EE 254

Electronic Instrumentation

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Lecture Note #04

Content (Brief)

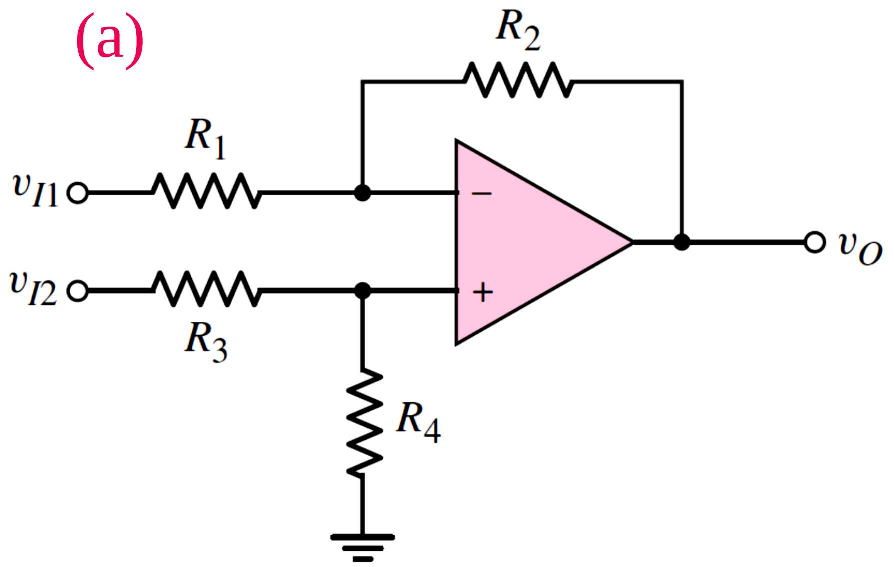
2. Op-Amp Applications

- Linear Applications
  - Inverting amplifiers
  - Noninverting amplifiers
  - Differential amplifiers
  - Summing amplifiers
  - Integrators
  - Differentiators
  - Low/ High pass filters
  - Instrumentational amplifiers
- Nonlinear Applications
  - Precision rectifiers
  - Peak detectors
  - Schmitt-trigger comparator
  - Logarithmic amplifiers

Differential Amplifier

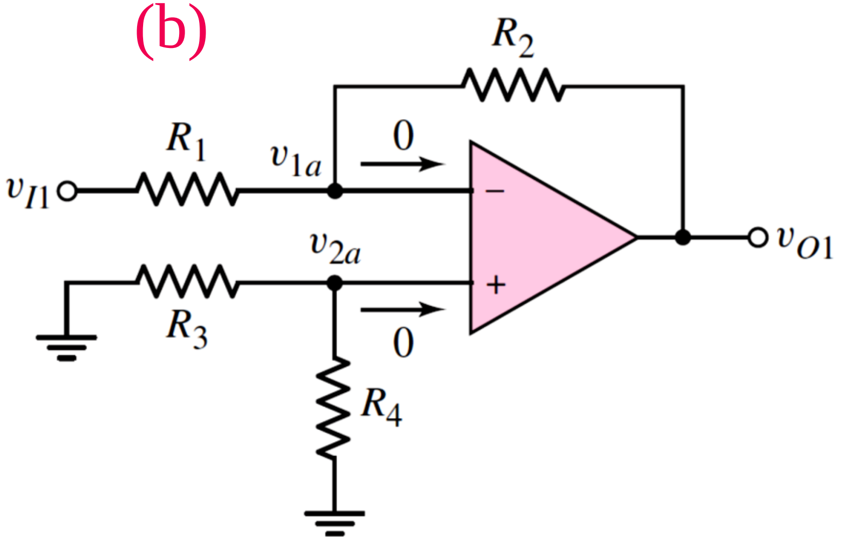
Differential Amplifier

(a)

