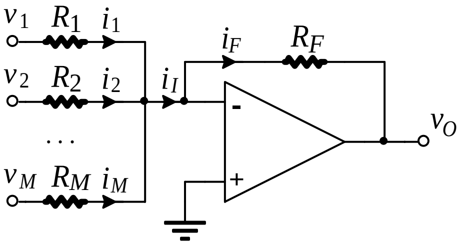
Linear Combination Circuit

The circuit has two or more inputs and one output such that:

$$v_O = A_1 v_1 + A_2 v_2 + ... + A_M v_M \ ,$$

where $A_1, A_2, \ldots, A_M$. Are constant values and v_O is said to be a linear combination of the voltages v_1 through v_M.



$$i_1 + i_2 + ... + i_M = i_F \ , \ v_O = -i_F \cdot R_F$$

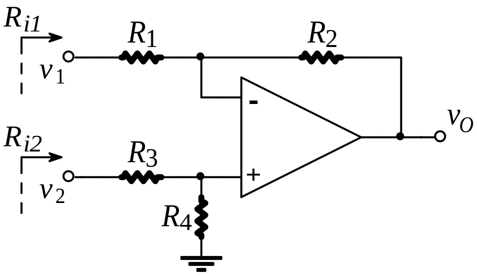
$$\frac{v_1}{R_1} + \frac{v_2}{R_2} + ... + \frac{v_M}{R_M} = -\frac{v_O}{R_F}$$

$$v_O = -\frac{R_F}{R_1} v_1 + -\frac{R_F}{R_2} v_2 + ... + -\frac{R_F}{R_M} v_M$$

For $R_1 = R_2 = ... = R_M = R_F$ the circuit is an **inverting summing circuit**:

$$v_O = -(v_1 + v_2 + ... + v_M) .$$

The Differential Amplifier



The circuit has one output and two inputs, one applied to the inverting terminal and the other one to the non-inverting terminal of the Op Amp.

The circuit is easily analyzed through the principle of superposition: $v_O = v_{O1} + v_{O2}$, where v_{O1} is the value of v_O with v_2 set to zero and v_{O2} that wit v_1 set to zero.

A) $v_2 = 0 \Rightarrow v_P = 0$, the circuit acts as an inverting amplifier:

$$v_{O1} = -\frac{R_2}{R_1} v_1$$

The input resistance seen by v_1 is R_1.

B) For the circuit acts as a non-inverting amplifier with the input voltage taken from a voltage divider output:

$$v_{O2} = \left(1 + \frac{R_2}{R_{`}}\right) \cdot v_P = \left(1 + \frac{R_2}{R_1}\right) \cdot \frac{R_4}{R_4 + R_3} \cdot v_2$$

The input resistance seen by v_2 is R_3+R_4.

The resistances seen by the voltage sources are finite and different. If the sources are non-ideal, the circuit will load them down generally by a different amount. In the v_O equation one should replace R_1 by R_1+R_{s1} and R_2 by R_2+R_{s2}, where R_{s1} and R_{s2} are the output resistances of the sources and v_O will depend on the sources internal resistances.

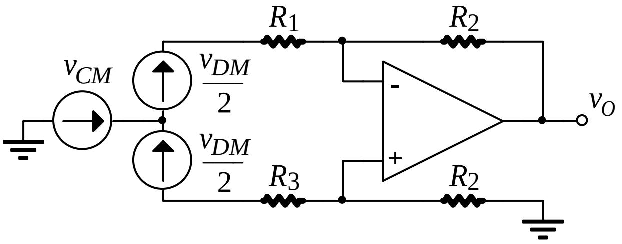
For $\frac{R_3}{R_4} = \frac{R_1}{R_2}$, the resistances form a balanced bridge:

$$v_O = \frac{R_2}{R_1} (v_2 - v_1) .$$

The balanced bridge circuit is a **difference amplifier**.

The difference amplifier forms the basis of the instrumentation and bridge amplifiers.

The input can be expressed in terms of common-mode and differential-mode components v_{CM} and v_{DM}:



$v_{DM} = v_2 - v_1$, $v_{CM} = \frac{v_2 + v_1}{2}$ and

$v_1 = v_{CM} - \frac{v_{DM}}{2}$, $v_2 = v_{CM} + \frac{v_{DM}}{2}$.

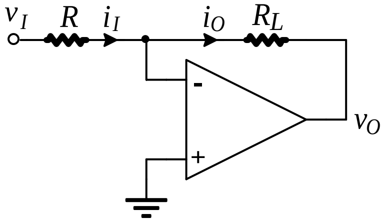
A true difference amplifier can be defined as a circuit that responds only to the differential mode component v_{DM}. If we apply a common-mode voltage v_{CM} and $v_{DM}=0$, a true difference amplifier will yield $v_O=0$.

