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Unit 1:-

Operational amplifiers :-  (op-amp).

An operational amplifier is a direct-coupled high-gain amplifier.

1. The operational amplifier is a versatile device that can be used to amplify dc as well as ac input.
2. The op-amp was originally designed for performing mathematical operations such as addition, subtraction multiplication and integration. Thus the name operational amplifier stems from its orignal use for these mathematical operation.

Symbol for the op-amp.

⇒ (+) input is the noninverting input. Any signal (AC or DC) applied to this input produces an inphase (or same polarity) signal at the output.

⇒ (−) input is the inveting input because any signal (AC or DC) applied to this input produces an 180° out of phase (opposite polarity) signal at the output.

V_1 = Voltage at the Non inverting input (Volts)
V_2 = Voltage at the inverting input (Volts)
V_0 = output voltage (Volts)

All the voltages are measured with respect to ground.

A = large-signal voltage gain.

Spiral

Integrated Circuits (IC)

IC – Integrated circuits, meaning that all the components in the circuit are fabricated on the same "chip".

Classification of IC's according to their mode of operation. IC's are of two basic types: Digital or linear.

(1) Digital ICs are complete functioning logic networks that are equivalents of basic transistor logic circuits. They are used to form such circuits as gates, counters, multiplexers, demultiplexers, shift registers and others. Digital circuits are primarily concerned with only two levels of voltage "high" and "low"

(2) Linear ICs are equivalents to discrete transistor networks, such as amplifiers, frequency multipliers, and modulators. That often require additional external components for satisfactory operation. Example, external resistors are necessary to control the voltage gain and frequency response of an op-amp.

Classification based on the number of components integrated on the same chip

Small-Scale integration	SSI	< 10 Components
Medium-Scale integration	MSI	< 100 Components.
Large-Scale integration	LSI	> 100 Components.
Very large-Scale integration.	VLSI	> 1000 Components

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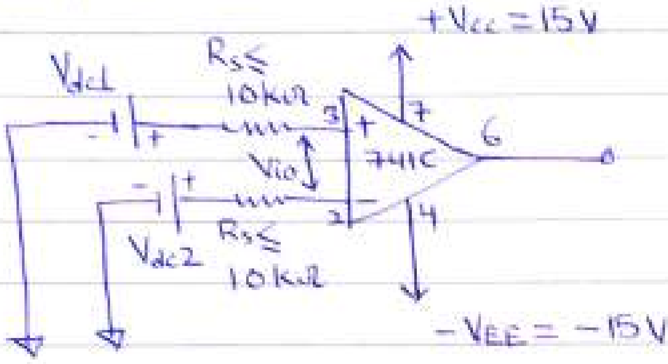
Few Electrical parameter of 741 (op-amp)

(*) Input offset Voltage :- Input offset voltage is the voltage that must be applied between two input terminals of an op-amp to null the output



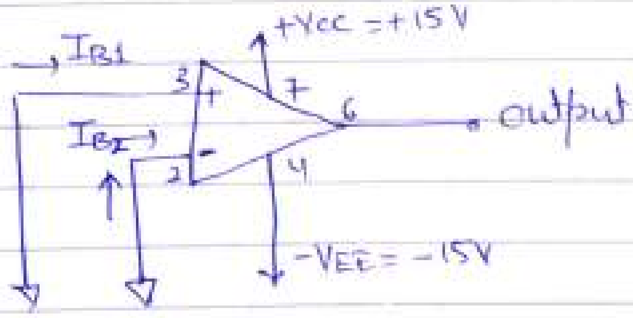
741 C → temperature range.

$$V_{io} = (V_{dc1} - V_{dc2})$$

Maximum V_{io} is 6mV dc for 741 C. Smaller the value of V_{io} the better the input terminals are matched.

(*) Input Bias Current :- Input bias current, I_B is the average of the currents that flow into the inverting and non-inverting input terminals of the op-amp.

$$I_B = \frac{I_{B1} + I_{B2}}{2}$$



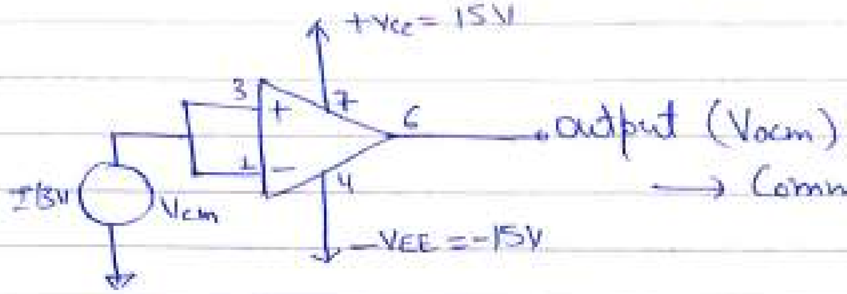
Maximum $I_B = 500\,nA$ for 741C

(*) $I_{io} = |I_{B1} - I_{B2}|$ → Input offset Current

Maximum $I_{io} = 200\,nA$ for 741C.