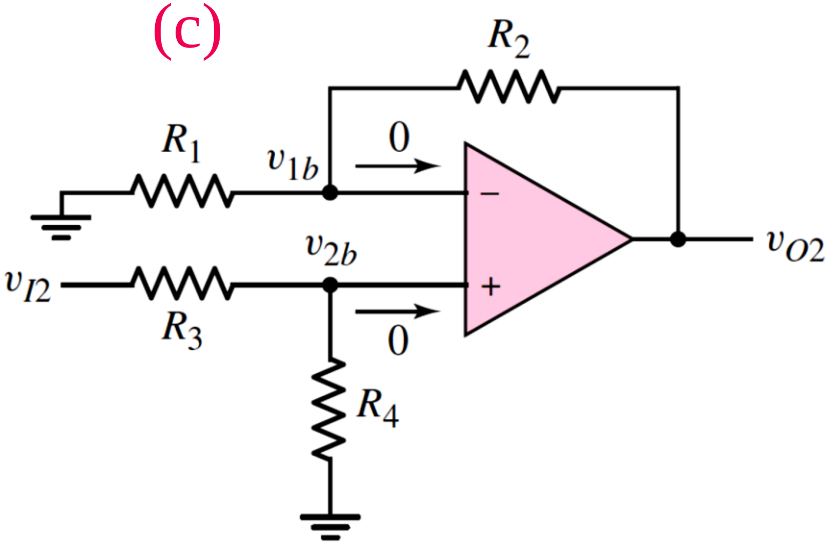


Using the **Superposition Theorem** and the **virtual short concept**

(b)

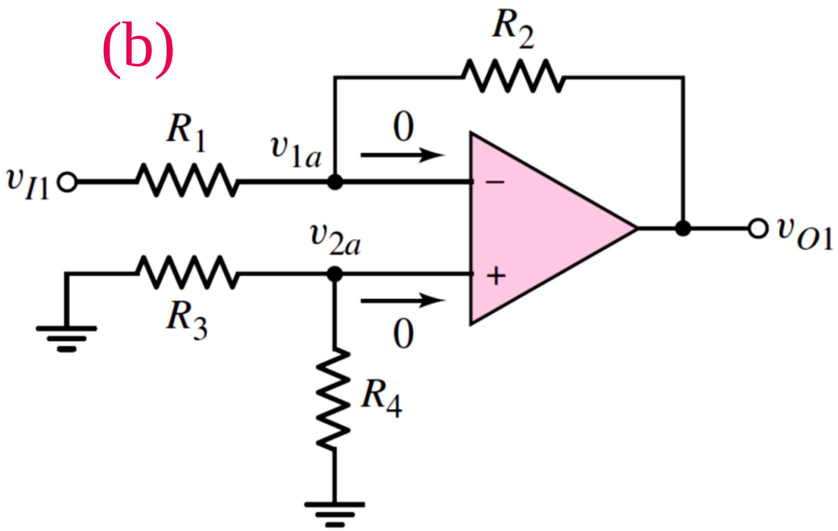


(c)



Differential Amplifier

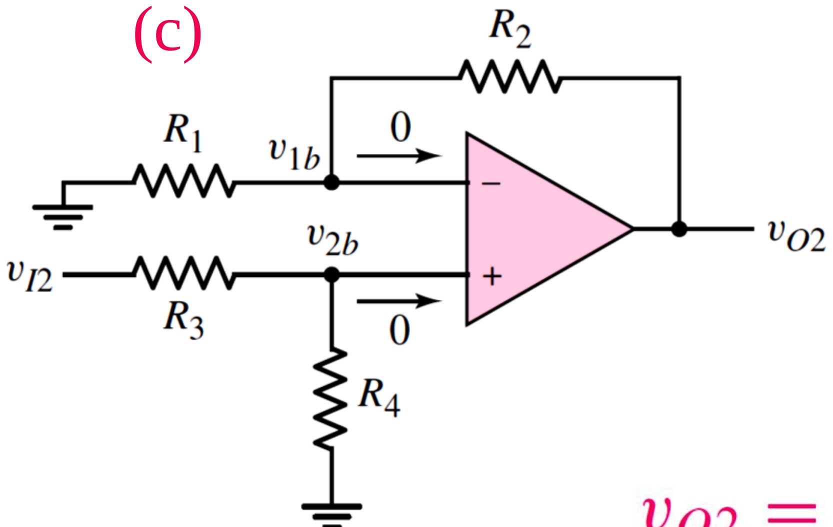
(b)



$$v_{O1} = -\frac{R_2}{R_1} v_{I1}$$

$$v_{2b} = \frac{R_4}{R_3 + R_4} v_{I2}$$

(c)

