Open – loop op-amp Configuration:

The term open- loop indicates that no feedback in any form is fed to the input from the output. When connected in open – loop, the op-amp functions as a very high gain amplifier. There are three open – loop configurations of op-amp namely,

1. differential amplifier
2. Inverting amplifier
3. Non-inverting amplifier

The above classification is made based on the number of inputs used and the terminal to which the input is applied. The op-amp amplifies both ac and dc input signals. Thus, the input signals can be either ac or dc voltage.

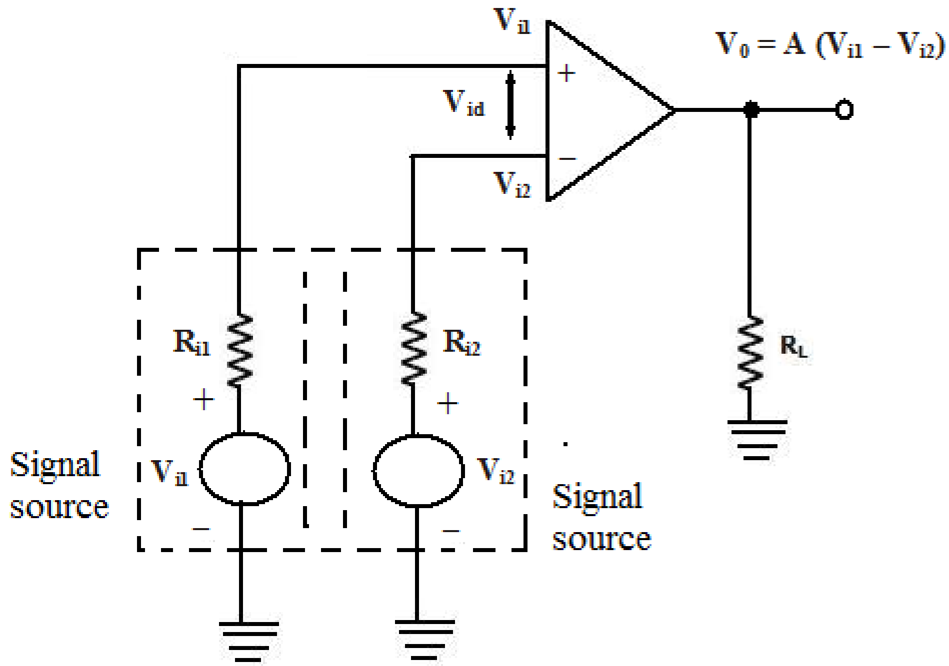
Open – loop Differential Amplifier:

In this configuration, the inputs are applied to both the inverting and the non- inverting input terminals of the op-amp and it amplifies the difference between the two input voltages. Figure shows the open- loop differential amplifier configuration.

The input voltages are represented by V_{i1} and V_{i2}. The source resistance R_{i1} and R_{i2} are negligibly small in comparison with the very high input resistance offered by the op-amp, and thus the voltage drop across these source resistances is assumed to be zero. The output voltage V_0 is given by