Spiral

Common-Mode Rejection Ratio (CMRR):-



→ Common-Mode Configr.

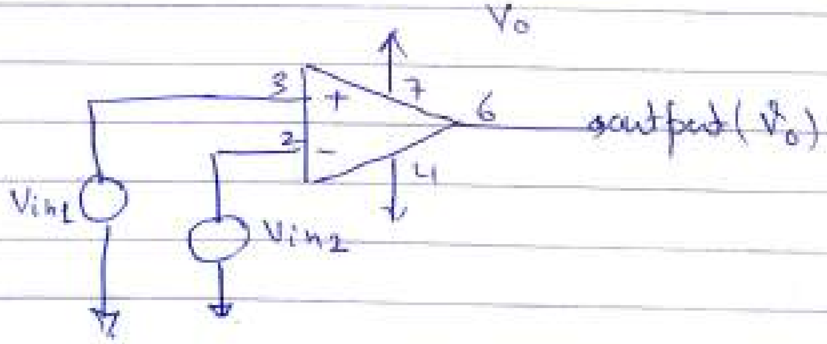
CMRR is defied as ratio of the differential voltage gain A_d to the common-mode voltage gain A_{cm}

$$CMRR = \frac{A_d}{A_{cm}} \qquad A_d = A$$

$$A_{cm} = \frac{V_{ocm}}{V_{cm}}$$

Where V_{ocm} = output common-mode voltage
V_{cm} = Input common-mode voltage
A_{cm} = common-mode voltage gain.

$$A_d = A = \frac{(V_{in1} - V_{in2})}{V_o} =$$ ~~$\frac{V_{ino}}{V_o}$~~



Where ~~V_{in1}~~ → V_{in1} → Input non-inverting voltage
V_{in2} → Input inverting voltage
V_o → output voltage.
A_d → Differential voltage gain.

Spiral

Generally the A_{cm} is very small and A_d is very large ∴ CMRR is very large.
CMRR is most often expressed in decibels (dB)
CMRR = 90 dB for 741C.

(*) Slew Rate :- slew rate (SR) is defined as the maximum rate of change of output voltage per unit of time and is expressed in volts per microseconds.

$$SR = \left.\frac{dV_o}{dt}\right|_{max.} \quad V/\mu s.$$

Slew rate indicates how rapidly the output of an op-amp change in response to change in the ~~i/p~~ input frequency.

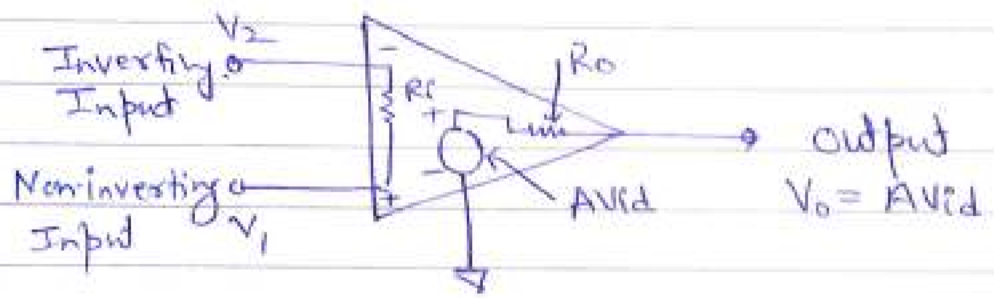
Slew rate = 0.5V/μs for 741C (drawbacks)

Characteristics of an ideal op-amp.

1. Infinite voltage gain A.
2. Infinite input resistance Ri so that almost any signal source can drive it and there is no loading of the preceding stage.
3. Zero output resistance Ro so that the output can drive an infinite number of other devices.
4. Zero output voltage when input voltage is zero.
5. Infinite bandwidth so that any frequency signal from 0 to ∞ Hz can be amplified without attenuation

6. Infinite common-mode rejection ration so that the output common-mode noise voltage is zero.
7. Infinite slew rate so that output voltage occurs simultaneously with input voltage changes.

