Votage - Series Feedback Amplifier

The schematic diagram of the voltage-series feedback amplifier is shown in Figure 1. The op-amp is represented by its schematic symbol, including its large-signal voltage gain A, and the feedback circuit is composed of two resistors, R_1 and R_F.

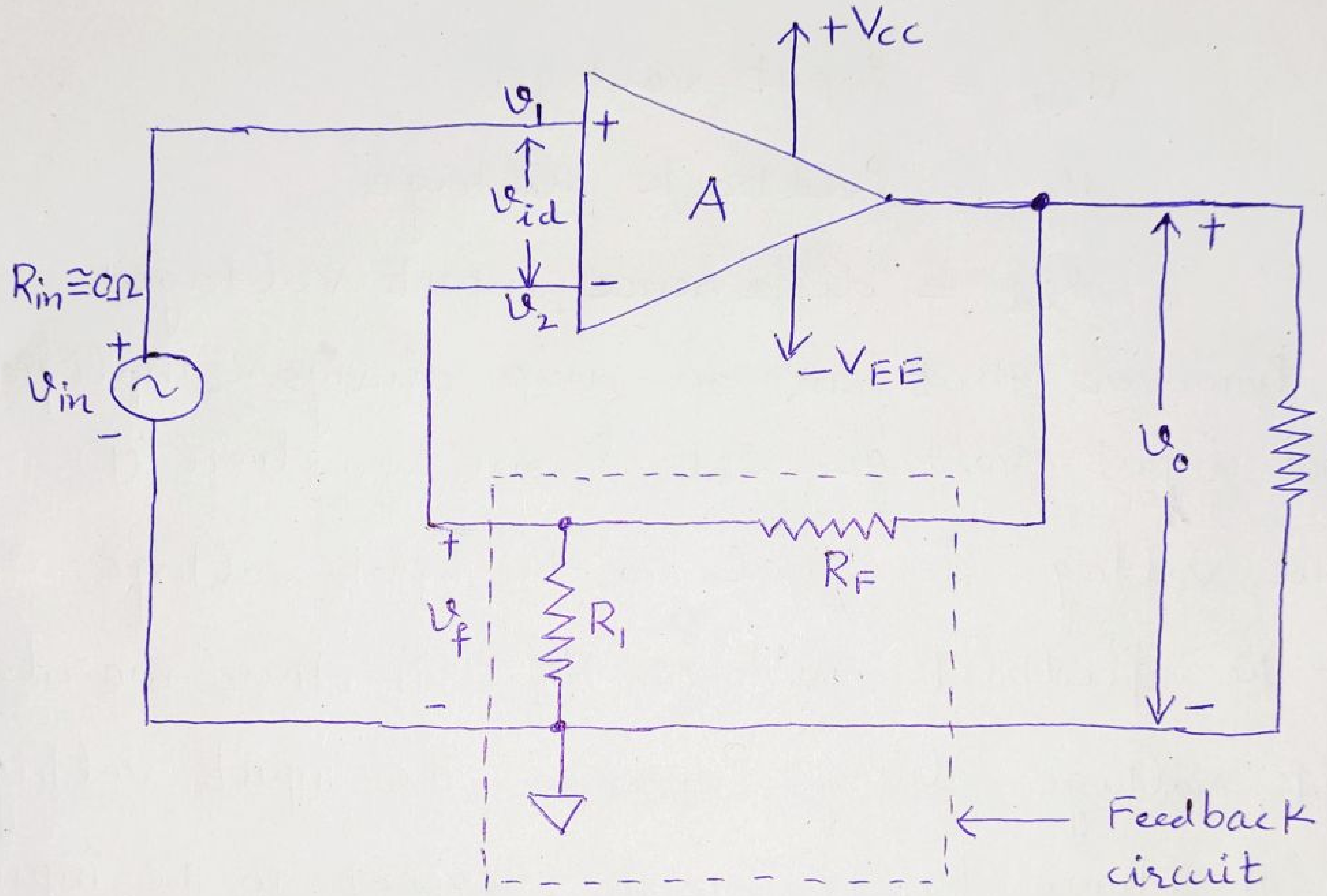

Figure 1: Voltage - Series Feedback Amplifier
(Non-inverting amplifier with feedback)

The circuit shown in Figure 1 is commonly known as a non inverting amplifier with feedback (or closed-loop noninverting amplifier) because it uses feedback, and the input signal is applied to the noninverting input terminal of the op-amp.

