Voltage - Shunt Feed back Amplifier

Figure 1. shows the voltage-shunt feedback amplifier using an op-amp. The input voltage drives the inverting terminal, and the amplified as well as inverted output signal is also applied to the inverting input via the feedback resistor R_F. This arrangement forms a negative feedback because any increase in the output signal results in a feedback signal into the inverting input, causing a decrease in the output signal.

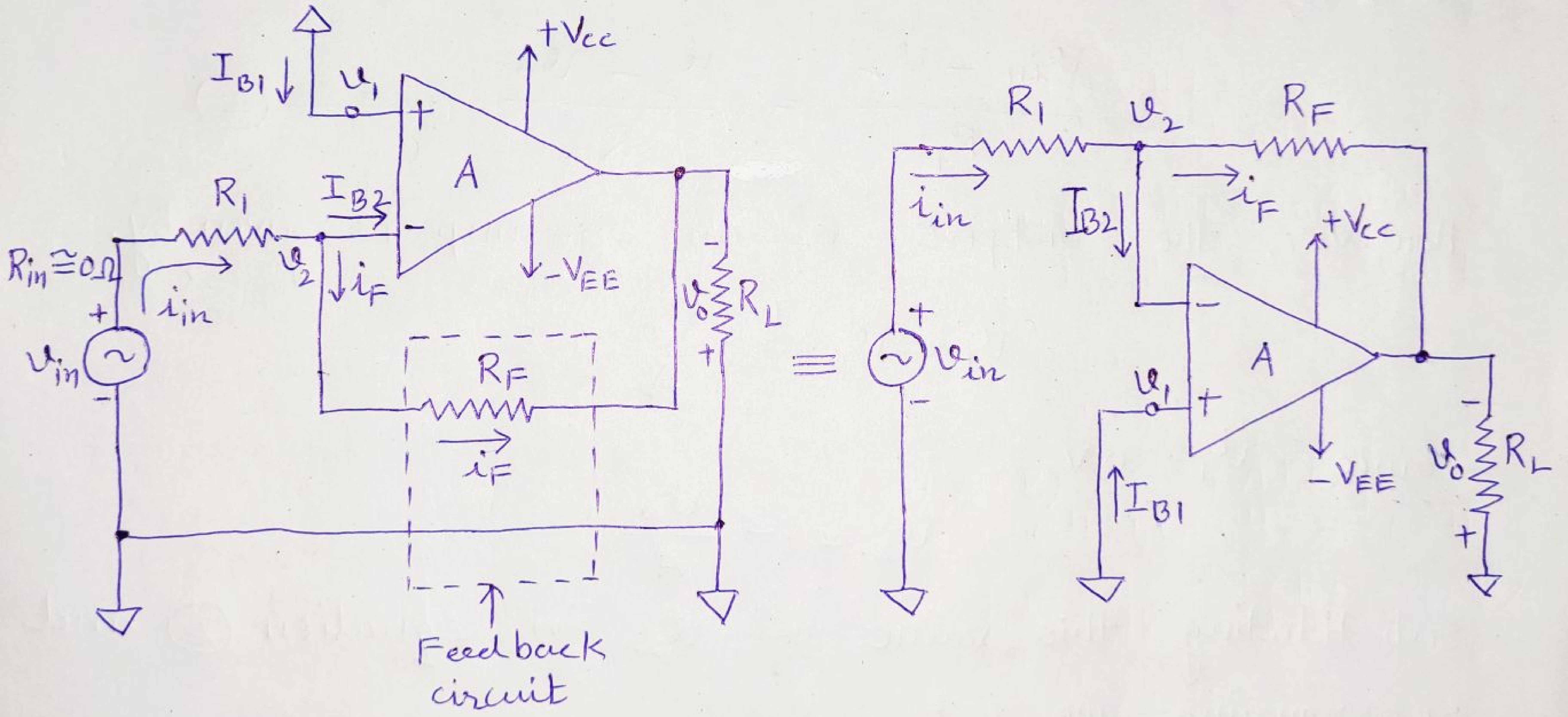

Figure 1. Voltage-shunt feedback amplifier (or inverting amplifier with feedback).