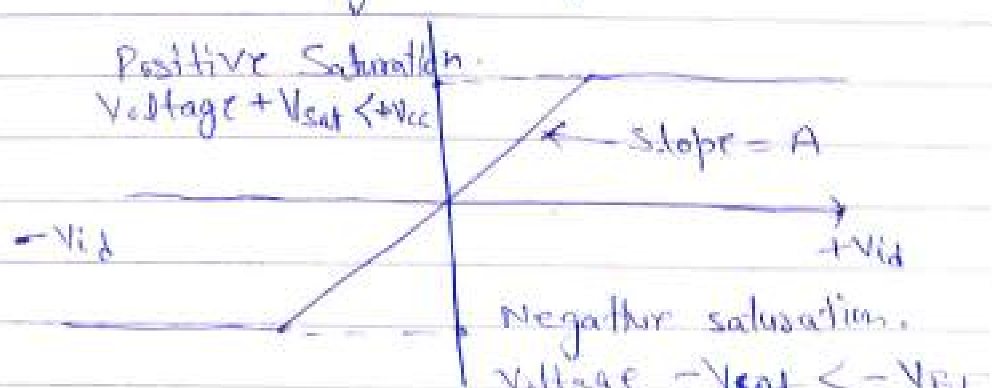
Equivalent Circuit of an Op-amp.



$$V_o = AV_{id} = A(V_1 - V_2)$$

A = large-signal voltage gain
V_{id} = difference input voltage
V_1 = Voltage at the noninverting input terminal w.r.t g
V_2 = Voltage at the inverting input terminal w.r.t ground

Ideal Voltage transfer curve.



Reference:- Op-amp and linear integrated circuits:- Ramakant A. Gayakwad Spiral

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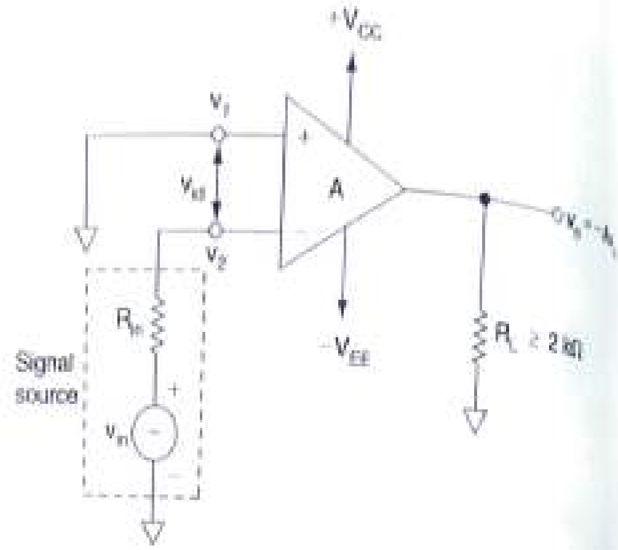

FIGURE 2-10 Inverting amplifier.

2-6-2 The Inverting Amplifier

In the inverting amplifier only one input is applied and that is to the inverting input terminal. The non inverting input terminal is grounded (refer to Figure 2-10). Since $v_1 = 0\ V$, and $v_2 = v_{in}$ from Equation (2-9),

$$v_0 = -Av_{in}$$

The negative sign indicates that the output voltage is out of phase with respect to input by 180° or is of opposite polarity. Thus in the inverting amplifier the input signal is amplified by gain A and is also inverted at the output.

2-6-3 The Noninverting Amplifier

Figure 2-11 shows the open-loop noninverting amplifier. In this configuration the input is applied to the noninverting input terminal, and the inverting terminal is connected to ground.

In the circuit of Figure 2-11, $v_1 = v_{in}$ and $v_2 = 0\ V$. Therefore, according to Equation (2-9),

$$v_0 = -Av_{in}$$

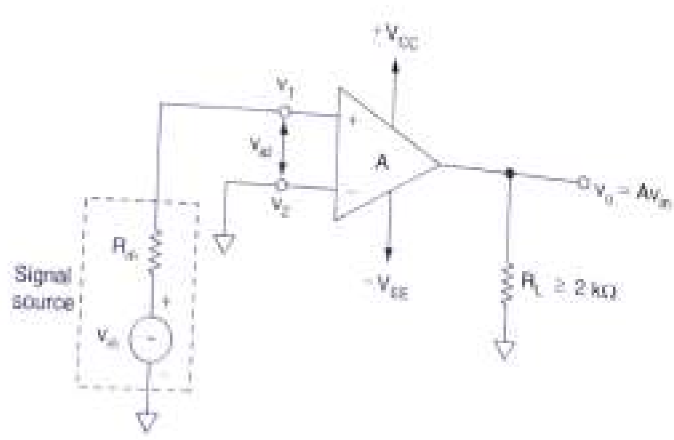

FIGURE 2-11 Non inverting amplifier

This means that the output voltage is larger than the input voltage by gain A and is in phase with the input signal.

