Electronics
Semester 5

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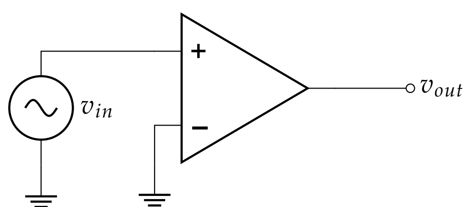
Contents

Chapter 1

Amplifiers

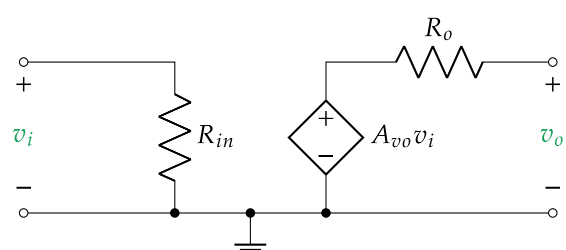
$$\text{Voltage Gain} = \frac{v_{out}}{v_{in}}$$
$$\text{Current Gain} = \frac{i_{out}}{i_{in}}$$
$$\text{Power Gain} = \frac{P_{out}}{P_{in}}$$



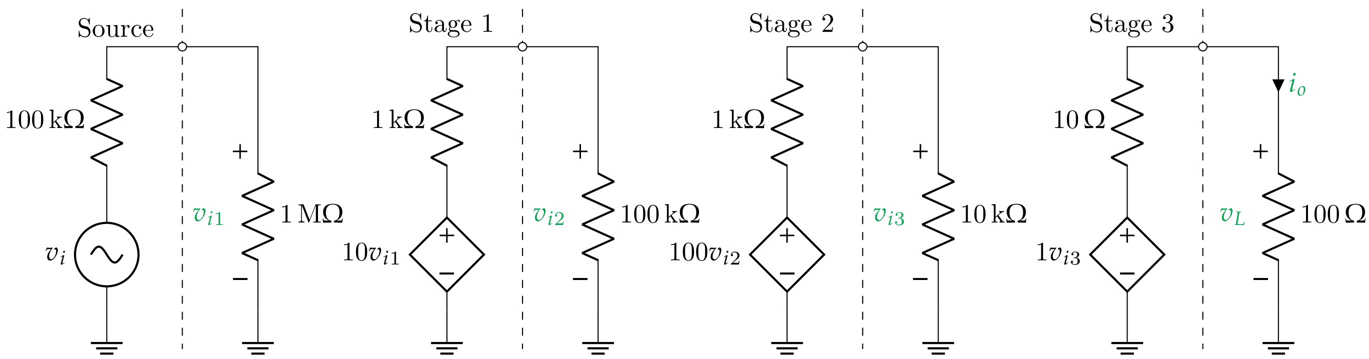
In decibels, the gain is given by

$$\text{Voltage Gain} = 20\log\left(\frac{v_{out}}{v_{in}}\right)$$
$$\text{Current Gain} = 20\log\left(\frac{i_{out}}{i_{in}}\right)$$
$$\text{Power Gain} = 10\log\left(\frac{P_{out}}{P_{in}}\right)$$

1.1 Equivalent Circuit of an Amplifier



1.2 Cascade Amplifiers



In the above circuit, the output voltage is given by

$$v_L = 10 \cdot \frac{1\,\mathrm{M\Omega}}{1\,\mathrm{M\Omega} + 100\,\mathrm{k\Omega}} \cdot 100 \cdot \frac{100\,\mathrm{k\Omega}}{100\,\mathrm{k\Omega} + 1\,\mathrm{k\Omega}} \cdot 1 \cdot \frac{10\,\mathrm{k\Omega}}{10\,\mathrm{k\Omega} + 1\,\mathrm{k\Omega}} \cdot \frac{100\,\Omega}{100\,\Omega + 10\,\Omega} \cdot v_i.$$

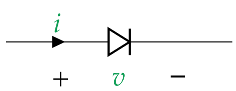
$$A_v = \frac{v_L}{v_i} = 743.876\,\mathrm{V/V}.$$

