Introduction to Operational Amplifier

Operational Amplifier (op-amp)

The operational amplifier is a versatile device that can be used to amplify dc as well as ac input signals and was originally designed for computing such mathematical functions as addition, subtraction, multiplication, and integration. Thus the name operational amplifier stems from its original use for these mathematical operations and is abbreviated to "op-amp."

With the addition of suitable external feedback components, the modern day op-amp can be used for a variety of applications, such as ac and dc signal amplification, active filters, oscillators, comparators, regulators, and others.

Block diagram of a typical Op-amp

Since an op-amp is a multistage amplifier, it can be represented by a block diagram as shown in Figure 1.

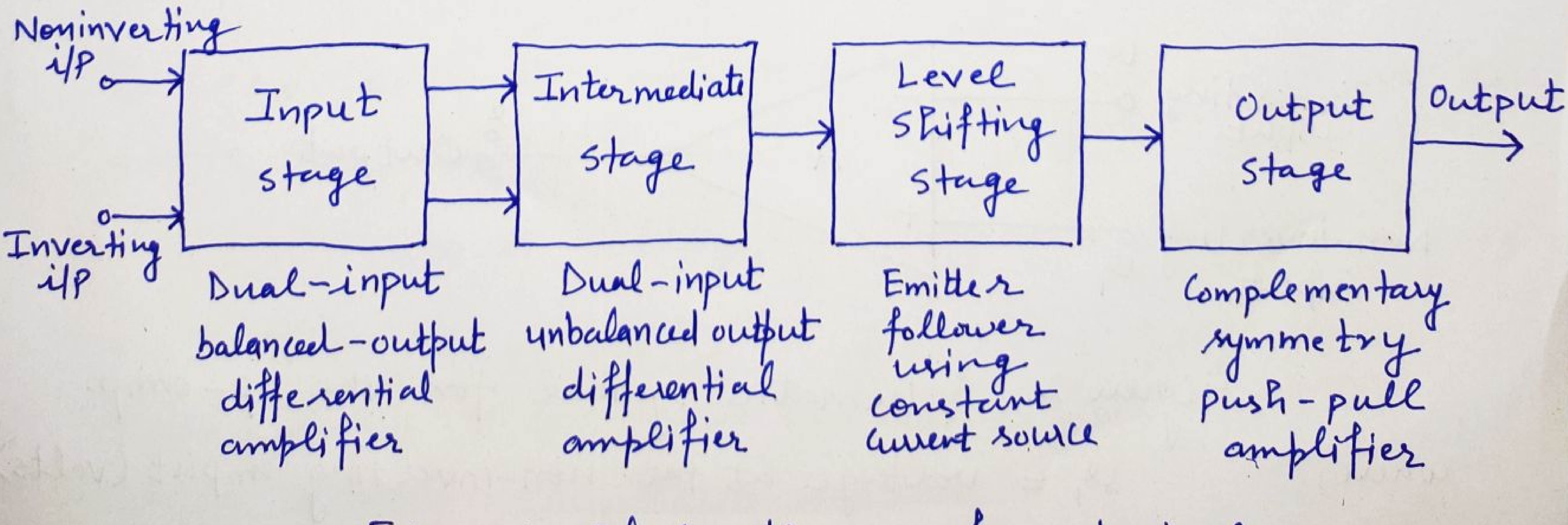

Figure 1. Block diagram of a typical op-amp.

The input stage is the dual-input, balanced-output differential amplifier which provides most of the voltage gain of the amplifier and also establishes the input resistance of the op-amp. In most amplifiers, the intermediate stage is dual input, unbalanced (single ended) output differential amplifier. Because direct coupling is used, the dc voltage at the output of the intermediate stage is well above ground potential.

Therefore, generally, the level shifting circuit is used after the intermediate stage to shift the dc level at the output of the intermediate stage downward to zero volts with respect to ground.

The output stage is usually a push-pull complementary amplifier output stage which increases the output voltage swing and raises the current supplying capability of the op-amp. A well designed output stage also provides low output resistance.

Schematic Symbol

Figure 2 shows the most widely used schematic symbol for an op-amp with two inputs and one output.