Note that the noninverting terminal is grounded, and the feedback circuit has only one resistor R_F. However, an extra resistor R_1 is connected in series with the input signal source v_{in}.

Closed - Loop Voltage Gain

The closed-loop voltage gain A_F of the voltage-shunt feedback amplifier can be obtained by writing Kirchhoff's current equation at the input node v_2 as follows:

$$i_{in} = i_F + I_B \quad \text{——— (1)}$$

Since R_i is very large, the input bias current I_B is negligibly small. For instance, $R_i = 2\,M\Omega$ and $I_B = 0.5\,\mu A$ for the 741C. Therefore,

$$i_{in} \cong i_F$$

That is,

$$\frac{v_{in} - v_2}{R_1} = \frac{v_2 - v_o}{R_F} \quad \text{——— (2)}$$

However, the output of an op-amp is given by,

$$v_1 - v_2 = \frac{v_o}{A}$$

Since $v_1 = 0\,V$,

$$v_2 = -\frac{v_o}{A}$$

Substituting this value of v_2 in equation (2) and rearranging, we get

$$\frac{v_{in} + v_o/A}{R_1} = \frac{-(v_o/A) - v_o}{R_F}$$

$$A_F = \frac{v_o}{v_{in}} = -\frac{AR_F}{R_1 + R_F + AR_1} \text{ (exact)} \quad (3)$$

The negative sign in equation (13) indicates that the input and output signals are out of phase by 180°.

In fact, because of this phase inversion, the configuration in Figure 1 is commonly called an inverting amplifier with feedback.

Since the internal gain A of the op-amp is very large (ideally infinity), $AR_1 >> R_1 + R_F$. This means that equation (3) can be written as,

$$A_F = \frac{v_o}{v_{in}} = -\frac{R_F}{R_1} \quad \text{(ideal)} \quad \text{——} (4)$$

This equation shows that the gain of the inverting amplifier is set by selecting a ratio of feedback resistance R_F to the input resistance R_1. In fact, the ratio R_F/R_1 can be set to any value whatsoever, even to less than 1. Because of this property of the gain equation, the inverting amplifier configuration with feedback lends itself to a majority of applications as against those of the noninverting amplifier.

To facilitate analysis of the inverting amplifier with feedback and to compare and contrast inverting and noninverting amplifier configuration, we must represent the current-summing junction at the input terminals of the amplifier as a voltage-summing junction.

To begin with, we divide both numerator and denominator of equation (3) by $(R_1 + R_F)$.

$$A_F = -\frac{AR_F/(R_1+R_F)}{1+\dfrac{AR_1}{R_1+R_F}}$$

or, $$A_F = -\frac{AK}{1+AB} \quad \text{— (5)}$$

where $K = \dfrac{R_F}{R_1+R_F}$, a voltage attenuator factor

$B = \dfrac{R_1}{R_1+R_F}$, gain of the feedback circuit.

Note that in addition to the phase inversion (− sign), the closed-loop gain of the inverting amplifier is K times the closed-loop gain of the noninverting amplifier where $K < 1$.

The one-line block diagram of the inverting amplifier with feedback is shown in Figure 2.

