Output Resistance with Feedback

The output resistance with feedback R_{OF} is the resistance measured at the output terminal of the feedback amplifier. The output resistance of the noninverting amplifier was obtained by using Thevenin's theorem, and we can do the same for the inverting amplifier. Thevenin's equivalent circuit for R_{OF} of the inverting amplifier is shown in Figure 4. Note that this Thevenin's equivalent circuit is exactly the same as that for noninverting amplifier because the output resistance R_{OF} of the inverting amplifier must be identical to that of the noninverting amplifier.

i.e $$R_{OF} = \frac{R_o}{1+AB} \qquad (8)$$

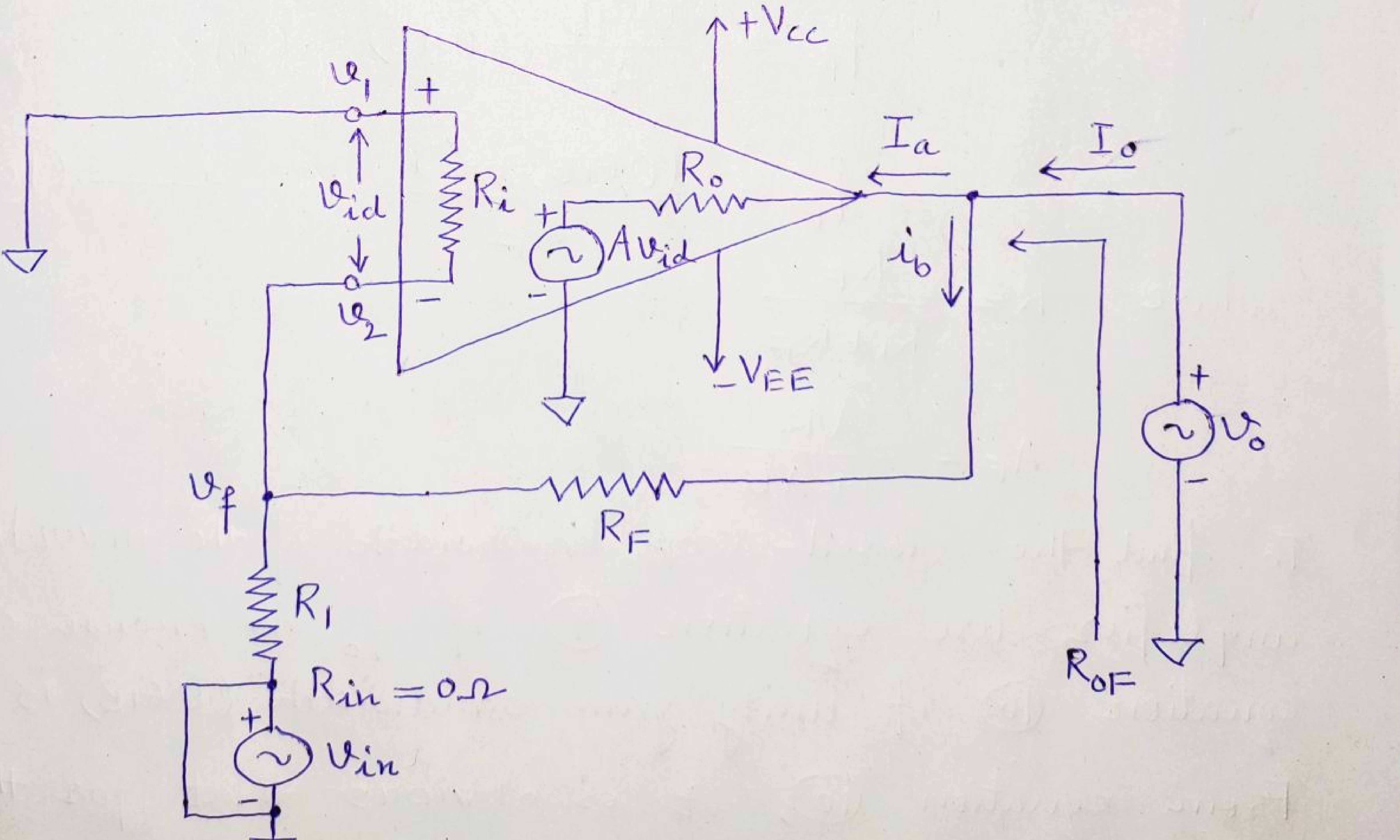

Figure 4. Thevenin's equivalent circuit for R_{OF} of the inverting amplifier.