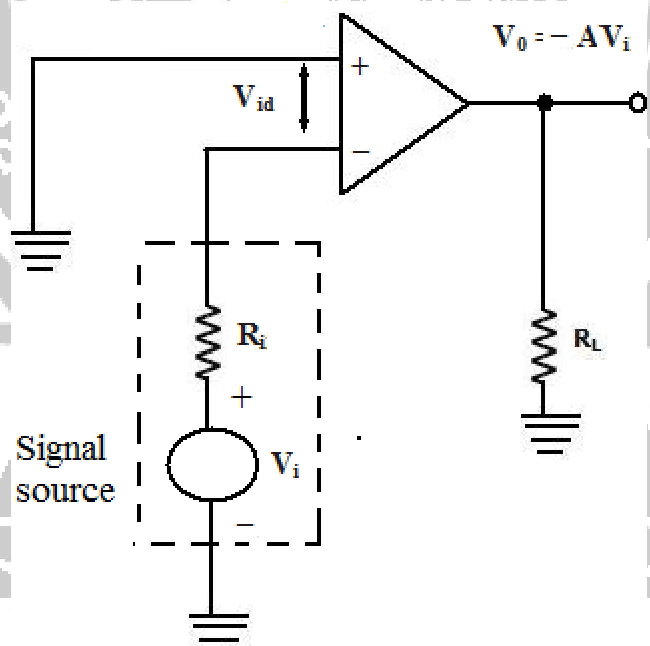
$$V_0 = A(V_{i1} – V_{i2})$$

where A is the large signal voltage gain. Thus the output voltage is equal to the voltage gain A times the difference between the two input voltages. This is the reason why this configuration is called a differential amplifier. In open – loop configurations, the large signal voltage gain A is also called open- loop gain A.



Open - loop Differential Amplifier

Inverting amplifier:



Open - loop Inverting Amplifier

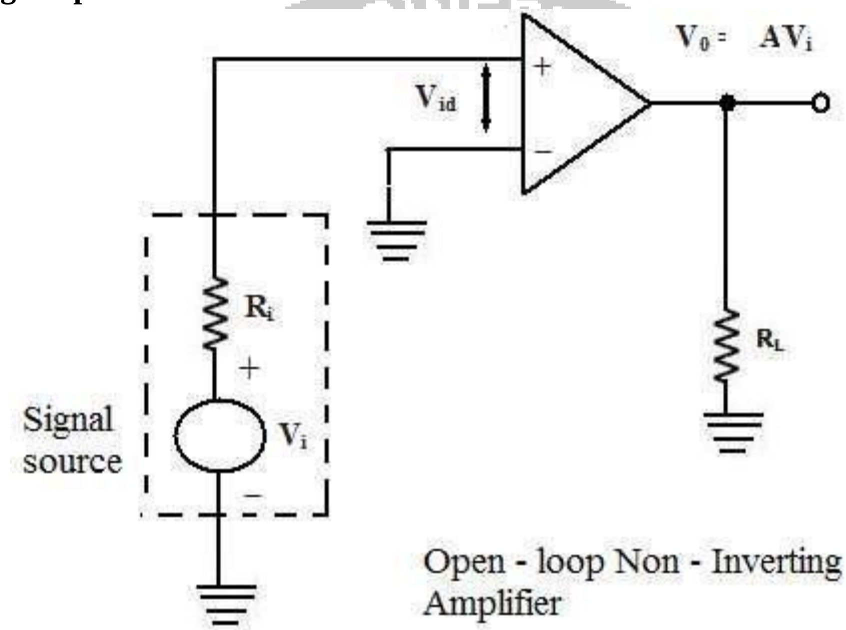
In this configuration the input signal is applied to the inverting input terminal of the op-amp and the non-inverting input terminal is connected to the ground. Figure shows the circuit of an open – loop inverting amplifier.

The output voltage is 180^0 out of phase with respect to the input and hence, the output voltage V_0 is given by,

$V_0 = -AV_i$

Thus, in an inverting amplifier, the input signal is amplified by the open- loop gain A and in phase – shifted by 180^0.

Non-inverting Amplifier:



Open - loop Non - Inverting Amplifier

Figure shows the open – loop non- inverting amplifier. The input signal is applied to the non- inverting input terminal of the op-amp and the inverting input terminal is connected to the ground.

The input signal is amplified by the open – loop gain A and the output is in-phase with input signal.

$V_0 = AV_i$

In all the above open- loop configurations, only very small values of input voltages can be applied. Even for voltages levels slightly greater than zero, the output is driven into saturation, which is observed from the ideal transfer characteristics of op-amp shown in figure. Thus, when operated in the open- loop configuration, the output of the op-amp is either in negative or positive saturation, or switches between positive and negative saturation levels. This prevents the use of open – loop configuration of op-amps in linear applications.