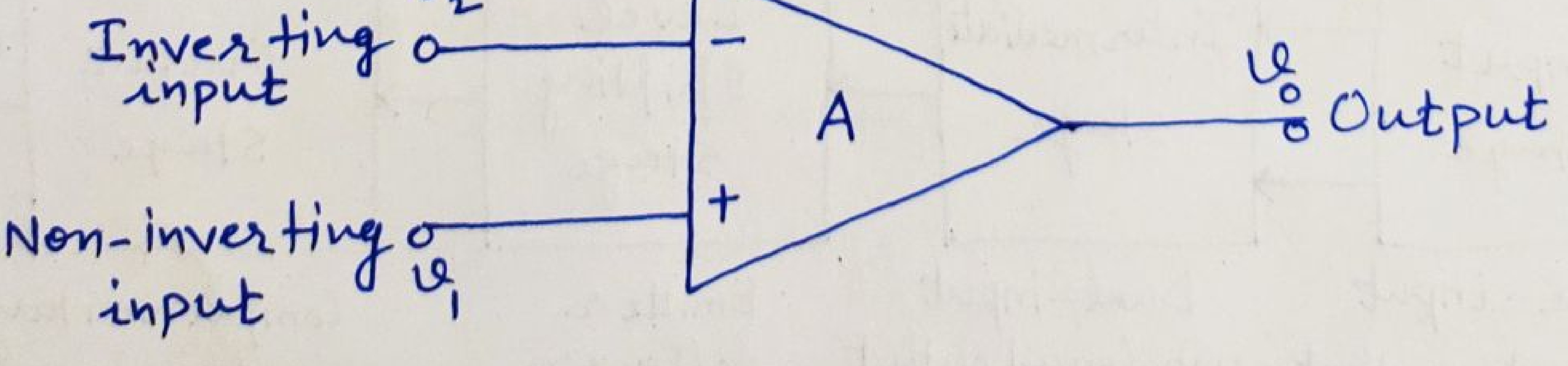

Figure 2. Schematic symbol for the op-amp.

where, v_1 = voltage at the non-inverting input (volts)

v_2 = voltage at the inverting input (volts)

v_o = output voltage (volts)

All these voltages are measured with respect to ground.

A = large-signal voltage gain, which is specified on the data sheet for an op-amp.

Note: The differential inputs are designated by the (+) and (−) notations. The (+) input is the non-inverting input. An ac signal (or dc voltage) applied to this input produces an inphase signal at the output. On the other hand, the (−) input is the inverting input because an ac signal (or dc voltage) applied to this input produces an 180° out of phase signal at the output.

The Ideal OP-AMP

An ideal op-amp would exhibit the following electrical characteristics:

1. Infinite voltage gain A.
2. Infinite input resistance R_i so that almost any signal source can drive it and there is no loading of the preceding stage.
3. Zero output resistance R_o so that 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 ratio so that the output common-mode noise voltage is zero.

Note: The common-mode rejection ratio (CMRR) is defined as the ratio of the differential voltage gain A_d to the common-mode voltage gain A_{cm}; that is,

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

The differential voltage gain A_d is the same as the large-signal voltage gain A and the common-mode voltage gain can be determined using the equation

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

where V_{ocm} = output common-mode voltage

V_{cm} = input common-mode voltage

A_{cm} = common-mode voltage gain

Generally, the A_{cm} is very small and $A_d = A$ is very large; therefore the CMRR is very large.

7. Infinite slew rate so that output voltage changes occur simultaneously with input voltage changes.

Note: 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. In equation form,

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

Slew rate indicates how rapidly the output of an op-amp can change in response to change in the input frequency.

There are practical op-amps that can be made to approximate some of these above mentioned characteristics using a negative feedback arrangement. In particular, the input resistance, output resistance, and bandwidth can be brought close to ideal values by this method.

Equivalent Circuit of an op-amp

Figure 3. shows an equivalent circuit of an op-amp. Av_{id} is an equivalent Thevenin voltage source, and R_o is the Thevenin equivalent resistance looking back into the output terminal of an op-amp.