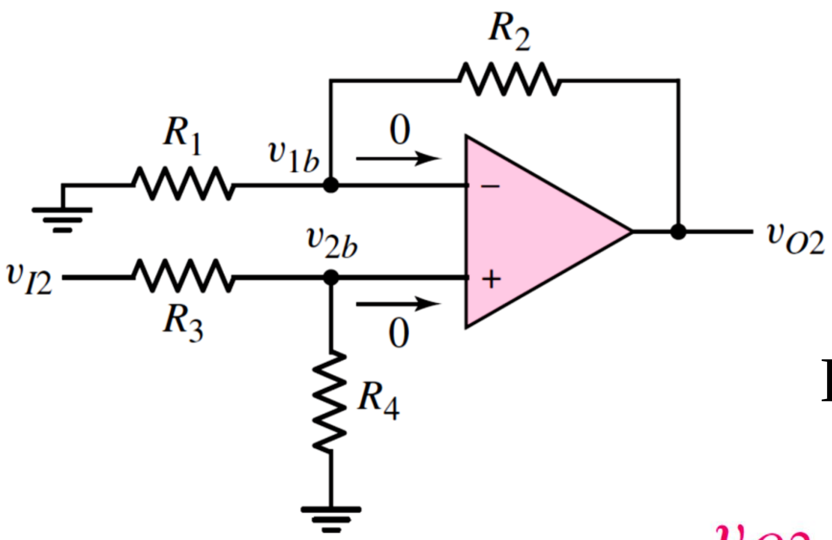


Using the virtual short concept

$$v_{1b} = v_{2b}$$

$$v_{O2} = \left(1 + \frac{R_2}{R_1}\right) v_{1b} = \left(1 + \frac{R_2}{R_1}\right) v_{2b}$$

Differential Amplifier



Then,

$$v_{O2} = \left(1 + \frac{R_2}{R_1}\right)\left(\frac{R_4}{R_3 + R_4}\right)v_{I2}$$

By rearranging,

$$v_{O2} = (1 + R_2/R_1)\left(\frac{R_4/R_3}{1 + R_4/R_3}\right)v_{I2}$$

Found that:

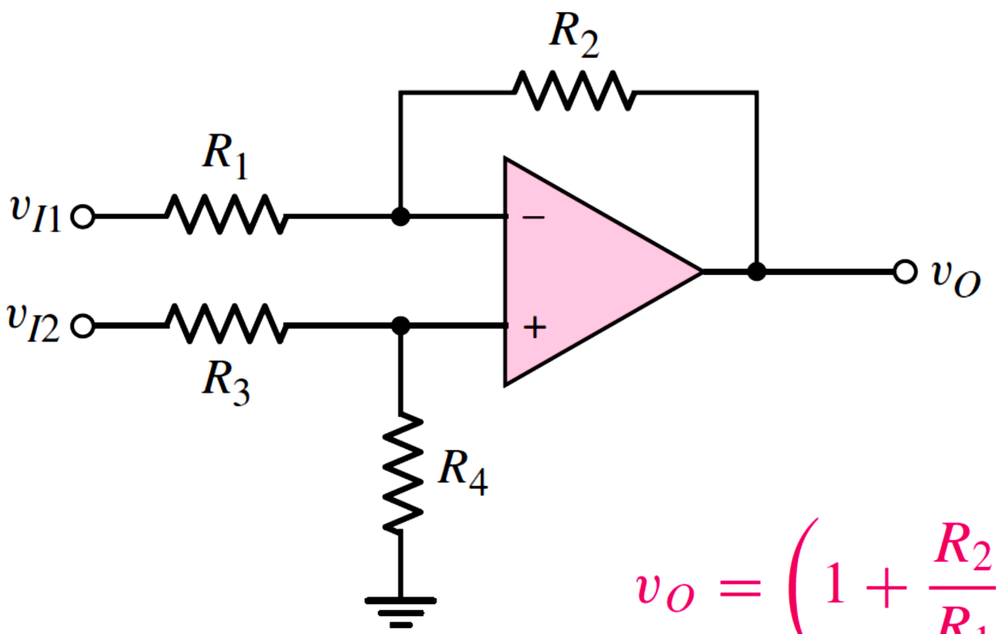
$$v_{O1} = -\frac{R_2}{R_1}v_{I1}$$

Since the net output voltage is the sum of the individual terms

$$v_O = v_{O1} + v_{O2}$$

$$v_O = \left(1 + \frac{R_2}{R_1}\right)\left(\frac{\frac{R_4}{R_3}}{1 + \frac{R_4}{R_3}}\right)v_{I2} - \left(\frac{R_2}{R_1}\right)v_{I1}$$