Limitations of Open – loop Op – amp configuration:

Firstly, in the open – loop configurations, clipping of the output waveform can occur when the output voltage exceeds the saturation level of op-amp. This is due to the very high open – loop gain of the op-amp. This feature actually makes it possible to a mplify very low frequency signal of the order of microvolt or even less, and the amplification can be achieved accurately without any distortion. However, signals of such magnitudes are susceptible to noise and the amplification for those application is almost impossible to obtain in the laboratory.

Secondly, the open – loop gain of the op – amp is not a constant and it varies with changing temperature and variations in power supply. Also, the bandwidth of most of the open- loop op amps is negligibly small. This makes the open – loop configuration of op-amp unsuitable for ac applications. The open – loop bandwidth of the widely used 741 IC is approximately 5Hz. But in almost all ac applications, the bandwidth requirement is much larger than this.

For the reason stated, the open – loop op-amp is generally not used in linear applications. However, the open – loop op amp configurations find use in certain non – linear applications such as comparators, square wave generators and astable multivibrators.

Closed – loop op-amp configuration:

The op-amp can be effectively utilized in linear applications by providing a feedback from the output to the input, either directly or through another network. If the signal feedback is out- of-phase by 180^0 with respect to the input, then the feedback is referred to as negative feedback or degenerative feedback. Conversely, if the feedback signal is in phase with that at the input, then the feedback is referred to as positive feedback or regenerative feedback.

An op – amp that uses feedback is called a closed – loop amplifier. The most commonly used closed – loop amplifier configurations are 1. Inverting amplifier (Voltage shunt amplifier) 2. Non-Inverting amplifier (Voltage – series Amplifier)

Inverting Amplifier:

The inverting amplifier is shown in figure and its alternate circuit arrangement is shown in figure, with the circuit redrawn in a different way to illustrate how the voltage shunt feedback is achieved. The input signal drives the inverting input of the op – amp through resistor R_1 .

The op – amp has an open – loop gain of A, so that the output signal is much larger than the error voltage. Because of the phase inversion, the output signal is 180^0 out – of – phase with the input signal. This means that the feedback signal opposes the input signal and the feedback is negative or degenerative.

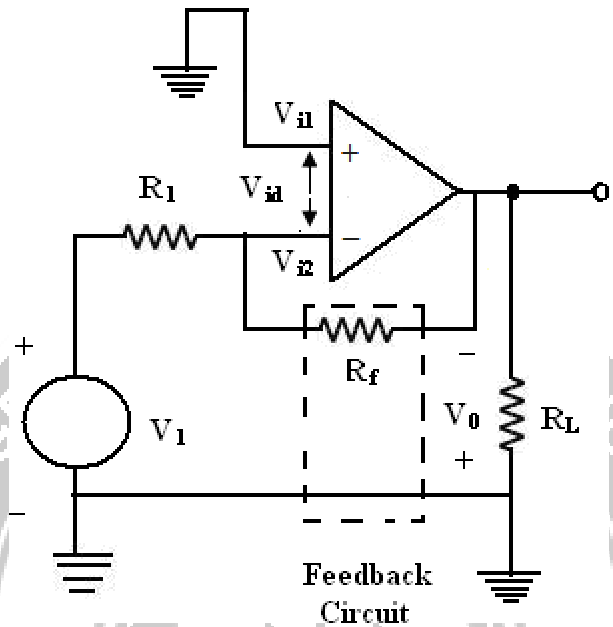
Virtual Ground:

A virtual ground is a ground which acts like a ground . It may not have physical connection to ground. This property of an ideal op – amp indicates that the inverting and non – inverting terminals of the op –amp are at the same potential. The non – inverting input is grounded for the inverting amplifier circuit. This means that the inverting input of the op –amp is also at ground potential. Therefore, a virtual ground is a point that is at the fixed ground potential (0V), though it is not practically connected to the actual ground or common terminal of the circuit.