Bandwidth with Feedback

The gain-bandwidth product of a single break frequency op-amp is always constant. We also saw that the gain of the amplifier with feedback is always less than the gain without feedback. Therefore, the bandwidth of the amplifier with feedback f_F must be larger than that without feedback.

$$f_F = f_o (1 + AB) \quad \text{——} \quad (9)$$

where f_o = break frequency of the op-amp

$$= \frac{\text{Unit gain bandwidth}}{\text{open-loop voltage gain}}$$

$$f_o = \frac{UGB}{A}$$ [true only for the single break frequency op-amp as 741]

Substituting the value of f_o in equation - (9), we get

$$f_F = \frac{UGB}{A}(1 + AB)$$

$$f_F = \frac{(UGB).(K)}{A_F} \quad \text{——} \quad (10)$$

where $K = \dfrac{R_F}{R_1 + R_F}$

$$A_F = \frac{AK}{1 + AB}$$

To find the closed-loop bandwidth of the inverting amplifier, use equation (9) if f_o is known and use equation (10) if unity gain-bandwidth (UGB) is given. From equation (10), it is obvious that for the same closed loop gain, the closed loop bandwidth for the inverting amplifier is lower than that for the noninverting amplifier by a factor of K (<1). For example, when the closed loop gain is equal to 1, the bandwidths will be (9)

$$f_F = UGB \text{ for the noninverting amplifier}$$

and

$$f_F = \frac{UGB}{2} \text{ for the inverting amplifier, since } R_1 = R_F.$$

However, as the closed-loop gain A_F approaches the open-loop gain A, the difference between the noninverting and inverting amplifier bandwidths approaches zero. As an extreme limit, when $K \cong 1$, the value of f_F for both the noninverting and inverting amplifiers is approximately the same.

Total Output Offset Voltage with Feedback

When the temperature and power supply voltages are fixed, the output offset voltage is a function of the gain of an op-amp. However, we saw that the gain of the op-amp with feedback is always less than that without feedback. Therefore, the output offset voltage with feedback V_{OOT} must always be smaller than that without feedback.

Therefore,

$$\text{Total output offset voltage with feedback} = \frac{\text{Total output offset voltage without feedback}}{1 + AB}$$

i.e.

$$V_{OOT} = \frac{\pm V_{sat}}{1+AB} \quad \text{--- (11)}$$

where $\pm V_{sat}$ = Saturation voltage

A = open-loop voltage gain of the op-amp

B = gain of the feedback circuit

The output voltage of the op-amp without feedback can be either $+V_{sat}$ or $-V_{sat}$ because of its very high voltage gain A, which is typically of the order of 10^5.

Note that the V_{OOT} equation for the inverting amplifier is the same as that for the noninverting amplifier. This is because, when the input signal v_{in} is reduced to zero, both inverting and noninverting amplifiers result in the same circuit.

In addition, because of the negative feedback, the effect of noise, variations in supply voltages, and changes in temperature on the output voltage of the inverting amplifiers are significantly reduced.

Finally, the two special cases of the inverting amplifier with feedback are the current-to-voltage converter and the inverter.

Current-to-Voltage Converter

Let us reconsider the ideal voltage-gain equation of the inverting amplifier,

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

Therefore,

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

However, since $v_1 = 0V$ and $v_1 = v_2$

$$\therefore \quad \frac{v_{in}}{R_1} = i_{in}$$

and

$$v_o = -i_{in} R_F$$

This means that if we replace the v_{in} and R_1 combination by a current source i_{in} as shown in Figure 5, the output voltage v_o becomes proportional to the input current i_{in}. In other words, the circuit of Figure 5 converts the input current into a proportion output voltage.