Before proceeding, it is necessary to define some important terms for the voltage-series feedback amplifier.

Open-loop voltage gain (or gain without feedback) $A = \dfrac{v_o}{v_{id}}$

Closed-loop voltage gain (or gain with feedback) $A_F = \frac{v_o}{v_{in}}$

Gain of the feedback circuit, $B = \frac{v_f}{v_o}$

Negative Feedback

Referring to the circuit of Figure 1, Kirchhoff's voltage equation for the input loop is,

$$v_{id} = v_{in} - v_f \quad \text{——— (1)}$$

where
v_{in} = input voltage
v_f = feedback voltage
v_{id} = difference input voltage

Recall, however, that an op-amp always amplifies the difference input voltage v_{id}. From equation (1), this difference voltage is equal to the input voltage v_{in} minus the feedback voltage v_f. In other words, the feedback voltage always opposes the input voltage (or is out of phase by 180° with respect to the input voltage); hence the feedback is said to be negative.

Closed-Loop Voltage Gain

As defined previously, the closed-loop voltage gain is,

$$A_F = \frac{v_o}{v_{in}}$$

However, by output equation of op-amp,

$$v_o = A(v_1 - v_2)$$

Referring to Figure 1, we see that

$$v_1 = v_{in}$$

$$v_2 = v_f = \frac{R_1 v_o}{R_1 + R_F}$$ Since $R_i >> R_1$

Therefore,

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

Rearranging, we get

$$v_o = \frac{A(R_1 + R_F)\, v_{in}}{R_1 + R_F + AR_1}$$

Thus

$$A_F = \frac{v_o}{v_{in}} = \frac{A(R_1 + R_F)}{R_1 + R_F + AR_1} \quad \text{—— (2)}$$

Generally, A is very large (typically 10^5). Therefore,

$AR_1 >> (R_1 + R_F)$ and $(R_1 + R_F + AR_1) \cong AR_1$

Thus,

$$A_F = \frac{v_o}{v_{in}} = 1 + \frac{R_F}{R_1} \quad \text{—— (3)}$$

Equation (3) is important because it shows that the gain of the voltage-series feedback amplifier is determined by the ratio of two resistors, R_1 and R_F.

As defined previously, the gain of the feedback circuit (B) is the ratio of v_f and v_o. Referring to Figure 1, this gain is

$$B = \frac{v_f}{v_o}$$

$$B = \frac{R_1}{R_1 + R_F} \quad \text{—— (4)}$$

Comparing equations (3) and (4), we can conclude that

$$A_F = \frac{1}{B} \quad \text{—— (5)}$$

This means that the gain of the feedback circuit is the reciprocal of the closed-loop voltage gain. In other words, for given R_1 and R_F, the values of A_F and B are fixed.

Finally, the closed-loop voltage gain A_F can be expressed in terms of open-loop gain A and feedback circuit gain B as follows. Rearranging equation (2)

$$A_F = \frac{A\left(\frac{R_1 + R_F}{R_1 + R_F}\right)}{\frac{R_1 + R_F}{R_1 + R_F} + \frac{A R_1}{R_1 + R_F}}$$

Using equation (4) yields

$$A_F = \frac{A}{1 + AB} \qquad \text{——— (6)}$$

where A_F = closed-loop voltage gain

A = open-loop voltage gain

B = gain of the feedback circuit

AB = loop gain

A one-line block diagram of equation (6) is shown in Figure 2.