In all three open-loop configurations any input signal (differential or single) that is only slightly greater than zero drives the output to saturation level. This results from the very high gain (A) of the op-amp. Thus, when operated open-loop, the output of the op-amp is either negative or positive saturation or switches between positive and negative saturation levels. For this reason, open-loop op-amp configurations are not used in linear applications.

EXAMPLE 2-1

Determine the output voltage in each of the following cases for the open-loop differential amplifier of Figure 2-9:

a. $v_{in1} = 5\ \mu V$ dc, $v_{in2} = -7\ \mu V$ dc
b. $v_{in1} = 10$ mV rms, $v_{in2} = -20$ mV rms

The op-amp is a 741 with the following specifications: $A = 200{,}000$, $R_i = 2\ M\Omega$, $R_o = 75\Omega$, $+V_{CC} = +15\ V$, $-V_{EE} = -15$ V, and output voltage swing $= \pm 14$ V.

SOLUTION

a. By Equation (2-9),

$$v_o = 200{,}000[(5)(10^{-6}) - (-7)(10^{-6})] = 2.4 \text{ V dc}$$

Remember that $v_o = 2.4$ V dc with the assumption that the dc output voltage is zero when the input signals are zero.

b. Equation (2-9) is valid for both ac and dc input signals. However, the re-striction on ac input signals is that they must be of the same frequency (see Figure 2-12). By Equation (2-9),

$$v_o = 200{,}000[(10)(10^{-3}) - (20)(10^{-3})] = -2000 \text{ V rms}$$

Thus the theoretical value of output voltage $v_o = -2000$ V rms. However, the op-amp saturates at ±14 V. Therefore, the actual output waveform will be *clipped* as shown in Figure 2-12. This nonsinusoidal waveform is unacceptable in amplifier applications. The normal solution to this problem is to use a negative feed-back, which is discussed in Chapter 3.

EXAMPLE 2-2

Determine the output voltage for the inverting amplifier shown in Figure 2-10, if

a. $v_{in} = 20$ mV dc
b. $v_{in} = -50\ \mu V$ peak sine wave

Assume that the op-amp is a 741.

Reference:- Op-amp and linear integrated circuits:- Ramakant A. Gayakwad

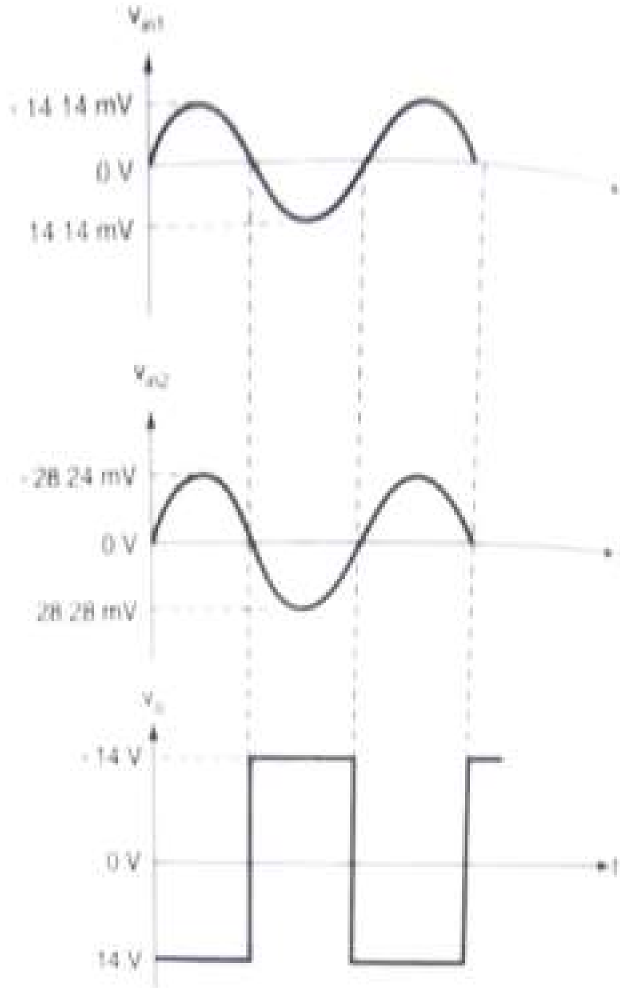

FIGURE 2-12 Waveforms for Example 2-1

SOLUTION

By Equation (2-9),

a. $v_o = -Av_{id} = -(2)(10^5)(20)(10^{-3}) = -4000$ V

This is the theoretical value; the actual value will be a negative saturation voltage of −14 V.

b. $v_o = -Av_{id} = -(2)(10^5)(-50)(10^{-6}) = 10$ V peak sine wave

This means that the output is a sine wave, since it is less than the output voltage swing of ±14 V or 28 V peak to peak.