The open – loop gain of an op – amp is extremely high, typically 200,000 for a 741. For ex, when the output voltage is 10V, the input differential voltage V_{id} is given by

Further more, the open – loop input impedance of a 741 is around 2MΩ. Therefore, for an input differential voltage of 0.05mV, the input current is only

Since the input current is so small compared to all other signal currents, it can be approximated as zero. For any input voltage applied at the inverting input, the input differential voltage V_{id} is negligibly small and the input current is ideally zero. Hence, the inverting input acts as a virtual ground. The term virtual ground signifies a point whose voltage with respect to ground is zero, and yet no current can



The expression for the closed – loop voltage gain of an inverting amplifier can be obtained from figure. Since the inverting input is at virtual ground, the input impedance is the resistance between the inverting input terminal and the ground. That is, $Z_i = R_1$. Therefore, all of the input voltage appears across R_1 and it sets up a current through R_1 that equals . The current must flowthrough R_f because the virtual ground accepts negligible current. The left end of R_f is ideally grounded, and hence the output voltageappears wholly across it. Therefore,

The input impedance can be set by selecting the input resistor R_1 . Moreover, the above equation shows that the gain of the inverting amplifier is set by selecting a ratio of feedback resistor R_f to the input resistor R_1 . The ratio R_f /R_1 can be set to any value less than or greater than unity. This feature of the gain equation makes the inverting amplifier with feedback very popular and it lends this configuration to a majority of applications.

Practical Considerations:

1. Setting the input impedance R_1 to be too high will pose problems for the bias current, and it is usually restricted to 10KΩ.
2. The gain cannot be set very high due to the upper limit set by the fain – bandwidth (GBW = A_v * f) product. The A_v is normally below 100.
3. The peak output of the op – amp is limited by the power supply voltages, and it is about 2V less than supply, beyond which, the op – amp enters into saturation.
4. The output current may not be short – circuit limited, and heavy loads may damage the op – amp. When short – circuit protection is provided, a heavy load may drastically distort the output voltage.

Practical Inverting amplifier:

The practical inverting amplifier has finite value of input resistance and input current, its open voltage gain A_0 is less than infinity and its output resistance R_0 is not zero, as against the ideal inverting amplifier with finite input resistance, infinite open – loop voltage gain and zero output resistance respectively.

Figure shows the low frequency equivalent circuit model of a practical inverting amplifier. This circuit can be simplified using the Thevenin's equivalent circuit shown in figure. The signal source Vi and the resistors R_1 and R_i are replaced by their Thevenin's equivalent values. The closed – loop gain A_V and the input impedance R_{if} are calculated as follows.

The input impedance of the op- amp is normally much larger than the input resistance $R_{1.}$ Therefore, we can assume $V_{eq} \approx V_i$ and $R_{eq} \approx R_1$. From the figure we get,