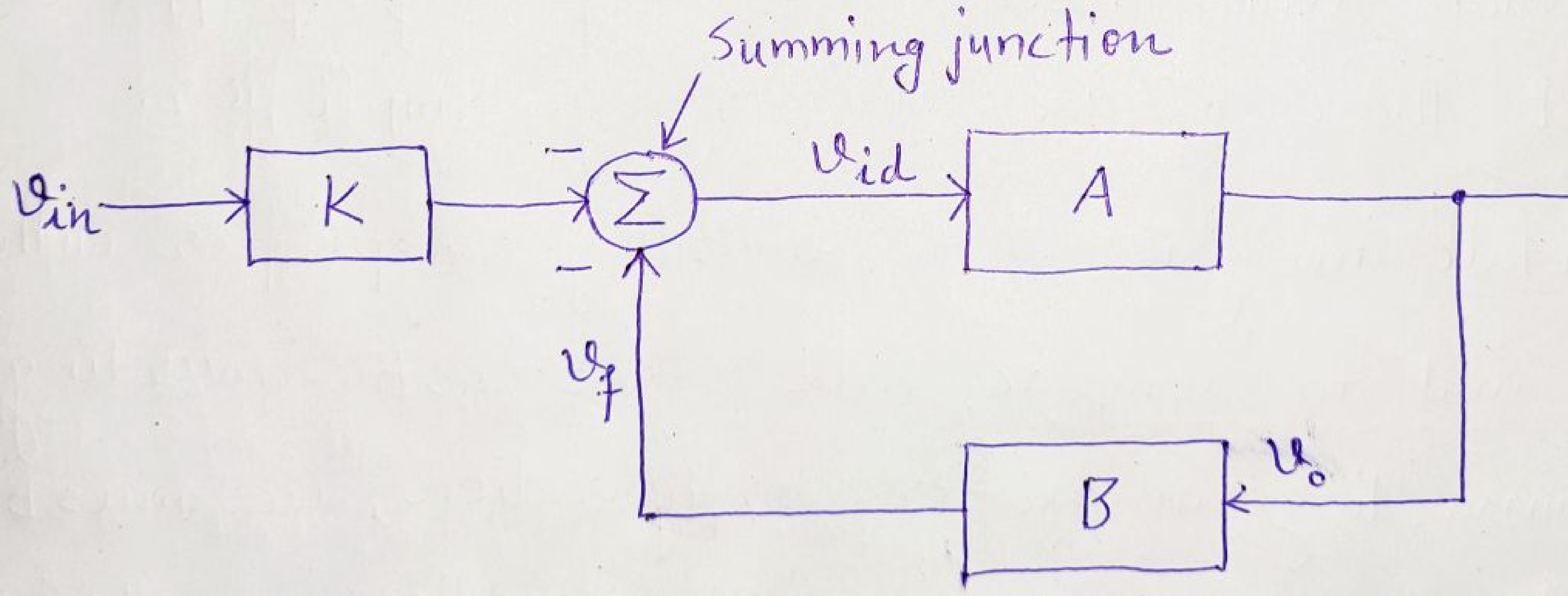

Figure 2. Block diagram of inverting amplifier with feedback using a voltage-summing junction as a model for current summing.

To derive the ideal closed-loop gain, we can use equation (5) as follows.

If $AB \gg 1$, then $(1+AB) \cong AB$ and

$$A_F = -\frac{K}{B}$$

$$A_F = -\frac{R_F}{R_1} \quad \text{——— (6)}$$

Inverting Input Terminal at Virtual Ground

Refer again to the inverting amplifier in Figure 1. In this figure, the noninverting terminal via resistor R_1. However, the difference input voltage is ideally zero; i.e, the voltage at the inverting terminal (v_2) is approximately equal to that at the noninverting terminal (v_1). In other words, the inverting terminal voltage v_2 is approximately at ground potential. Therefore, the inverting terminal is said to be at virtual ground. This concept is extremely useful in the analysis of closed-loop inverting amplifier circuits. For example, ideal closed loop gain can be obtained using the virtual-ground concept as follows:

In the circuit of Figure 1,

$$i_{in} \cong i_F$$

That is,

$$\frac{v_{in} - v_2}{R_1} = \frac{v_2 - v_o}{R_F}$$

However,

$$v_1 = v_2 = 0\,V$$

Therefore,

$$\frac{v_{in}}{R_1} = -\frac{v_o}{R_F}$$

or $$A_F = \frac{v_o}{v_{in}} = -\frac{R_F}{R_1}$$

Input Resistance with Feedback

The easiest method of finding the input resistance is to Millerize the feedback resistor R_F; that is, split R_F into its two Miller components, as shown in Figure 3.