Differential Amplifier



A property of the ideal difference amplifier is that the output voltage is zero when

$$v_{I1} = v_{I2}$$

$$v_O = \left(1 + \frac{R_2}{R_1}\right)\left(\frac{\frac{R_4}{R_3}}{1 + \frac{R_4}{R_3}}\right)v_{I2} - \left(\frac{R_2}{R_1}\right)v_{I1}$$

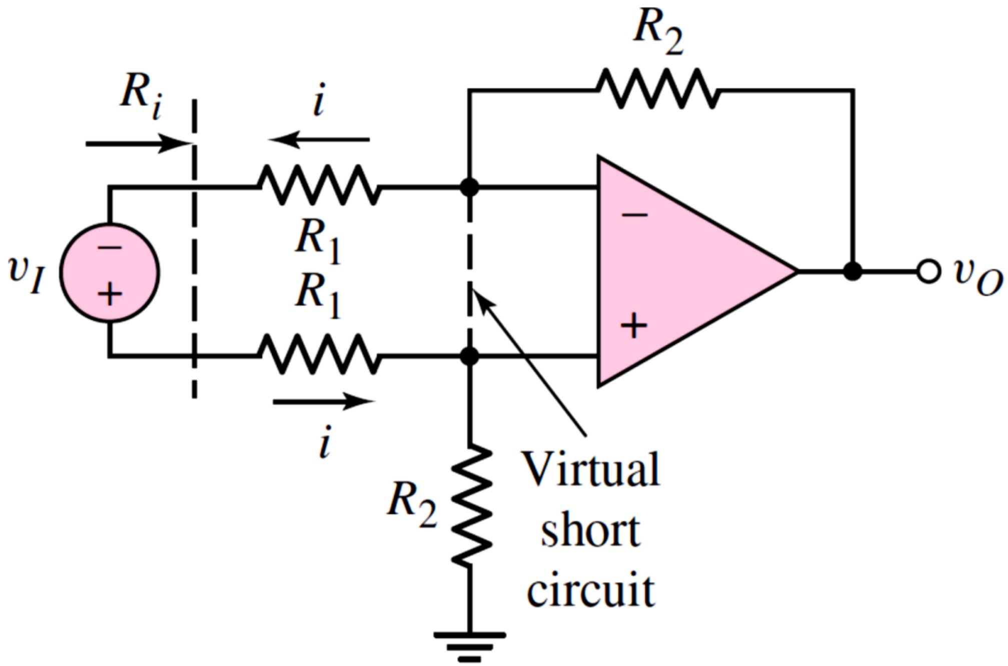
Then to meet this condition,

$$\frac{R_4}{R_3} = \frac{R_2}{R_1}$$

The output voltage

$$v_O = \frac{R_2}{R_1}(v_{I2} - v_{I1})$$

Differential Amplifier



Calculation of the differential input resistance

We set

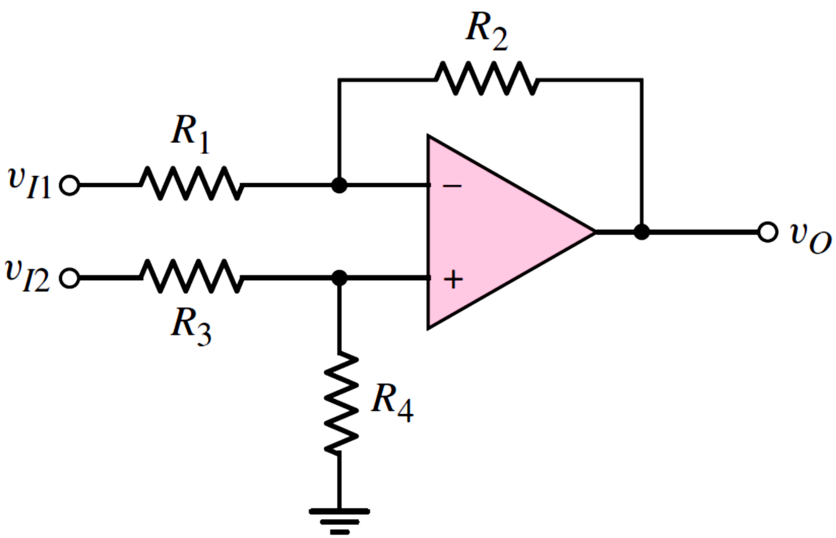
$R_1 = R_3$ And $R_2 = R_4$

The input resistance $$R_i = \frac{v_I}{i}$$

Taking into account the virtual short concept;