$$V_0 = IR_0 + AV_{id}$$

$$\text{and } V_{id} + IR_f + V_0 = 0$$

Substituting the value of V_{id} from above eqn , we get,

$$V_0(1+A) = I(R_0 - AR_f)$$

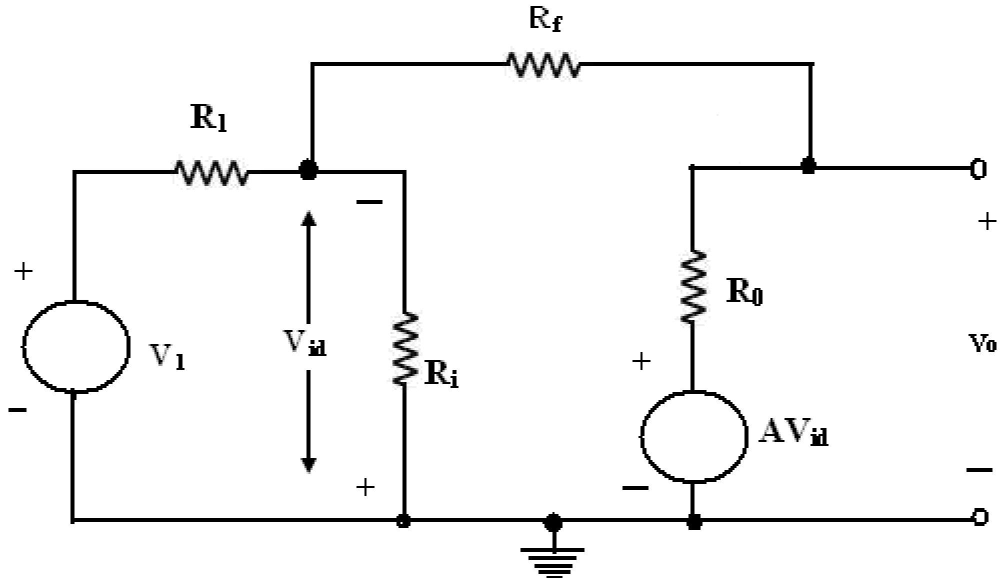
Also using the KVL , we get

$$V_i = I(R_1 + R_f) + V_0$$

Substituting the value of I derived from above eqn and obtaining the closed loop gain A_v, we get

It can be observed from above eqn that when A>> 1, R_0 is negligibly small and the product AR_1 >> $R_0 + R_f$, the closed loop gain is given by

Which is as the same form as given in above eqn for an ideal inverter.



Equivalent Circuit of a Practical Inerting Amplifier

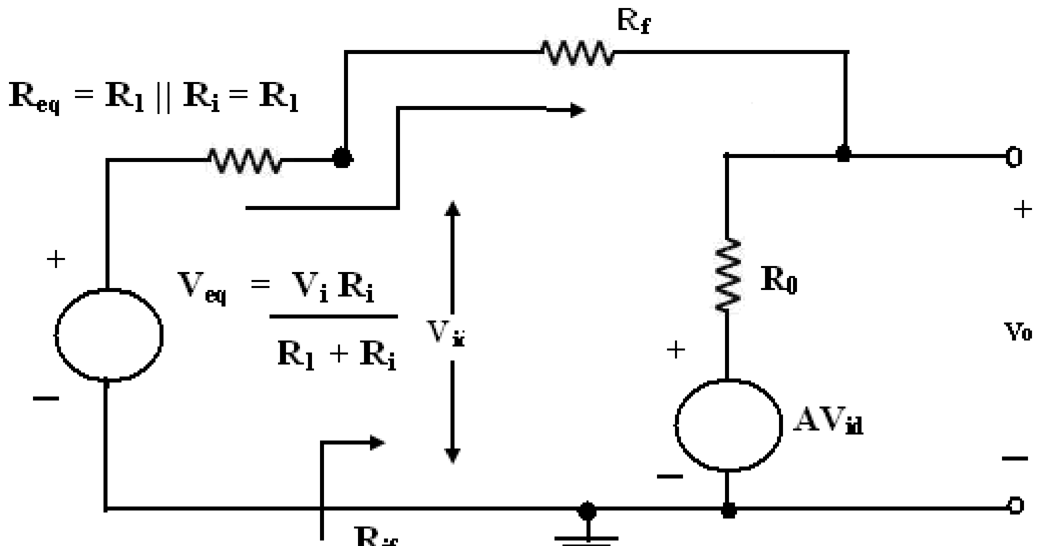
Input Resistance:

From figure we get,

Using KVL, weget,

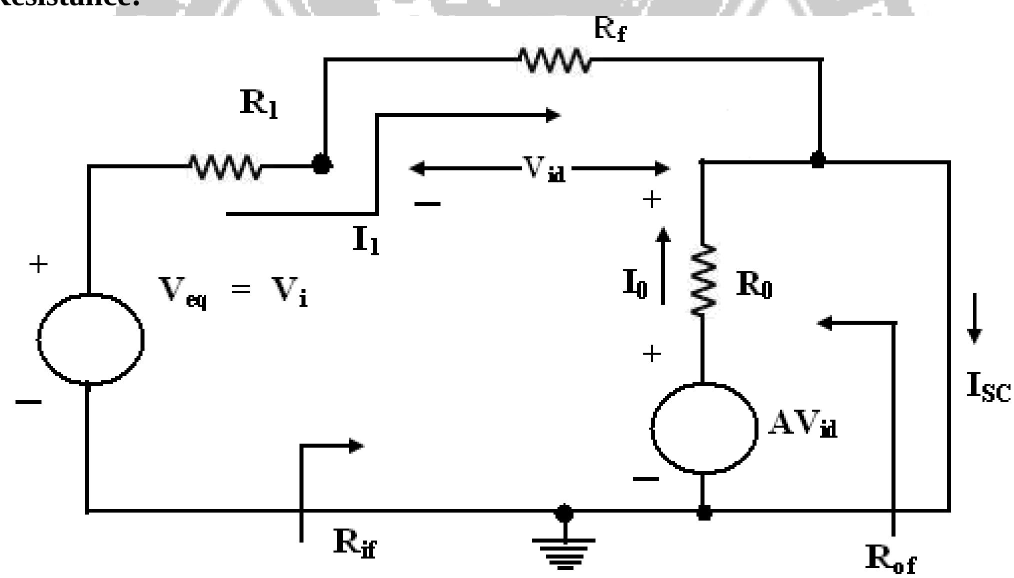
$$V_{id} \;\square\; I_1 R_f \;\square\; R_0 \;\square\; AV_{id} \;\square\; 0$$

which can be simplified for R_{if} *as*



Thevenin's Equivalent Circuit

Output Resistance:



Equivalent circuit to determine Rof

Figure shows the equivalent circuit to determine R_{of} . The output impedance R_{of} without the load resistance factor R_L is calculated from the open circuit output voltage V_{oc} and the short circuit output current I_{SC} .

Non –Inverting Amplifier:

The non – inverting Amplifier with negative feedback is shown in figure. The input signal drives the non – inverting input of op-amp. The op-amp provides an internal gain A. The external resistors R_1 and R_f form the feedback voltage divider circuit with an attenuation factor of β. Since the feedback voltage is at the inverting input, it opposes the input voltage at the non – inverting input terminals, and hence the feedback is negative or degenerative.

The differential voltage V_{id} at the input of the op-amp is zero, because node a is at the same voltage as that of the non- inverting input terminal. As shown in figure, R_f and R_1 form a potential divider. Therefore,

V

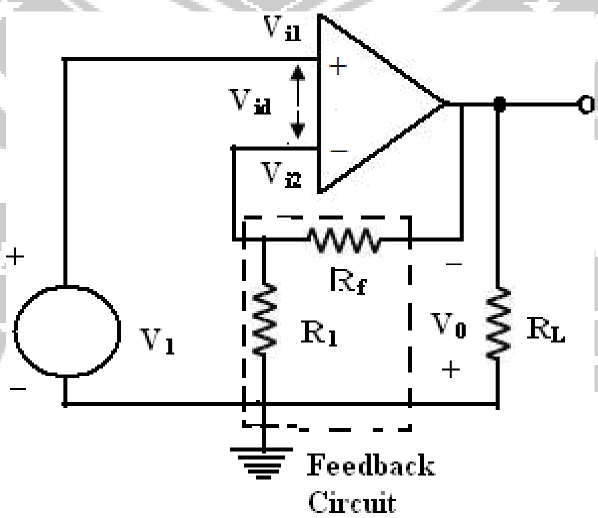
Since no current flows into the op-amp.

