac{V_{in}}{R_{in}}$$

The current flowing through the feedback capacitor C is given as:

$$I_{in} = C\frac{dV_{out}}{dt} = C\frac{dQ}{Cdt} = \frac{dQ}{dt}$$

Assuming that the input impedance of the op-amp is infinite (ideal op-amp), no current flows into the op-amp terminal. Therefore, the nodal equation at the inverting input terminal is given as:

$$I_{in} = I_f = \frac{V_{in}}{R_{in}} = C\frac{dV_{out}}{dt}$$

$$\therefore \frac{V_{in}}{V_{out}} X \frac{dt}{R_{in}C} = 1$$

From which we derive an ideal voltage output for the **Op-amp Integrator** as:

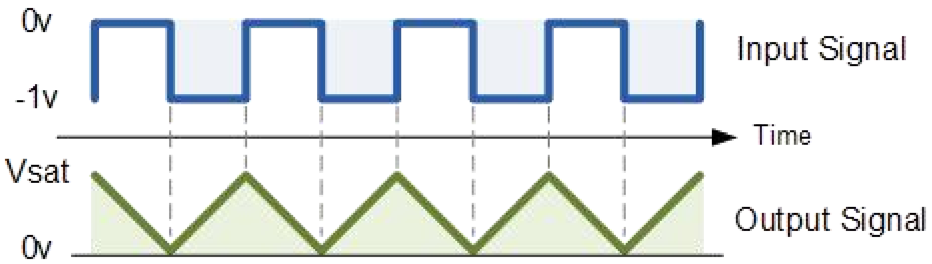
$$V_{out} = -\frac{1}{R_{in}C}\int_0^t V_{in}\, dt$$

To simplify the math’s a little, this can also be re-written as:

$$V_{out} = -\frac{1}{jwRC} V_{in}$$

Where,ω = 2πƒ and the output voltage Vout is a constant 1/RC times the integral of the input voltage V_{IN} with respect to time.

Thus the circuit has the transfer function of an inverting integrator with the gain constant of -1/RC. The minus sign (–) indicates a 180^o phase shift because the input signal is connected directly to the inverting input terminal of the operational amplifier.



Voltage to Current Converter:

Voltage to Current Converter with floating loads (V/I):

Voltage to current converter in which load resistor R_L is floating (not connected to ground). V_{in} is applied to the non- inverting input terminal, and the feedback voltage across R_1 devices the inverting input terminal. This circuit is also called as a current – series negative feedback amplifier. Because the feedback voltage across R_1 (applied Non-inverting terminal) depends on the output current i_0 and is in series with the input difference voltage V_{id}.

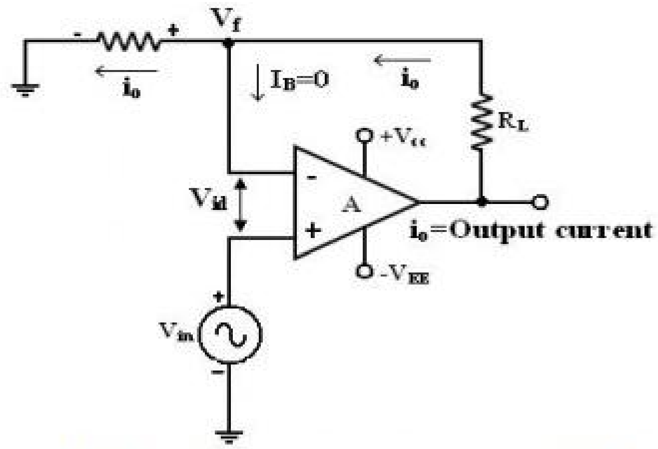


Fig. 2.7 Voltage to Current Converter with floating loads (V/I):

Writing KVL for the input loop,

Voltage V_{id}=V_f and I_B = 0 , vi=$R_L i_0$, where , i_0=v_i/R_L

From the fig input voltage Vin is converted into output current of V_{in}/R_L [V_{in} -> i_0]. In other words, input volt appears across R_1. If R_L is a precision resistor, the output current ($i_0 = V_{in}/R_1$) will be precisely fixed.

Applications:

1. Low voltage ac and dc voltmeters
2. Diode match finders
3. LED and Zener diode testers.

Voltage to current converter with Grounded load:

This is the other type V – I converter, in which one terminal of the load is connected to ground.

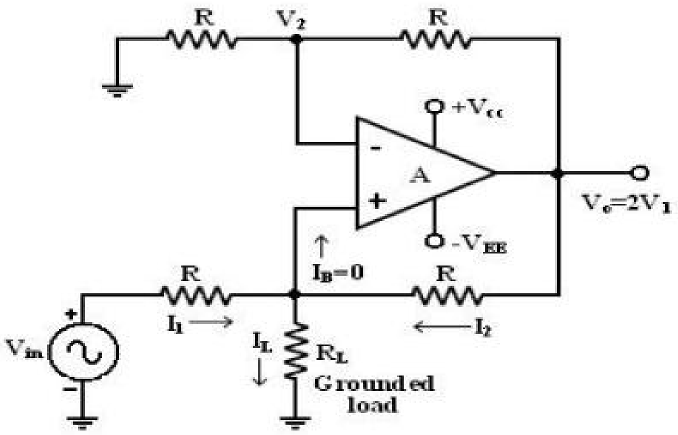


Fig 2.8 V – I converter with grounded load

Analysis of the circuit:

The analysis of the circuit can be done by following 2 steps.

