Summing, Scaling and Averaging Amplifiers

This section shows how the inverting, noninverting, and differential configurations are useful in such applications as summing, scaling and averaging amplifiers.

1. Inverting Configuration

Figure 1 shows the inverting configuration with three inputs V_a, V_b and V_c. Depending on the relationship between the feedback resistor R_F and the input resistors R_a, R_b, and R_c, the circuit can be used as either a summing amplifier, scaling amplifier, or averaging amplifier.

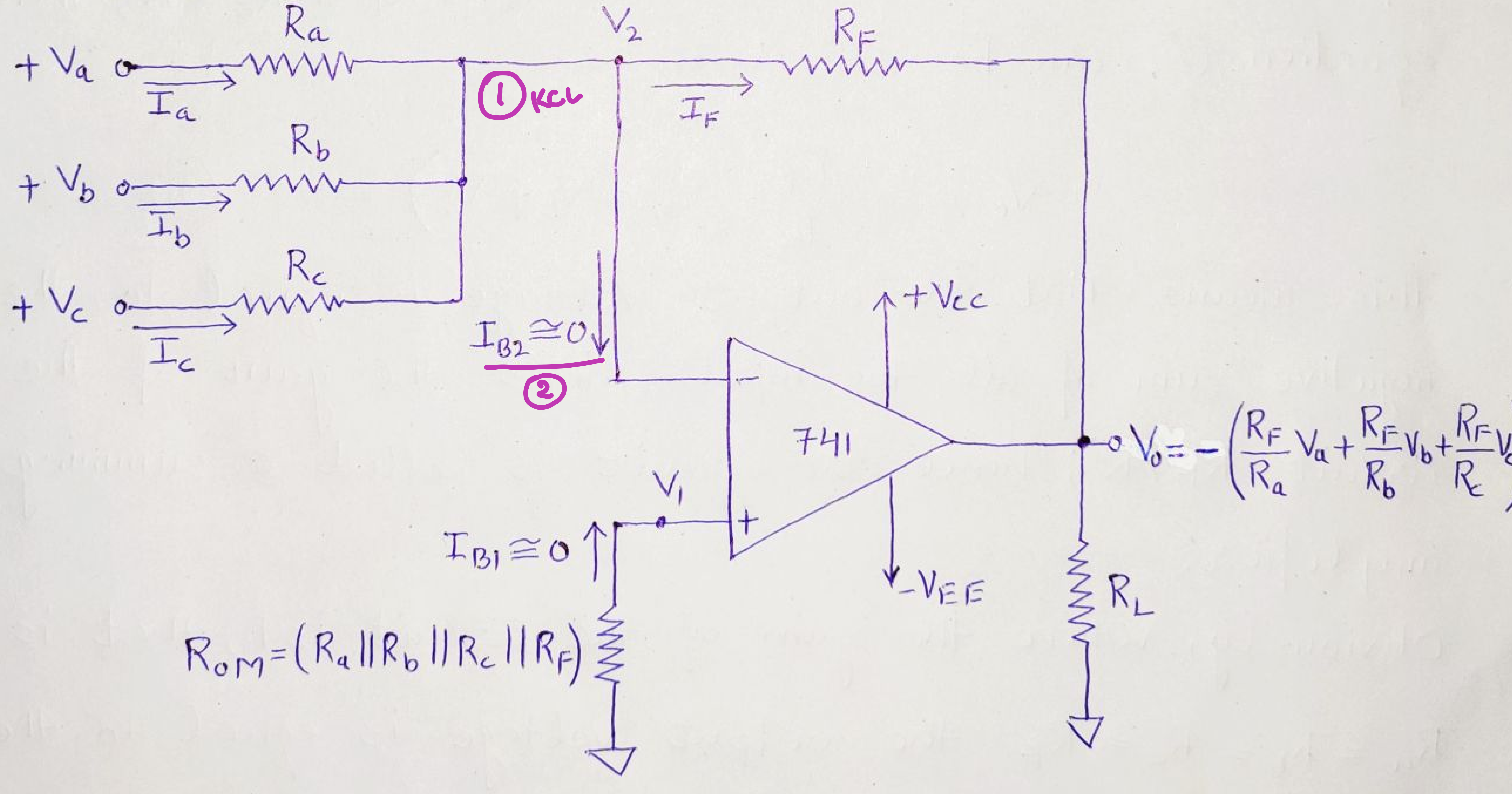


Figure 1. Inverting configuration with three inputs can be used as a summing amplifier, scaling amplifier, or averaging amplifier.

The circuit's function can be verified by examining the expression for the output voltage V_o, which is obtained from Kirchhoff's current equation written at node V_2, i.e.

$$I_a + I_b + I_c = I_B + I_F \quad \text{—— (1)}$$

since R_i and A of the op-amp are ideally infinity, $I_B = 0\,A$ and $V_1 = V_2 \cong 0\,V$.

