1   Operational Amplifier

An operational amplifier(op-amp) is a voltage controlled voltage source with high gain. The equivalent circuit model of an op-amp is shown on Figure 1. The voltage V_i is the differential input voltage $V_i = V_p - V_n$. R_i is the input resistance of the device and R_o is the output resistance. The gain parameter A is called the open loop gain.
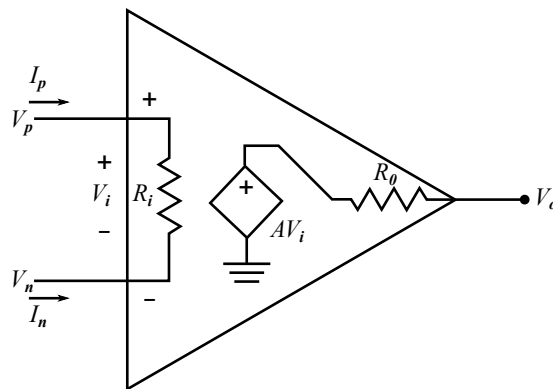

FIGURE 1 – **Equivalent circuit model of op-amp device**

If there is no load at the output, the output voltage is

$$V_o = AV_i = A(V_p - V_n) \tag{1.1}$$

From the equation above, output voltage V_o is a function of the difference between the input voltage V_p and V_n. For this reason, the op-amps are also called **difference amplifiers**.

The figure that reflects relation between the output voltage and the input voltage is called the voltage transfer curve and is fundamental in designing and understanding amplifier circuits. The voltage transfer curve of the op-amp is shown on Figure 2.
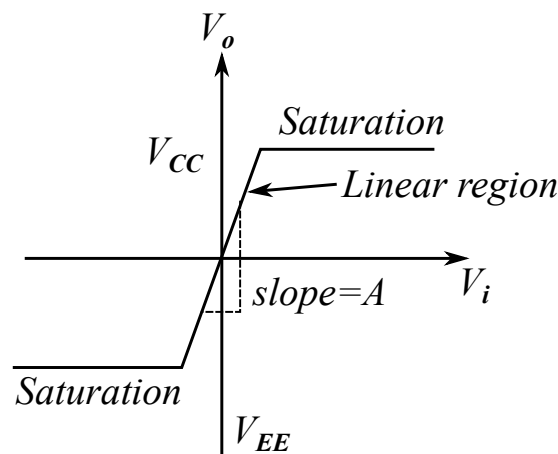

FIGURE 2 – **Op-amp voltage transfer characteristics**

1.1 The ideal op-amp model

Practically speaking, an ideal op-amp is a device which acts as an ideal voltage controlled voltage source. Referring to Figure 3, this implies that the device will have the following characteristics :

* No current flows into the input terminals of the device. This is equivalent to having an infinite input resistance $R_i = \infty$. In practical terms this implies that the amplifier device will make no power demands on the input signal source.
* Have a zero output resistance($R_o = 0$). This implies that the output voltage is independent of the load connected to the output.

In addition the ideal op-amp model will have infinite open loop gain($A \to \infty$). The ideal op-amp model can be shown schematically on Figure 3.
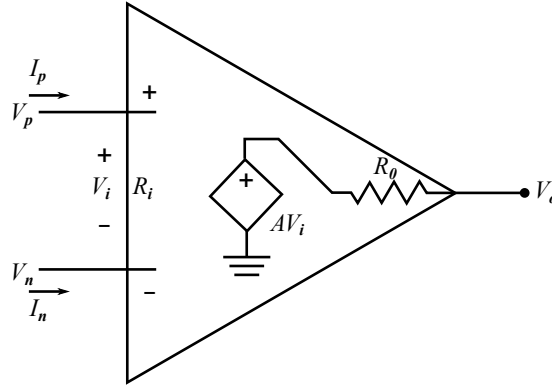

FIGURE 3 – **Op-amp voltage transfer characteristics**

In summary, the ideal op-amp conditions are :

* $I_p = I_n = 0$ **No current into the input terminals**
* $I_p = I_n = 0$ **No current into the input terminals**
* $R_i = \infty$ **Infinite input resistance**
* $R_0 = 0$ **Zero output resistance**

Even though real op-amps deviate from these ideal conditions, the ideal op-amp rules are very useful and are used extensively in circuit design and analysis.

1.2 Ideal op-amp in a negative feedback configuration

When an op-amp is arranged with a negative feedback the ideal rules are :

* $I_p = I_n = 0$ **input current constraint**
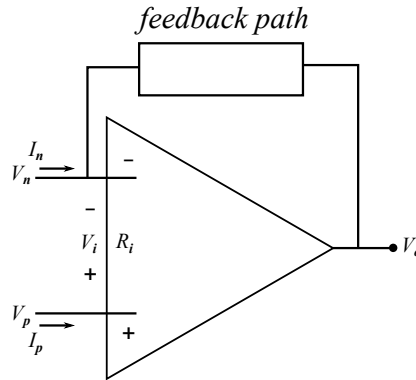* $V_n = V_p$ **input voltage constraint**

FIGURE 4 – **Op-amp voltage transfer characteristics**

1.3   Computational Devices

So far we have explored the use of op amps to multiply a signal by a constant. For the inverting amplifier the multiplication constant is the gain $-\frac{R_2}{R_1}$ and for the non inverting amplifier the multiplication constant is the gain $1+\frac{R_2}{R_1}$. Op amps may also perform other mathematical operations ranging from addition and subtraction to integration, differentiation and exponentiation. We will next explore these fundamental "operational" circuits.

1.3.1   Summing Amplifier

A basic summing amplifier circuit with three input signals is shown in Figure 5.