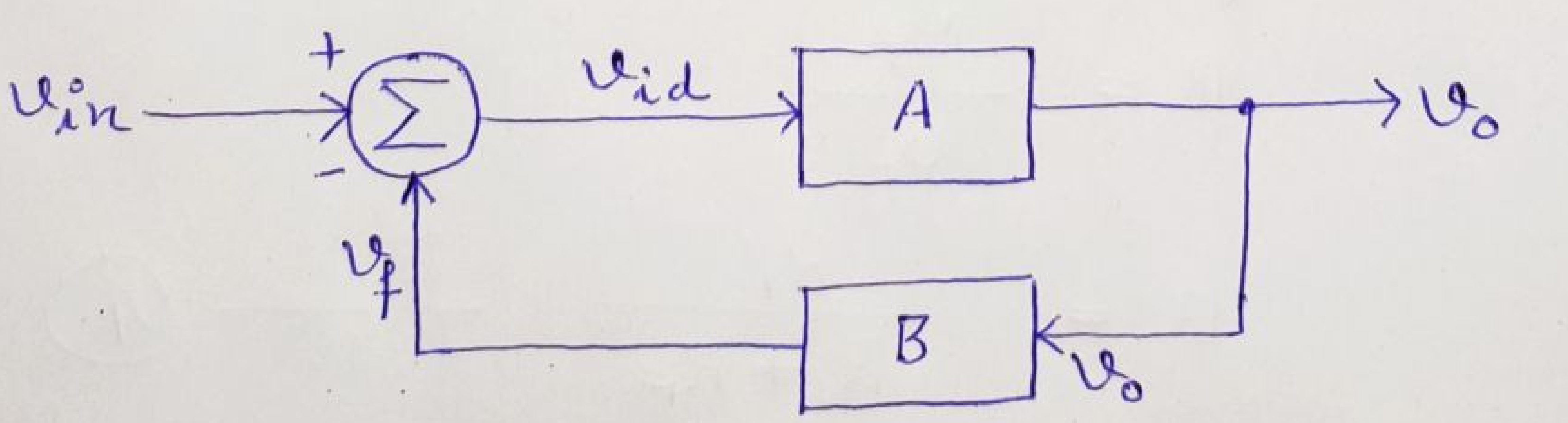

Figure 2. Block diagram representation of noninverting amplifier with feedback.

This block diagram illustrates a standard form form for representing a system with feedback and also indicates the relationship between different variables of the system.

Input Resistance with Feedback

Figure 3. shows a voltage series feedback amplifier with the op-amp equivalent circuit. In this circuit R_i is the input resistance (open loop) of the op-amp, and R_{iF} is the input resistance of the amplifier with feedback.