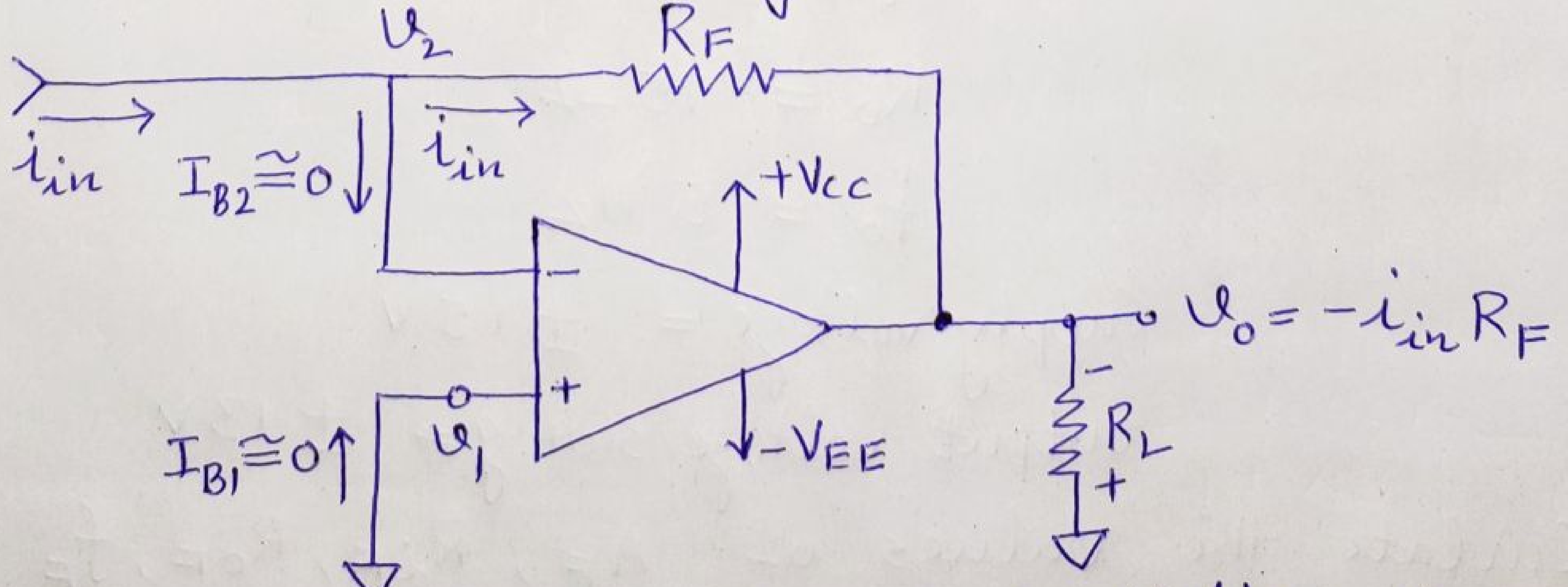

Figure 5. Current-to-Voltage Converter

One of the most common uses of the current-to-voltage converter is in sensing current from photo-detectors.

Inverter

If we need an output signal equal in amplitude but opposite in phase to that of the input signal, we can use the inverter. The inverting amplifier with feedback works as an inverter if $R_1 = R_F$. Since the inverter is a special case of the inverting amplifier, all the equations developed for the inverting amplifier are also applicatile here. The equations can be applied by merely substituting $(A/2)$ for $(1+AB)$, since $B = \frac{1}{2}$.

Q1. For the inverting amplifier, $R_1 = 470\,\Omega$ and $R_F = 4.7\,K\Omega$. Assume that the op-amp is the 741 having the specifications given as:

$$A = 200000$$

$$R_i = 2\,M\Omega$$

$$R_o = 75\,\Omega$$

$$f_o = 5\,Hz$$

$$\text{Supply voltage} = \pm 15\,V$$

$$\text{output voltage swing} = \pm 13\,V$$

Calculate the values of A_F, R_{iF}, R_{oF}, f_F and V_{OOT}.

Solution: Using the given values of R_1 and R_F,

$$K = \frac{R_F}{R_1 + R_F} = \frac{4700}{470 + 4700} = \frac{1}{1.1}$$

$$B = \frac{R_1}{R_1 + R_F} = \frac{470}{470 + 4700} = \frac{1}{11}$$

and

$$1 + AB = \left[1 + (2 \times 10^5)\left(\frac{1}{11}\right)\right] = 18182.8$$

Therefore the values of the closed-loop parameters are

$$A_F = -\frac{AK}{1 + AB}$$

$$\therefore, \quad A_F = -\frac{200000 \times (1/1.1)}{18182.8} = -10$$

$$R_{iF} = R_1 + \left(\frac{R_F}{1 + A} \| R_i\right)$$

$$\therefore, \quad R_{iF} = 470 + \left[\frac{4700}{200000} \| 2 \times 10^6\right]$$

$$R_{iF} = 470 \ \Omega$$

$$R_{oF} = \frac{R_o}{1 + AB} = \frac{75}{18182.8} = 4.12 \ m\Omega$$

$$f_F = \frac{(UGB)(K)}{A_F} = \frac{f_o . A . K}{A_F}$$

$$f_F = \frac{f_o . A . (1 + AB)}{A} = f_o(1 + AB)$$

$$= 5 \times 18182.8 = 90.9 \ KHz$$

$$V_{OOT} = \frac{\pm 13V}{18182.8} = \pm 0.715 mV.$$