1. To determine the voltage V_1 at the non-inverting (+) terminals and

2. To establish relationship between V_1 and the load current I_L. Applying KCL at node a,

$$R = R_f$$

$$I_1 + I_2 = I_L$$

$$(V_i + V_a)/R + (V_0 - V_a)/R = I_L$$

$$V_o = (V_i + V_o - I_L R)/2 \text{ and gain } = 1 + R/R = 2.$$

$$\therefore V_i = I_L R \; ; \; I_L = V_i/R$$

Current to Voltage Converter (I –V):

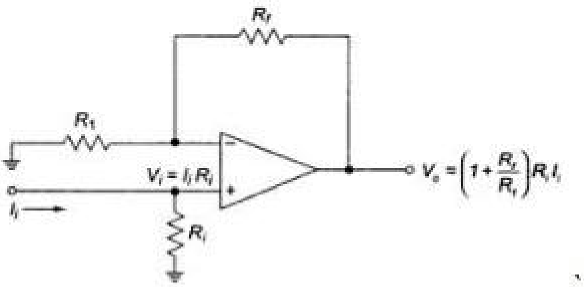


Fig. 2.9 Non inverting current to voltage convertor

Open – loop gain A of the op-amp is very large. Input impedance of the op amp is very high.

Sensitivity of the I – V converter:

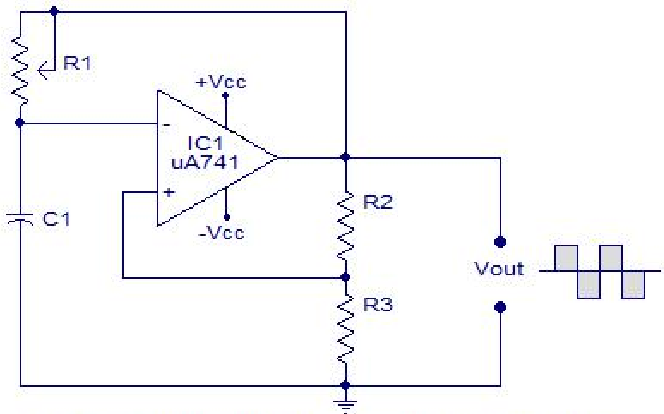
1. The output voltage $V_0 = -R_F$ Iin.

2. Hence the gain of this converter is equal to -RF. The magnitude of the gain (i.e.) is called as sensitivity of I to V converter.

3. The amount of change in output volt ΔV0 for a given change in the input current ΔIin is decide by the sensitivity of I-V converter.

4.By keeping RF variable, it is possible to vary the sensitivity as per the requirements.

Square Wave Generator:



Square wave generator using uA741 www.circuitstoday.com

Initially the voltage across the capacitor C1 will be zero and the output of the opamp will be high. As a result the capacitor C1 starts charging to positive voltage through potentiometer R1. When the C1 is charged to a level so that the voltage at the inverting terminal of the opamp is above the voltage at the non-inverting terminal, the output of the opamp swings to negative. The capacitor quickly discharges through R1 and then starts charging to negative voltage. When the C1 is charged to a negative voltage so that the voltage at the inverting input more negative than that of the non-inverting pin, the output of the opamp swings back to positive voltage. Now the capacitor quickly discharges the negative voltage through R1 and starts charging to positive voltage. This cycle is repeated endlessly and the result will a continuous square wave swinging between +Vcc and -Vcc at the output.

The time period of the output of the uA741 square wave generator can be expressed using the following equation:

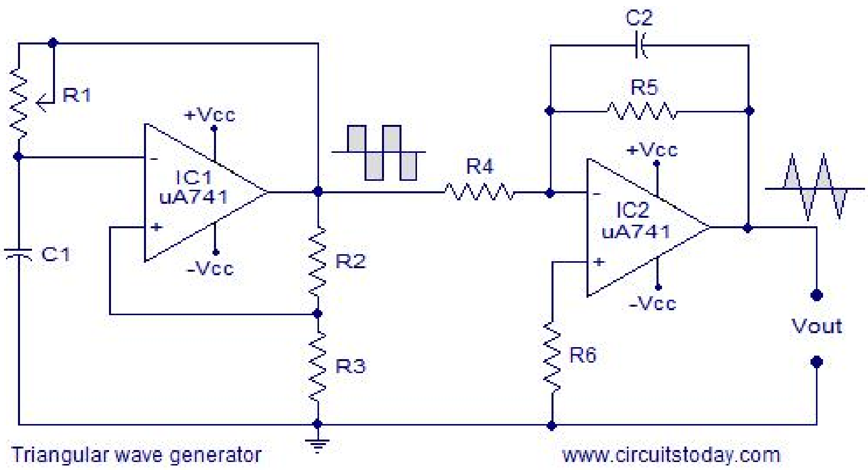
$$T = 2 \text{ x } 2.303\ R_1C_1\log_{10}\left(\frac{2R_3+R_2}{R_2}\right) \text{ second}$$