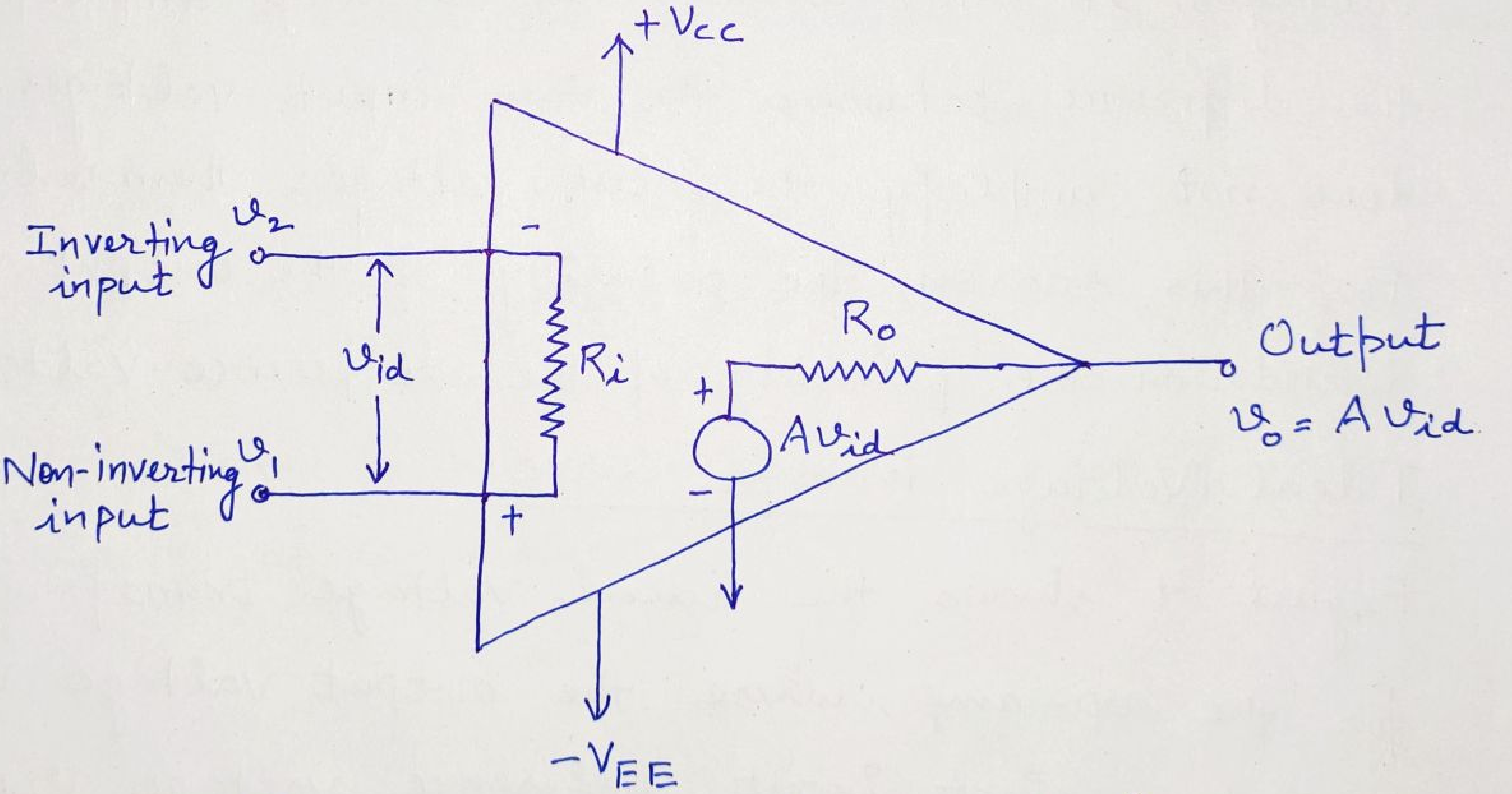

Figure 3. Equivalent circuit of an op-amp.

The equivalent circuit is useful in analyzing the basic operating principles of op-amps and in observing the effects of feedback arrangements.

For the circuit shown in Figure 3, the output voltage is

$$v_o = A v_{id} = A(v_1 - v_2)$$

where A = large-signal voltage gain

v_{id} = difference input voltage

v_1 = voltage at the noninverting input terminal with respect to ground

v_2 = voltage at the inverting terminal with respect to ground.

The above equation for output voltage indicates that the output voltage v_o is directly proportional to the algebraic difference between the two input voltages. In other words, the op-amp amplifies the difference between the two input voltages. It does not amplify the input voltages themselves. For this reason, the polarity of the output voltage depends on the polarity of the difference voltage.

Ideal Voltage Transfer Curve

Figure 4 shows the ideal voltage transfer curve for the op-amp, where the output voltage v_o is plotted against input difference voltage v_{id}, keeping gain A constant.

Note that the output voltage cannot exceed the positive and negative saturation voltages. These saturation voltages are specified by an output voltage swing rating of the op-amp for given values of supply voltages.