Eqn can be written as

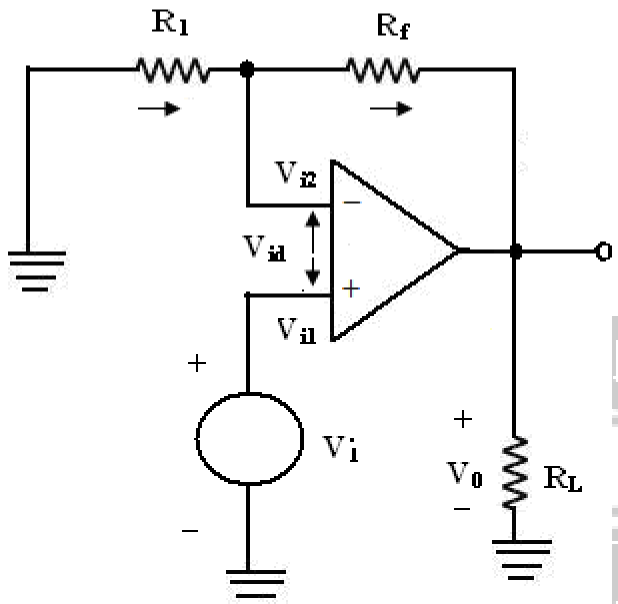
Hence, the voltage gain for the non – inverting amplifier is given by

Using the alternate circuit arrangement shown in figure, the feedback factor of the feedback voltage divider network is

From the above eqn, it can be observed that the closed – loop gain is always greater than one and it depends on the ratio of the feedback resistors. If precision resistors are used in the feedback network, a precise value of closed – loop gain can be achieved. The closed – loop gain does not drift with temperature changes or op – amp replacements.



Its alternate Circuit Arrangement



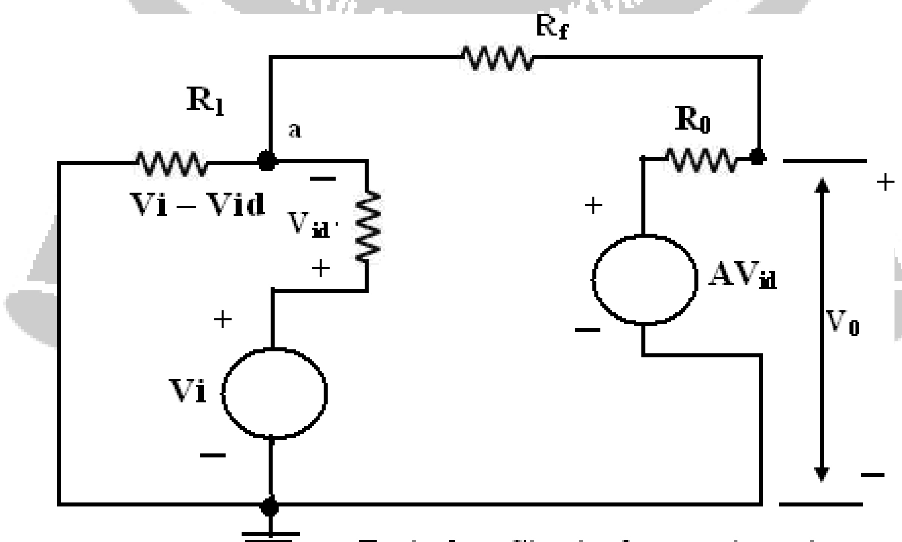
Closed Loop Non – Inverting Amplifier

The input resistance of the op – amp is extremely large (approximately infinity,) since the op –

amp draws negligible current from the input signal.

Practical Non –inverting amplifier:

The equivalent circuit of a non- inverting amplifier using the low frequency model is shownbelow in figure. Using Kirchhoff's current law at node a,



Equivalent Circuit of a non - inverting Amplifier using low frequency