Therefore

$$\frac{V_a}{R_a} + \frac{V_b}{R_b} + \frac{V_c}{R_c} = -\frac{V_o}{R_F}$$

or

$$V_o = -\left(\frac{R_F}{R_a}V_a + \frac{R_F}{R_b}V_b + \frac{R_F}{R_c}V_c\right) \quad \text{—— (2)}$$

Summing Amplifier

If in the circuit of Figure 1, $R_a = R_b = R_c = R$, then equation (2) can be rewritten as

$$V_o = -\frac{R_F}{R}(V_a + V_b + V_c) \quad \text{—— (3)}$$

This means that the output voltage is equal to the negative sum of all the inputs times the gain of the circuit R_F/R; hence the circuit is called a summing amplifier.

Obviously, when the gain of the circuit is 1, that is $R_a = R_b = R_c = R_F$, the output voltage is equal to the negative sum of all input voltages. Thus

$$V_o = -(V_a + V_b + V_c) \quad \text{—— (4)}$$

Scaling or weighted Amplifier

If each input voltage is amplified by a different factor, in other words, weighted differently at the output, then the circuit in Figure 1 is then called a scaling or weighted amplifier. This condition can be accomplished if R_a, R_b, and R_c are different in value. Thus the output voltage of the scaling amplifier is

$$V_o = -\left(\frac{R_F}{R_a} V_a + \frac{R_F}{R_b} V_b + \frac{R_F}{R_c} V_c \right) \quad (5)$$

where

$$\frac{R_F}{R_a} \neq \frac{R_F}{R_b} \neq \frac{R_F}{R_c}$$

Average Circuit

The circuit of Figure 1 can be used as an averaging circuit, in which the output voltage is equal to the average of all the input voltages. This is accomplished by using all input resistors of equal value, i.e.,

$$R_a = R_b = R_c = R.$$

In addition, the gain by which each input is amplified must be equal to 1 over the number of inputs; that is

$$\frac{R_F}{R} = \frac{1}{n}$$

where n is the number of inputs.

Thus, if there are three inputs (as shown in Figure 1) we want $R_F/R = \frac{1}{3}$. Consequently, from equation (3),

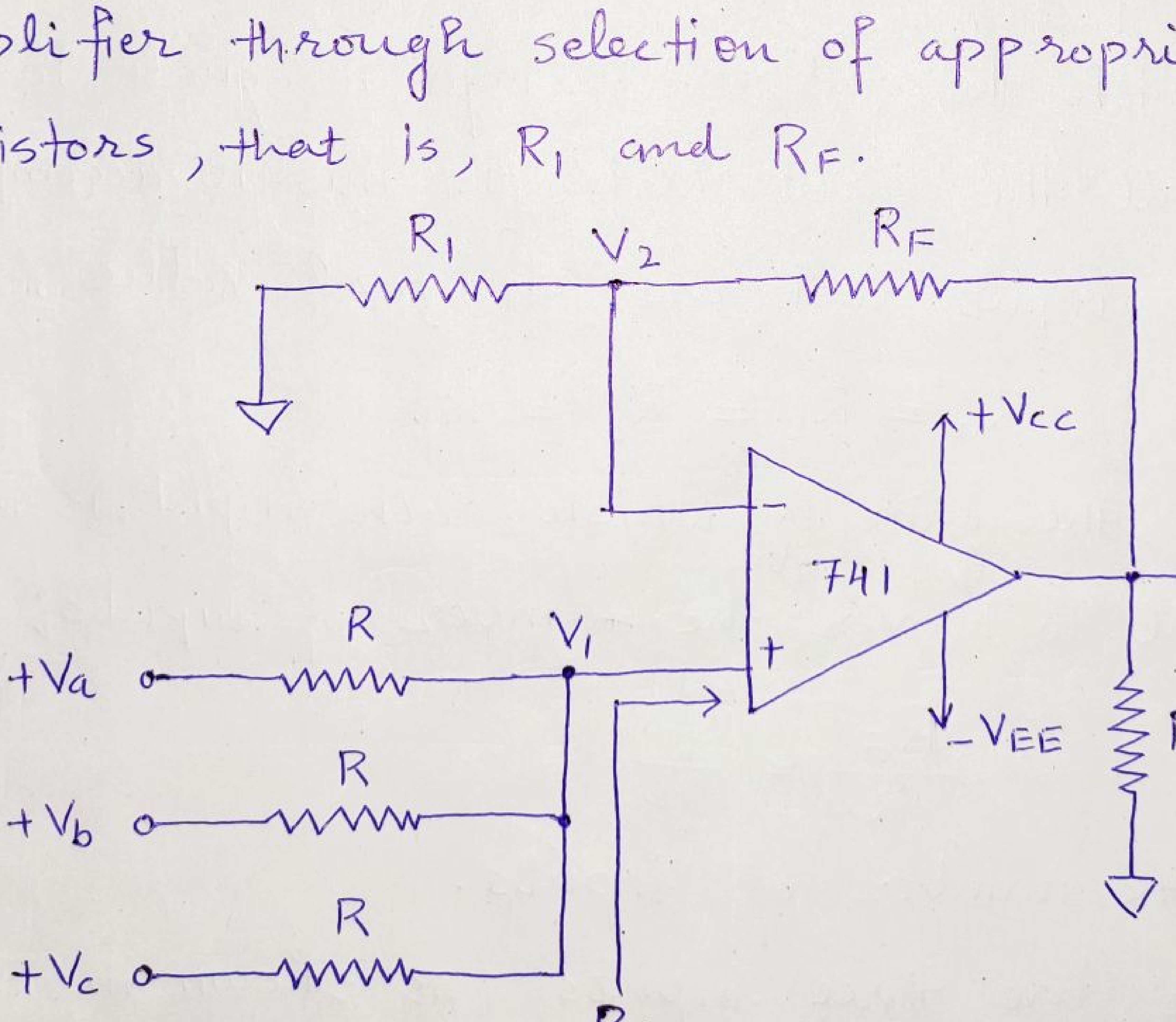
$$V_o = -\left(\frac{V_a + V_b + V_c}{3} \right) \quad (6)$$