$$v_I = iR_1 + iR_1 = i(2R_1) \qquad R_i = 2R_1$$

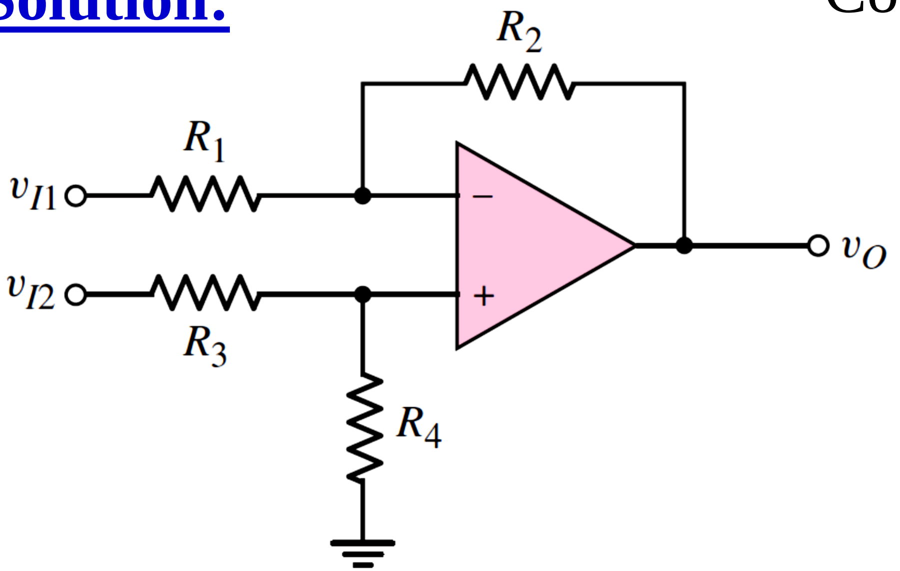
Ex.01: Design a Difference Amplifier



Design the difference amplifier with the configuration shown in Figure such that the differential gain is 30. Standard valued resistors are to be used and the maximum resistor value is to be $500\ k\Omega$.

Ex.01: Design a Difference Amplifier

Solution:



Consider an ideal op-amp available.

The differential gain:

$$\frac{R_2}{R_1} = \frac{R_4}{R_3} = 30$$

We can select standard resistors;

$$R_2 = R_4 = 390k\Omega$$

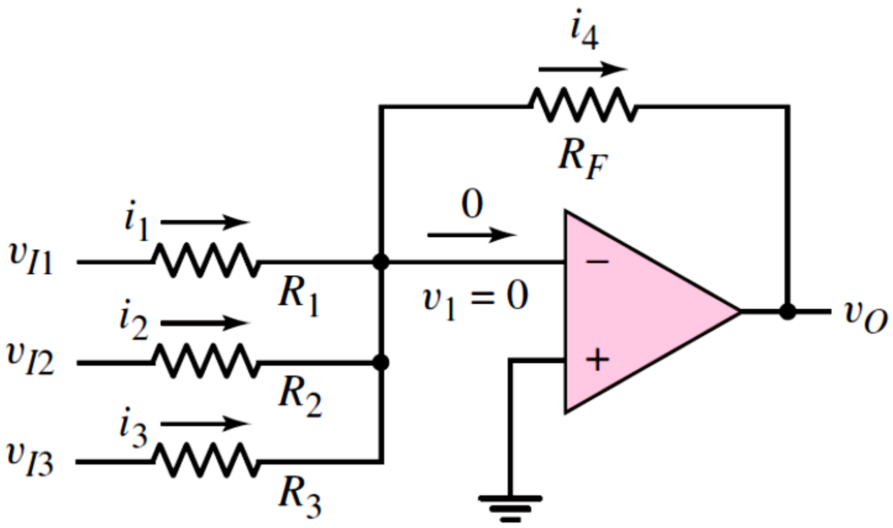
and $$R_1 = R_3 = 13k\Omega$$

These resistor values are obviously less than $500k\Omega$ and will give an input resistance of $R_i = 2R_1 = 2(13) = 26k\Omega$.

