1 Ideal Opamp Circuits

1.1 The Voltage Follower

We redraw the circuit of non-inverting amplifier as shown in Fig.(1).

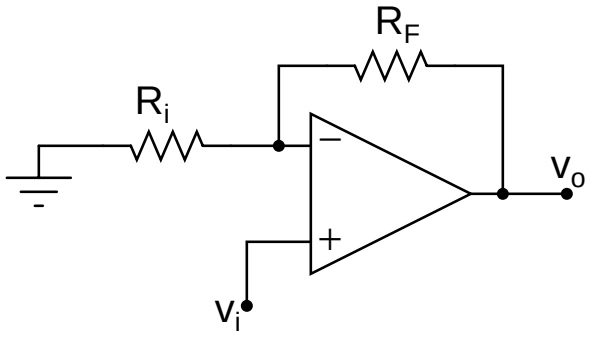


Figure 1: The non-inverting amplifier

If we force either $R_F = 0$ or $R_i = \infty$ we obtain $v_o = v_i$. In practice both actions are performed simultaneously to obtain the voltage follower circuit as shown in Fig.(2).

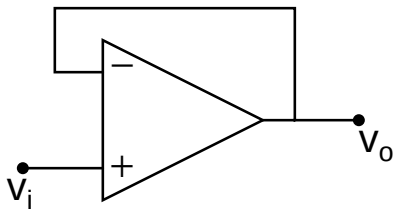


Figure 2: The voltage follower or buffer amplifier

The voltage follower is so called as the output voltage follows the input with absolute faithfulness. Besides, it eliminates the presence of loading - it tends to separate the load from the source. It behaves like an voltage controlled voltage source (VCVS). VCVS is another name for voltage buffer and it job is to isolate the effects of source and load. VCVS has the following properties: $R_i = \infty$ and $R_o = 0$ Fig.(3) clarifies the necessity for VCVS.

Any practical voltage source can be modelled as an ideal voltage source with a series resistance R_s coming along with it. If it were directly connected to load the voltage experienced by the load is:

$$v_L = \frac{R_L}{R_s + R_L} v_i \tag{1}$$

It is less than the intended voltage v_i. Now, we will insert the VCVS or buffer as seen in Fig.(4) to see the isolation process:

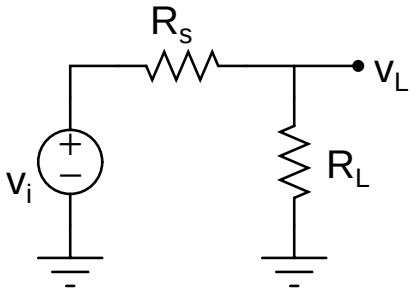


Figure 3: A practical voltage source connected to load.

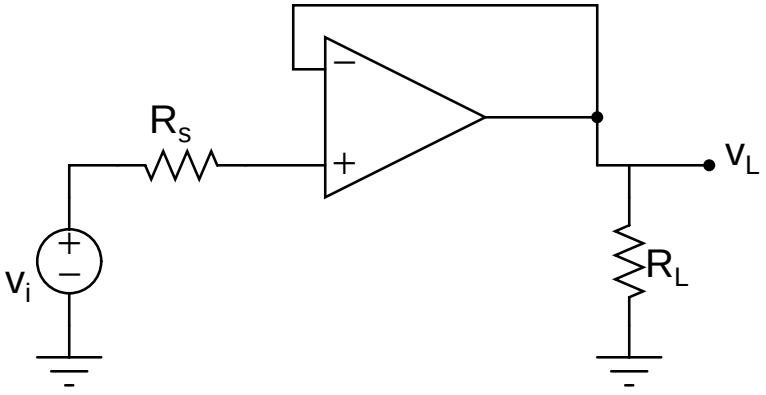


Figure 4: Source-load isolation using voltage follower.

Since the input impedance is infinity for an ideal opamp, no current flows through R_s and hence no voltage loss occurs across it. Hence, we have $v_+ = v_i$. The voltage follower configuration makes the output equal to $v_L = v_+ = v_i$. The voltage follower makes the practical voltage source appear as though it were an ideal voltage source nullifying the effect of R_s. Table (1) shows the properties of other controlled sources which we will see later.

Controlled Source	R_i	R_o
VCVS	∞	0
VCCS	∞	∞
CCVS	0	0
CCCS	0	∞

Table 1: Properties of controlled sources

Next, we see some applications of opamp. In all these circuits the opamp is embedded in negative feedback loop.

1.2 Inverting Summing Amplifier

We will now turn our attention to an important amplifier called as the Summer or Summing amplifier whose circuit is shown in Fig.(5).