Remember that in the preceding applications, the inputs V_a, V_b, and V_c could be either ac or dc. These circuits are commonly used in analog computers and audio mixers, in which a number of inputs is added up to produce a desired output.

In Figure 1, the offset minimizing resistor R_{OM} is used to minimize the effect of input bias currents on the output offset voltage.

2. Noninverting Configuration

If input voltage sources and resistors are connected to the noninverting terminal as shown in Figure 2, the circuit can be used either as a summing or averaging amplifier through selection of appropriate values of resistors, that is, R_1 and R_F.



$$V_o = \left(1 + \frac{R_F}{R_1}\right)\left(\frac{V_a + V_b + V_c}{3}\right)$$

Figure 2. Noninverting configuration with three inputs can be used as an averaging or summing amplifier.

Recall that the input resistance R_{iF} of the non-inverting amplifier is very large. Therefore, using the superposition theorem, the voltage V_1 at the noninverting terminal is

$$V_1 = \frac{R/2}{R + R/2} V_a + \frac{R/2}{R + R/2} V_b + \frac{R/2}{R + R/2} V_c$$

or,

$$V_1 = \frac{V_a}{3} + \frac{V_b}{3} + \frac{V_c}{3} = \frac{V_a + V_b + V_c}{3} \quad \text{— (7)}$$

Hence the output voltage V_o is

$$V_o = \left(1 + \frac{R_F}{R_1}\right) V_1$$

$$V_o = \left(1 + \frac{R_F}{R_1}\right) \frac{V_a + V_b + V_c}{3} \quad \text{—— (8)}$$

Averaging amplifier

Equation (8) shows that the output voltage is equal to the average of all input voltages times the gain of the circuit $(1 + R_F/R_1)$, hence the name averaging amplifier. Depending on the application requirement, the gain $(1 + R_F/R_1)$ can be set to a specific value. Obviously, if the gain is 1, the output voltage will be equal to the average of all input voltages.

Note that there are two basic differences between this averaging amplifier and that using the inverting configuration:

1. No sign change or phase reversal occurs between the average of the inputs and output.
2. The noninverting input voltage V_1 is the average of all inputs, whereas in the inverting averaging amplifier, the output is the average of all inputs, with a negative sign.

Summing amplifier

A close examination of equation (8) reveals that if the gain $(1 + R_F/R_1)$ is equal to the number of inputs, the output voltage becomes equal to the sum of all input voltages. That is, if $(1 + R_F/R_1) = 3$,

$$V_o = V_a + V_b + V_c$$

Hence the circuit is called a noninverting summing amplifier.

Q1. In the circuit of Figure 1, $V_a = +1\,V$, $V_b = +2\,V$, $V_c = +3\,V$, $R_a = R_b = R_c = 3\,K\Omega$, $R_F = 1\,K\Omega$; $R_{OM} = 270\,\Omega$, and supply voltages $= \pm 15\,V$. Assuming that the op-amp is initially nulled, determine the output voltage V_o.

Solution: Using equation (3), we obtain,

$$V_o = -\frac{R_F}{R}(V_a + V_b + V_c)$$

$$V_o = -\frac{1}{3}(1+2+3) = -2\,V$$

This value is equal to the average of three inputs with a negative sign.

Q2. In the circuit of Figure 2, supply voltages = ± 15 V, $V_a = +2$ V, $V_b = -3$ V, $V_c = +4$ V, $R = R_1 = 1$ KΩ and $R_F = 2$ KΩ. Determine the voltage V_1 at the non-inverting terminal and the output voltage V_o. Assume that the op-amp is initially nulled.

Solution: Using equation (7),

$$V_1 = \frac{2-3+4}{3} = 1 \text{ V}$$

which is the average of three inputs: +2V, −3 V, and +4 V. From equation (8),

$$V_o = \left(1 + \frac{2}{1}\right) \times 1 = 3 \text{ V}$$

[Note: $$V_o = \left(1 + \frac{R_F}{R_1}\right)\left(\frac{V_a + V_b + V_c}{3}\right)$$]

V_o is the sum of three inputs in this example.