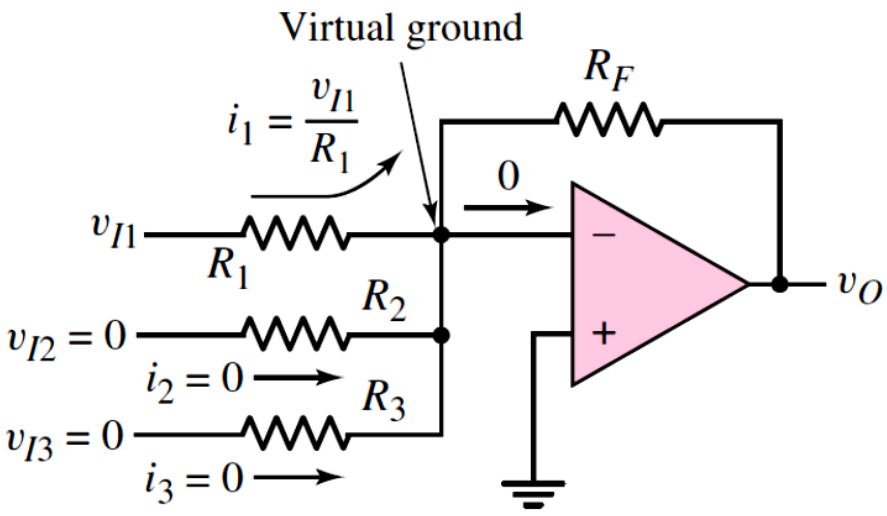
Resistor tolerances must be considered as we have done in other designs.