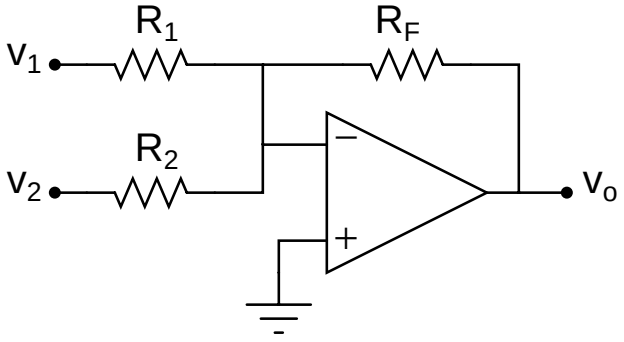


Figure 5: The summing amplifier

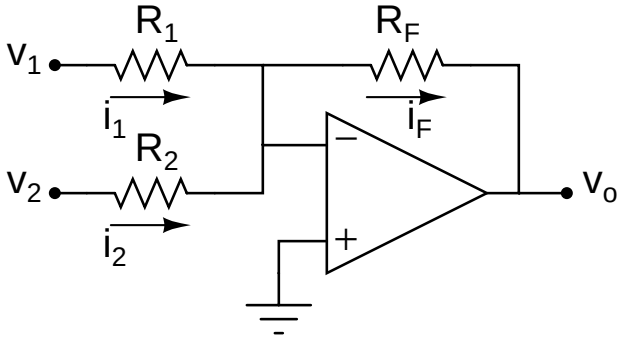


Figure 6: Summing Amplifier Analysis

From Fig.(6), since v_- is at virtual ground we have,

$$
\begin{aligned}
i_1 &= \frac{v_1}{R_1} && (2)\\
i_2 &= \frac{v_2}{R_2} && (3)\\
i_F &= i_1 + i_2 && (4)\\
&= \frac{v_1}{R_1} + \frac{v_2}{R_2} && (5)\\
-\frac{v_o}{R_F} &= \frac{v_1}{R_1} + \frac{v_2}{R_2} && (6)\\
\Rightarrow v_o &= -\left(\frac{R_F}{R_1}v_1 + \frac{R_F}{R_2}v_2\right) && (7)
\end{aligned}
$$

The output voltage v_o is the weighted sum of inputs v_1 and v_2 with weights $\frac{R_F}{R_1}$ and $\frac{R_F}{R_2}$, respectively. When the special condition $R_F = R_1 = R_2$ holds then,

$$v_o = -(v_1 + v_2) \tag{8}$$

The output is the negative of the sum of the input voltages and hence this circuit is called inverting summing amplifier. The circuit can be extended easily for three or more inputs.

1.3 Non-Inverting Summing Amplifier

Fig.(7) shows the non-inverting counterpart of the circuit shown in previous section.

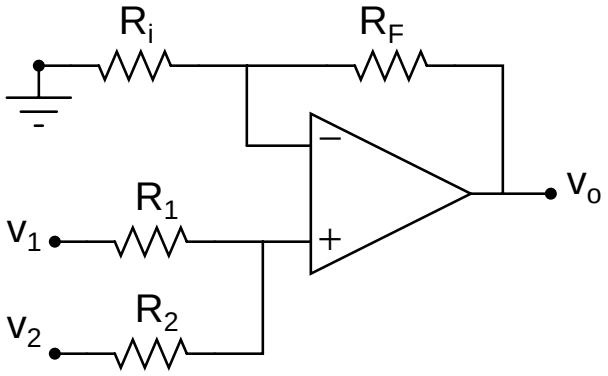


Figure 7: Non-Inverting Summing Amplifier

Now, this circuit appears a little tricky for analysis. However, we can use source superposition and analyze by using one source at a time. If v_2 is shorted and v_1 is only present (as seen in Fig.(8)), then the analysis proceeds as follows:

$$v_+ = \frac{R_2}{R_1 + R_2} v_1 \tag{9}$$

$$v_- = v_+ = \frac{R_2}{R_1 + R_2} v_1 \tag{10}$$

The voltage v_+ experiences the same gain as that of non-inverting amplifier of gain $1 + \frac{R_F}{R_i}$. That is the partial output due to v_1 is,

$$v_{o1} = \left(1 + \frac{R_F}{R_i}\right) \frac{R_2}{R_1 + R_2} v_1. \tag{11}$$

Likewise, the partial output due to the input v_2 is:

$$v_{o2} = \left(1 + \frac{R_F}{R_i}\right) \frac{R_1}{R_1 + R_2} v_2 \tag{12}$$

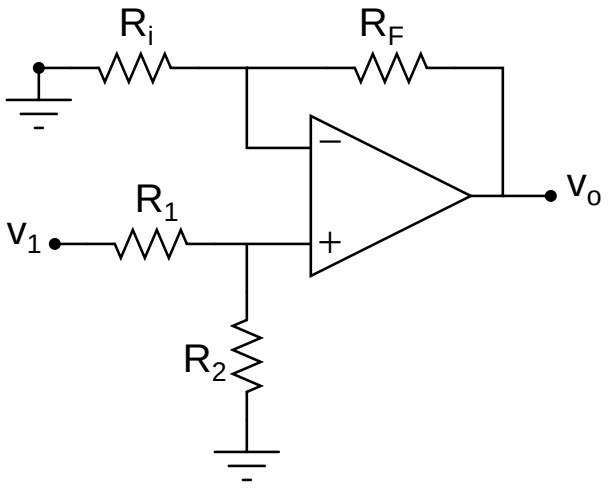


Figure 8: Non-Inverting Summing Amplifier Analysis

The total output is,

$$v_o = v_{o1} + v_{o2} = \left(1 + \frac{R_F}{R_i}\right) \frac{v_1 R_2 + v_2 R_1}{R_1 + R_2}. \tag{13}$$