In practice the useful signal is the differential one, and common-mode signal is produced by noise from environment.

For an ideal Op Amp if the bridge is unbalanced, the circuit will respond not only to v_{DM} but also to v_{CM}. This effect can be investigated by introducing the imbalance factor ε. We assume that three of the resistances posses their nominal value while the fourth is expressed as $R_2(1-\varepsilon)$ to account for the imbalance…

Voltage Controlled Current Sources (VCCS)

Floating Load Inverting VCCS



A floating load does not have any connection to ground; both load terminals are available and are connected in place of the feedback resistance of the inverting configuration, as indicated in the next figure.

$i_I = \frac{v_I}{R}$, $i_I = i_O = \frac{v_I}{R}$. The output current i_O is independent on the load resistance R_L.

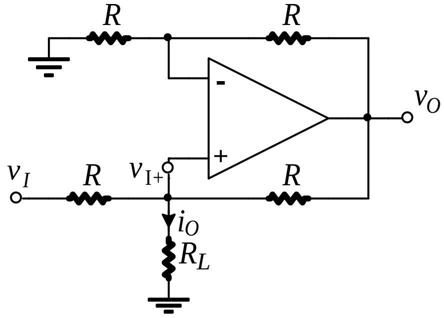
The current source parameter is the transconductance: $g_m = \frac{i_O}{v_I} = \frac{1}{R}$.

A limitation of the current source is the maximum possible voltage on the load. At the Op Amp output the voltage is limited by saturation. In order to have a linear operation (of the Op Amp) the output voltage should be less than saturation so that the limitation would be:

$$R_L \cdot |i_L| < V_{Sat}.$$

The input resistance of the control input is: $R_i = R$.

Grounded Load VCCS (Howland current source)



The current Kirchoff low write in the non-inverting input is:

$$\frac{v_O - v_{I+}}{R} = i_O + \frac{v_{I+} - v_I}{R}.$$

The voltage at the inverting input is the output voltage divided by the two equal resistances:

$v_{I-} = \frac{v_O}{2} (= v_{I+})$; by replacing in the previous equation:

$\frac{v_O}{2R} = i_O + \frac{v_O}{2} \cdot \frac{1}{R} - \frac{v_I}{R}$ the output current is: $i_O = \frac{v_I}{R}$.

The transconductance of the circuit is: $g_m = \frac{i_O}{v_I} = \frac{1}{R}$.

The constraint for linear operation: $v_O < V_{Sat}$, will give the limit of the load resistance from the equation: $v_{I+} < \frac{V_{Sat}}{2}$, that is: $R_L \cdot i_L < \frac{V_{Sat}}{2}$.

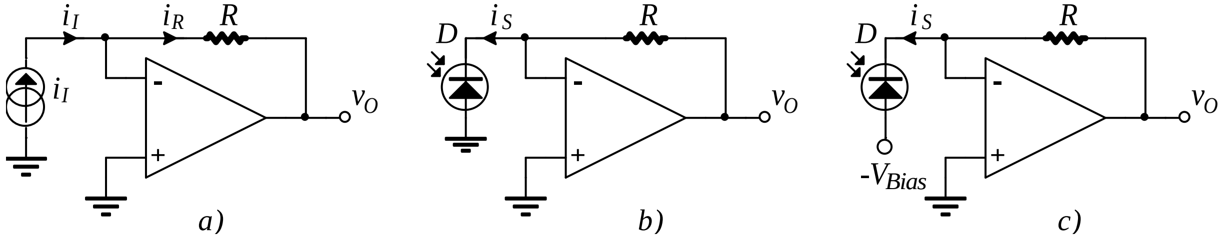
The 4 resistances should be closely matched.

Current to Voltage Converters

The basic circuit is given in the next figure, part *a)*. The equal currents give the transfer function of the circuit:

$$i_I = i_R = -\frac{v_O}{R},\ v_O = -R \cdot i_I .$$

The Op Amp eliminates loading effect both at the input and at the output of the circuit.



a) *b)* *c)*

Photo-detector Amplifier

One of the most widely used photodetectors (light detectors) is the silicon photodiode; there are two possible implementations:

- with zero bias – previous figure, *b)* – in the photovoltaic mode, it has low noise and it is used in the instrumentation applications;
- with reverse bias – previous figure, *c)* – in the photoconductive mode, it is used for high speed (high bandwidth) applications.

The reverse current of the photodiode, i_S, is proportional to the light, so the output voltage v_O would be also proportional to light.