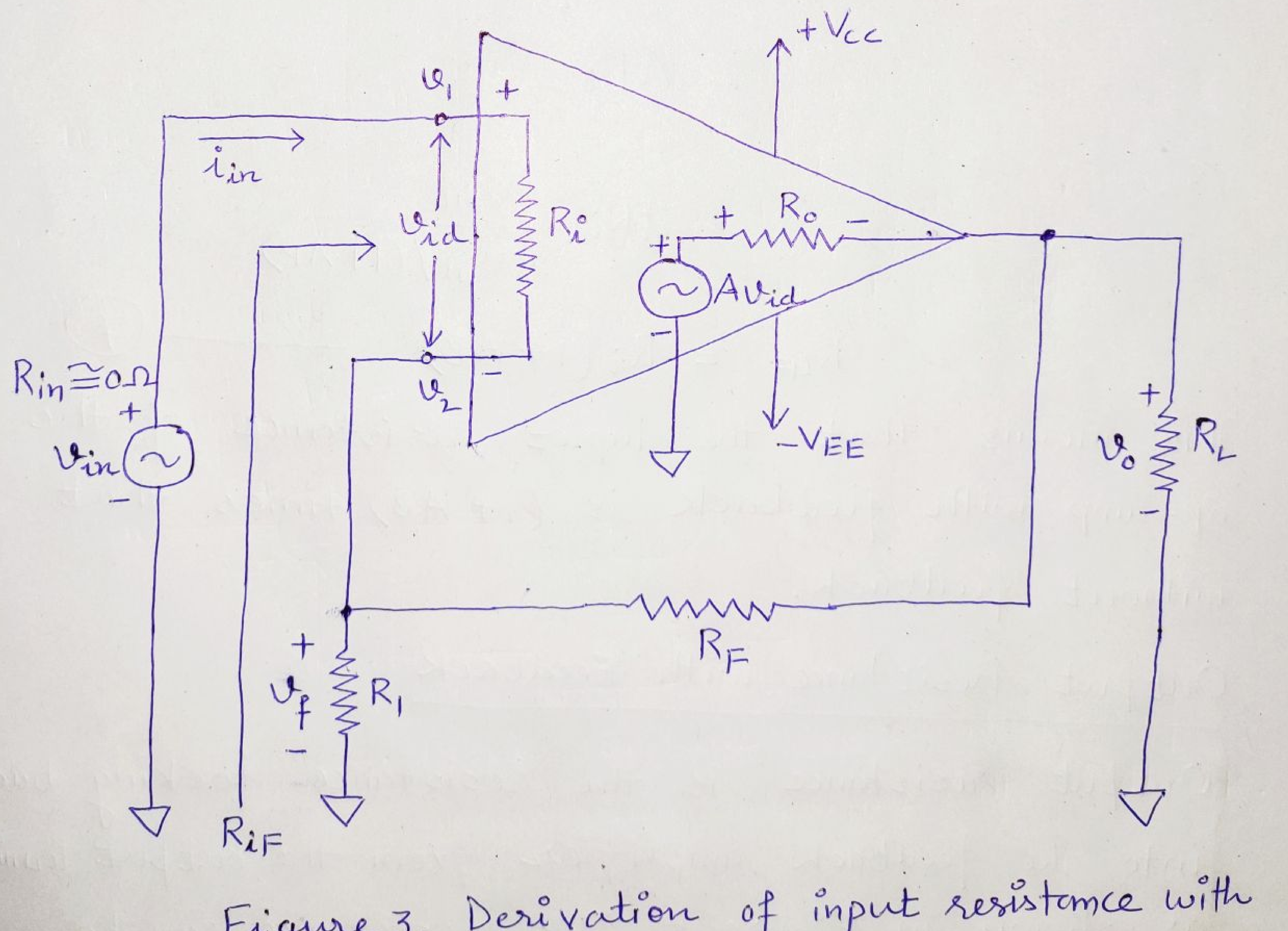

Figure 3. Derivation of input resistance with feedback.

The input resistance with feedback is defined as

$$R_{iF} = \frac{v_{in}}{i_{in}}$$

$$= \frac{v_{in}}{v_{id}/R_i}$$

However,

$$v_{id} = \frac{v_o}{A} \quad \text{and} \quad v_o = \frac{A}{1+AB} v_{in}$$

$$\left[\text{Note} \quad A = \frac{v_o}{v_{id}} \quad \text{and} \quad A_F = \frac{v_o}{v_{in}} = \frac{A}{1+AB} \right]$$

Therefore,

$$R_{iF} = R_i \frac{v_{in}}{v_o/A}$$

$$= AR_i \frac{v_{in}}{v_o}$$

$$= AR_i \frac{v_{in}}{A v_{in}/(1+AB)}$$

$$R_{iF} = R_i(1+AB) \qquad (7)$$

This means that the input resistance of the op-amp with feedback is $(1+AB)$ times that without feedback.

Output Resistance with Feedback

Output resistance is the resistance looking back into the feedback amplifier from the output terminal as shown in Figure 4. This resistance can be obtained by using Thevenin's theorem for dependent sources. Specifically, to find output resistance with (7) feedback R_{OF}, reduce independent source v_{in} to zero, apply an external voltage v_o, and then calculate the resulting current i_o. In short, the R_{OF} is defined as follows:

$$R_{OF} = \frac{v_o}{i_o} \qquad \text{——— (8)}$$

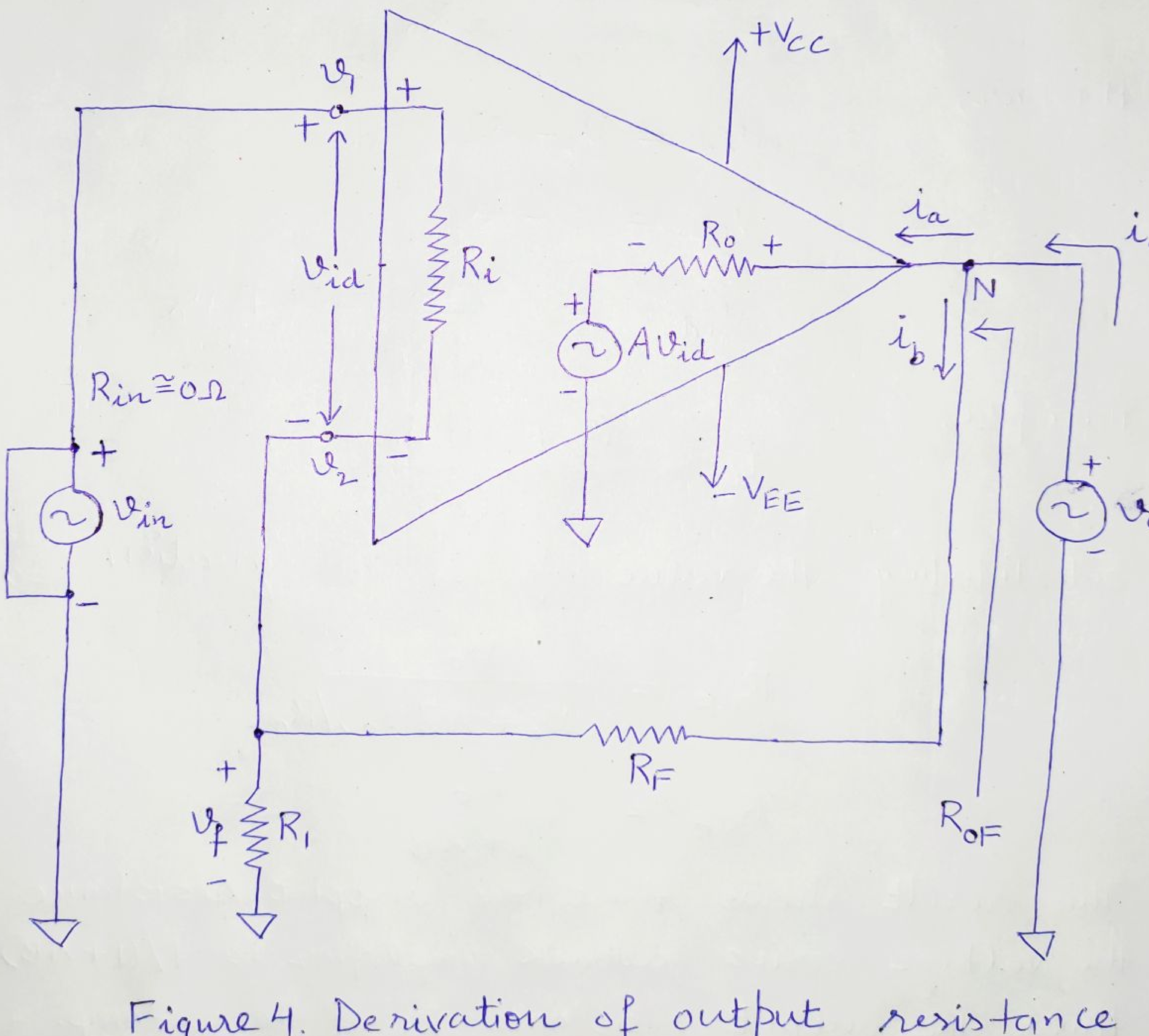

Figure 4. Derivation of output resistance with feedback.

Writing Kirchhoff's current equation at output node N, we get

$$i_o = i_a + i_b$$

Since $[(R_F + R_1) || R_i] >> R_o$ and $i_a >> i_b$,

Therefore, $i_o \cong i_a$

The current i_o can be found by writing Kirchhoff's voltage equation for the output loop:

$$v_o - R_o i_o - A v_{id} = 0$$

$$i_o = \frac{v_o - A v_{id}}{R_o}$$

However,

$$v_{id} = v_1 - v_2$$

$$v_{id} = 0 - v_f$$

$$v_{id} = - \frac{R_1 v_o}{R_1 + R_F} = - B v_o$$

Therefore,

$$i_o = \frac{v_o + A B v_o}{R_o}$$

Substituting the value of i_o in equation 8,

$$R_{OF} = \frac{v_o}{(v_o + A B v_o)/R_o}$$

$$R_{OF} = \frac{R_o}{1 + AB}$$

This result shows that the output resistance of the voltage-series feedback amplifier is $1/(1+AB)$ times the output resistance R_o of the op-amp. i.e the output resistance of the op-amp with feedback is much smaller then the output resistance without feedback.