In the special condition that all resistors are equal $R_1 = R_2 = R_i = R_F = R$ we have,

$$v_o = (1+1)\frac{v_1 + v_2}{1+1} = v_1 + v_2 \tag{14}$$

and is rightly called the Non-Inverting Summing Amplifier. Once again this procedure can be extended to three or more inputs.

1.4 Subtractor

Fig.(9) shows the subtractor circuit with all resistors equal.

Once again we use source superposition and apply each source induvidually. When v_1 is only present we short circuit v_2. The resulting circuit is shown in Fig.(10) In this circumstance $v_+ = 0$V as no current flows into opamp due to high input impedance. The circuit behaves as though it is an Inverting Amplifier with the partial output being,

$$v_{o1} = -\frac{R}{R} v_1 = -v_1 \tag{15}$$

When we switch roles, this time with v_1 shorted, the circuit is identical to an Non-Inverting Amplifier with gain $1 + \frac{R}{R} = 2$, however we also note that $v_+ = \frac{v_2}{2}$ because of voltage divider action (see Fig.(11)). Hence,

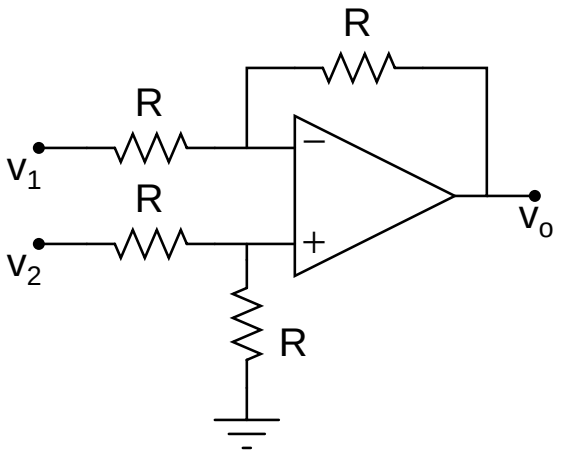


Figure 9: Opamp Subtractor Circuit

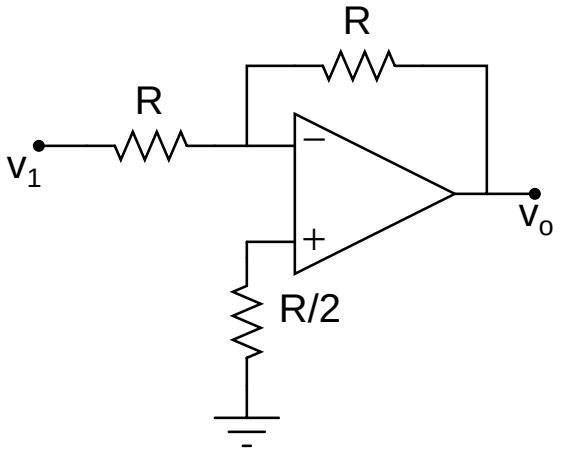


Figure 10: Subtractor with Partial input v_1

$$v_{o2} = \left(1 + \frac{R}{R}\right) \frac{v_2}{2} = v_2. \tag{16}$$

Finally, the total output is $v_o = v_{o1} + v_{o2} = v_2 - v_1$, hence the name subtractor.

1.5 Excercises

1. Design a circuit that simply adds three voltages.

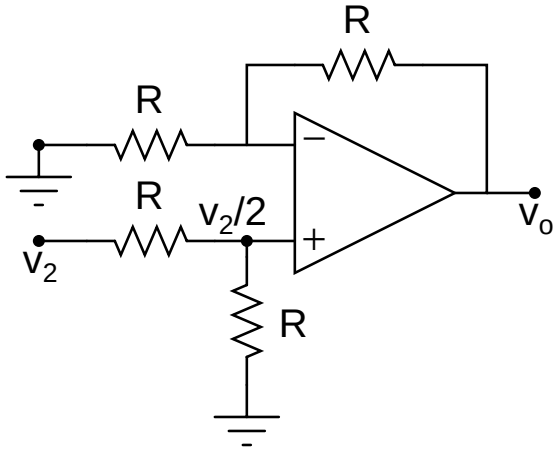


Figure 11: Subtractor with partial input v_2