The common practice is to make the R3 equal to R2. Then the equation for the time period can be simplified as:

T=2.1976R1C1

The frequency can be determined by the equation: **F=1/T**

Triangular Wave Generator:



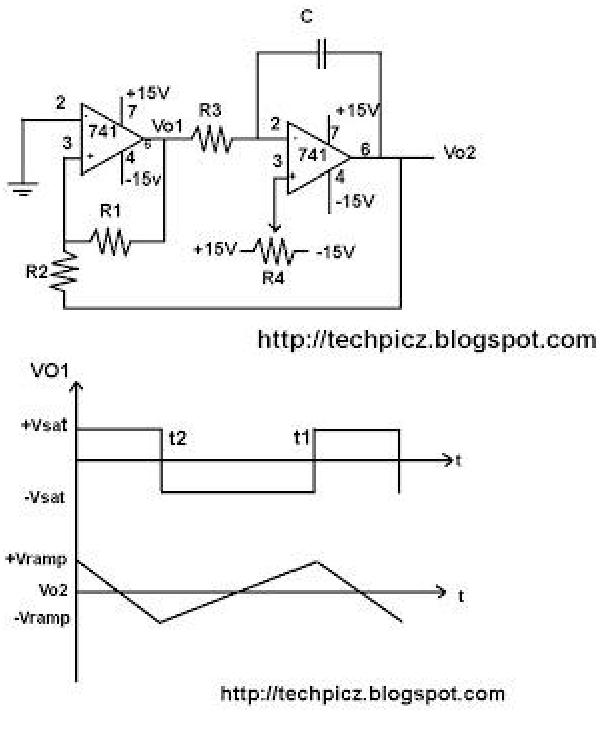
The square wave generator is based on a uA741 opamp (IC1). Resistor R1 and capacitor C1 determines the frequency of the square wave. Resistor R2 and R3 forms a voltage divider setup which feedbacks a fixed fraction of the output to the non-inverting input of the IC.

Initially, when power is not applied the voltage across the capacitor C1 is 0. When the power supply is switched ON, the C1 starts charging through the resistor R1 and the output of the opamp will be high (+Vcc). A fraction of this high voltage is fed back to the non- inverting pin by the resistor network R2, R3. When the voltage across the charging capacitor is increased to a point the voltage at the inverting pin is higher than the non-inverting pin, the output of the opamp swings to negative saturation (-Vcc). The capacitor quickly discharges through R1 and starts charging in the negative direction again through R1. Now a fraction of the negative high output (-Vcc) is fed back to the non-inverting pin by the feedback network R2, R3. When the voltage across the capacitor has become so negative that the voltage at the inverting pin is less than the voltage at the non-inverting pin, the output of the opamp swings back to the positive saturation. Now the capacitor discharges trough R1 and starts charging in positive direction. This cycle is repeated over time and the result is a square wave swinging between +Vcc and -Vcc at the output of the opamp.

If the values of R2 and R3 are made equal, then the frequency of the square wave can be expressed using the following equation:

F=1 / (2.1976 R1C1)

<u>Sawtooth Wave Generator:</u>



Here am going to explain sawtooth waveform generator using op-amp. sawtooth waveform can be also generated by an

asymmetrical astable multivibrator followed by an integrator The Sawtooth wave generators have wide application in time-base generators and pulse width modulation circuits.
The difference between the triangular wave and sawtooth waveform is that the rise time of triangular wave is always equal to its fall of time while in saw tooth generator, rise time may be much higher than its fall of tim , vise versa . The triangular wave generator can be converted in to a sawtooth wave generator by injecting a variable dc voltage into the non inverting terminal of the integrator.
In this circuit a potentiometer is used (47K) . Use of the potentiometer is when the wiper moves towards -V ,the rise tim of the sawtooth become longer than the fall time. If the wiper moves towards +V , the fall time becomes more than the rise time.
Reason is when comparator output is at -ve saturation. When wiper moves to -ve supply, a negative voltage is added to inverting terminal. This causes the potential difference across R1 decreases and hence the current through the resistor and capacitor decreases . Then slope of the output, I/C decreases and un tern rise time decreases. When the comparator output goes positive , due to presence of negative voltage at the inverting terminal, potential difference of across the resistor R1 increases and hence current increases. Then slope increases and fall time decreases. And obtained output as sawtooth wave.