In the circuit of Figure 3, the input resistance with feedback R_{iF} is then

$$R_{iF} = R_1 + \frac{R_F}{1+A} \parallel (R_i) \quad \text{(exact)}$$

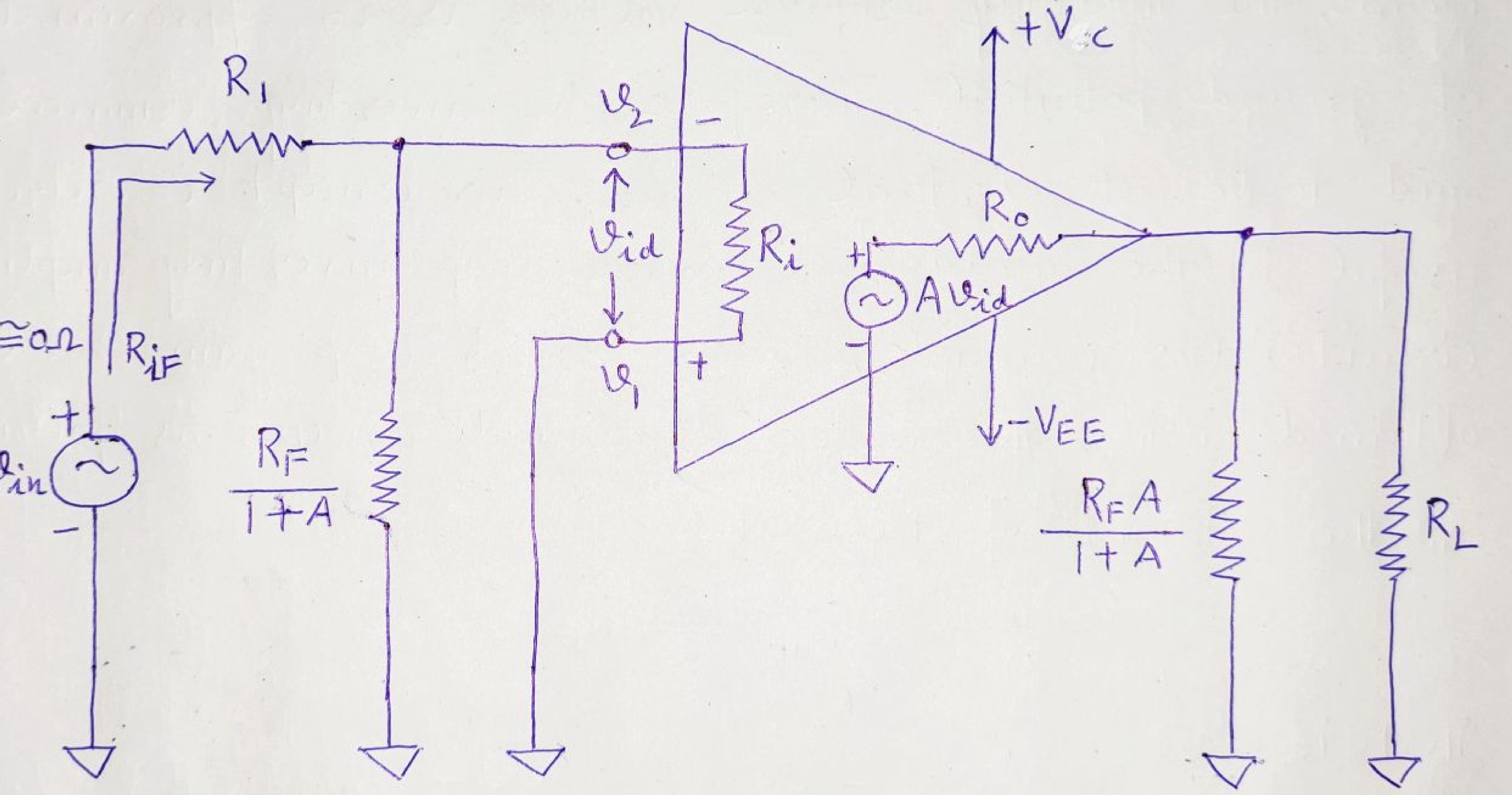

Figure 3. Inverting amplifier with Millerized feedback resistor.

Since, R_i and A are very large,

$$\frac{R_F}{1+A} \parallel R_i \cong 0\,\Omega$$

Hence,

$$R_{iF} = R_1 \quad \text{(ideal)}$$