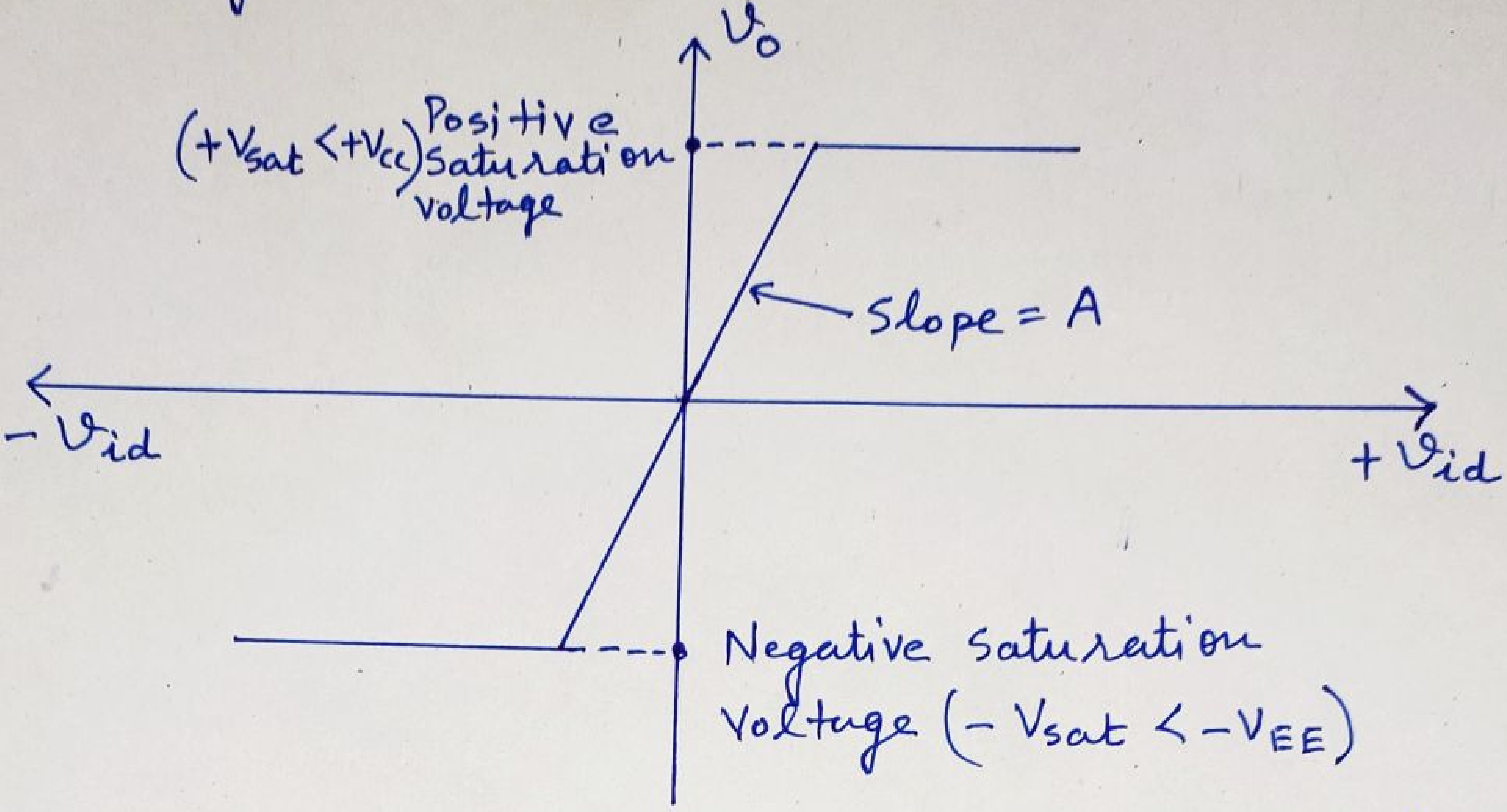

Figure 4. Ideal voltage transfer curve.

This means that the output voltage is directly proportional to the input difference voltage only until it reaches the saturation voltages and that thereafter output voltage remains constant.

The curve shown in Figure 4 is called an ideal voltage transfer curve, ideal because output offset voltage is assumed to be zero. In normal op-amp, this voltage is near zero and is ignored for simplicity of calculation.