Summing Amplifier

Summing Amplifier



Summing op-amp amplifier circuit



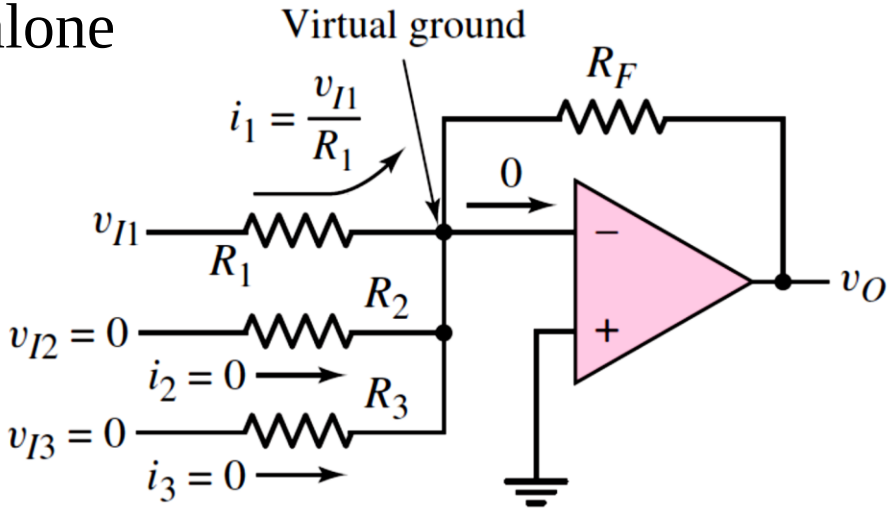
Currents and Voltages

If we set $v_{I2} = v_{I3} = 0$, the current i_1 is

$$i_1 = \frac{v_{I1}}{R_1}$$

Summing Amplifier

The output voltage due to v_{I1} acting alone



$$v_O(v_{I1}) = -i_1 R_F = -\left(\frac{R_F}{R_1}\right) v_{I1}$$

The output voltage due to v_{I2} and v_{I3}

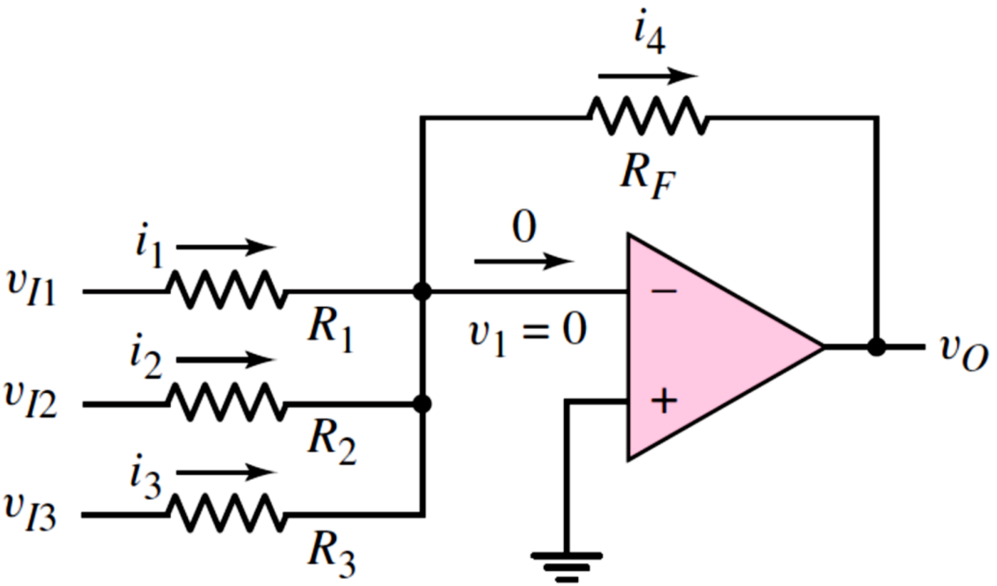
$$v_O(v_{I2}) = -i_2 R_F = -\left(\frac{R_F}{R_2}\right) v_{I2}$$

$$v_O(v_{I3}) = -i_3 R_F = -\left(\frac{R_F}{R_3}\right) v_{I3}$$

Which becomes

$$v_O = -\left(\frac{R_F}{R_1} v_{I1} + \frac{R_F}{R_2} v_{I2} + \frac{R_F}{R_3} v_{I3}\right)$$

Summing Amplifier



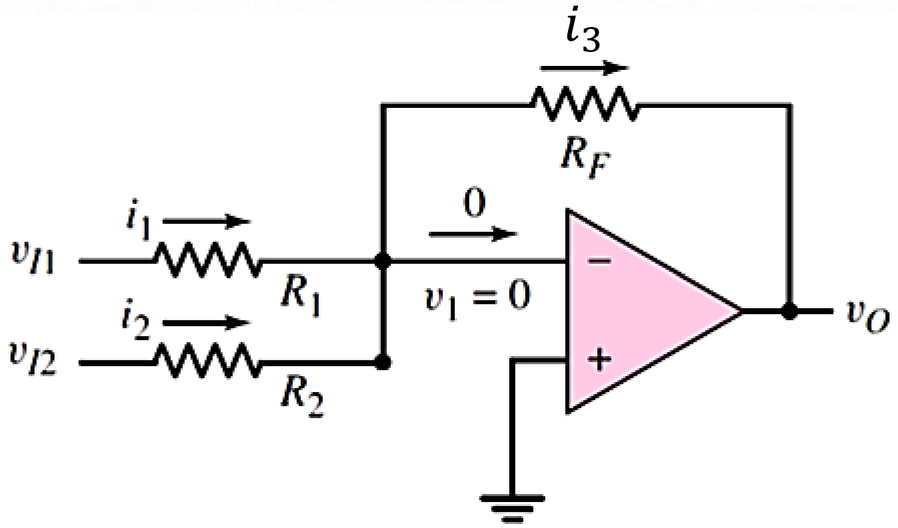
$$v_O = -\left(\frac{R_F}{R_1}v_{I1} + \frac{R_F}{R_2}v_{I2} + \frac{R_F}{R_3}v_{I3}\right)$$

When $R_1 = R_2 = R_3 \equiv R$, then

$$v_O = -\frac{R_F}{R_1}(v_{I1} + v_{I2} + v_{I3})$$

Ex.02: Design a Summing Amplifier

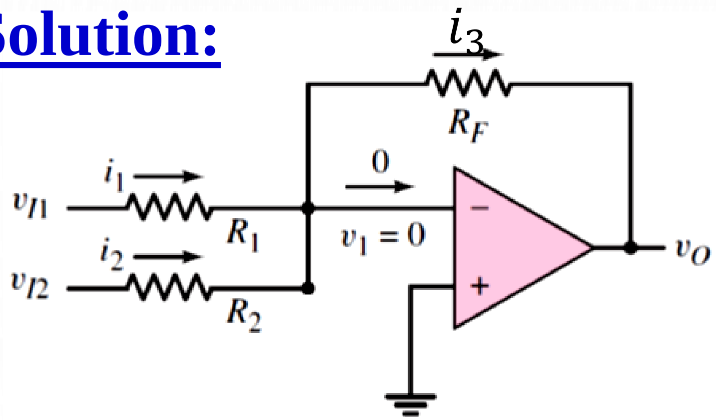
The output signal generated from an ideal amplifier circuit is $v_{O1} = 1.2 - 0.5\sin(\omega t)\ (V)$. Design a summing amplifier to be connected to the amplifier circuit such that the output signal is $v_O = 2\sin(\omega t)\ (V)$.



Choices: Standard precision resistors with tolerances of ±1 % are to be used in the final design. Assume an ideal op-amp is available.

Ex.02: Design a Summing Amplifier

Solution:



One input to the summing amplifier is

$$v_{I1} = v_{O1} = 1.2 - 0.5\sin(\omega t)\ (V)$$

The output of the summing amplifier is

$$v_O = 2\sin(\omega t)\ (V)$$

- If the voltage gains of each input to the summing amplifier are equal, then an input of −1.2 V at the second input will cancel the +1.2 V from the amplifier circuit.
- For a −0.5V sinusoidal input signal and a desired 2V sinusoidal output signal, the summing amplifier gain must be;

$$A_v = -\frac{R_F}{R_1} = -\frac{2}{0.5} = -4$$

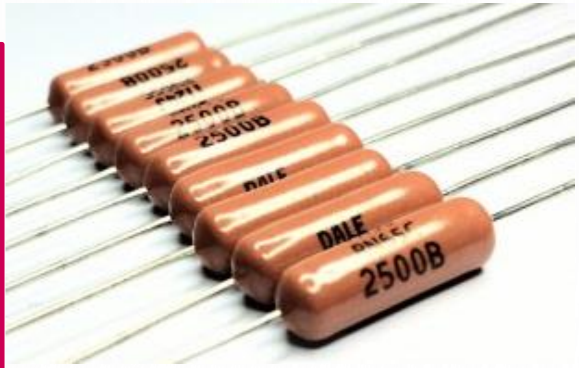
- If we choose the input resistances to be $R_1 = R_2 = 30\ k\Omega$, then the feedback resistance must be $R_F = 120\ k\Omega$.

Ex.02: Design a Summing Amplifier

Solution: **Trade-offs**

Table: Standard precision resistance values (1% Tolerance)

100	140	196	274	383	536	750
102	143	200	280	392	549	768
105	147	205	287	402	562	787
107	150	210	294	412	576	806
110	154	215	301	422	590	825
113	158	221	309	432	604	845
115	162	226	316	442	619	866
118	165	232	324	453	634	887
121	169	237	332	464	649	909
124	174	243	340	475	665	931
127	178	249	348	487	681	953
130	182	255	357	499	698	976
133	187	261	365	511	715	
137	191	267	374	523	732	



Metal-film precision resistors can have tolerance levels in the 0.5 % to 1% range.

Ex.02: Design a Summing Amplifier

Solution: **Trade-offs**

$$v_O = -\frac{R_F}{R_1} \cdot (1.2 - 0.5 \sin \omega t) - \frac{R_F}{R_1} \cdot (-1.2)$$

- From the table, we can choose precision resistor values of $R_F = 124k\Omega$ and $R_1 = R_2 = 30.9k\Omega$. The ratio of the ideal resistors is 4.013.
- Considering the ±1 percent tolerance values, the output of the summing amplifier will be:

$$v_O = -\frac{R_F(1 \pm 0.01)}{R_1(1 \pm 0.01)} \cdot (1.2 - 0.5 \sin \omega t) - \frac{R_F(1 \pm 0.01)}{R_1(1 \pm 0.01)} \cdot (-1.2)$$

- The dc output voltage is in the range

$$-0.1926 \leq v_O(dc) \leq 0.1926\,V$$

- The peak ac output voltage is in the range

$$1.967 \leq v_O(ac) \leq 2.047\,V$$