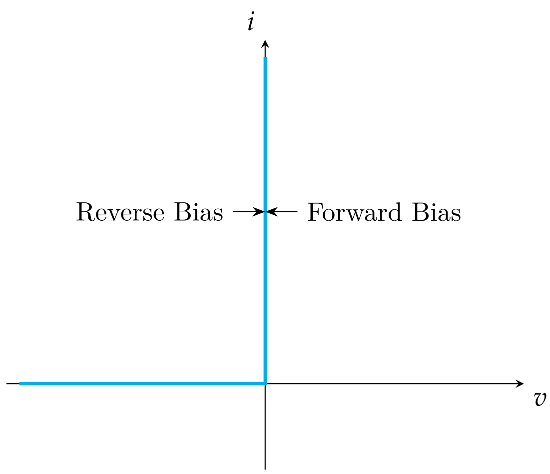
Chapter 2

Diodes

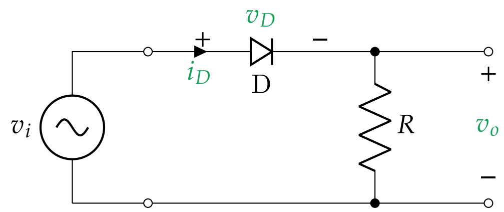
2.1 The Ideal Diode

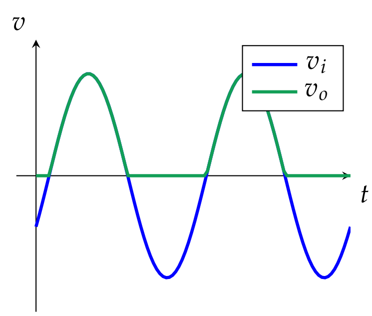
The ideal diode is a two terminal device that allows current to flow in one direction only.



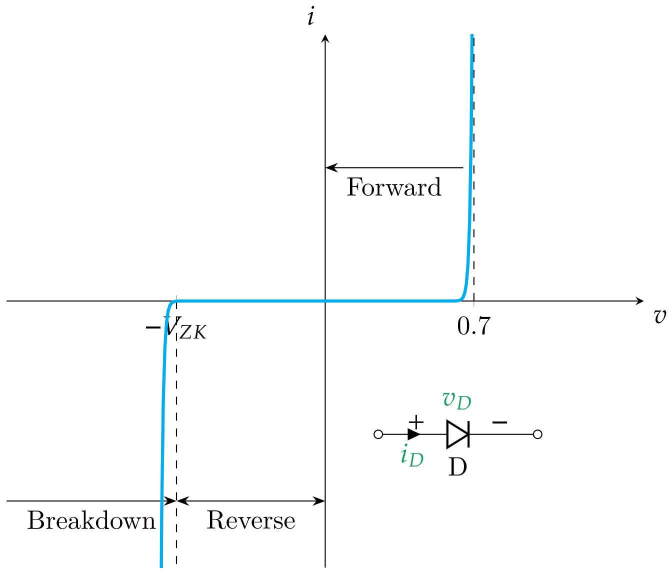


2.1.1 Simple Application: The Half-Wave Rectifier





2.2 Terminal Characteristics of Junction Diodes



The characteristic curve of a diode consists of three regions:

1. The forward bias region, where the diode conducts current. $v_D > 0$.
2. The reverse bias region, where the diode blocks current. $v_D < 0$.
3. The breakdown region, where the diode conducts current in the reverse direction. $v_D < -V_{ZK}$.

2.3 The Forward Bias Region

In the forward bias region, the diode conducts current. The current is given by

$$i = I_S \left(e^{v/V_T} - 1 \right).$$

Where I_S is the reverse saturation current, and $V_T \approx 25\,\mathrm{mV}$ is the thermal voltage.

2.4 Real Diode Models

2.4.1 The Exponential Model

The exponential model of a diode is given by

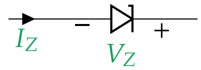
$$I_D = I_S e^{v_D/V_T}.$$

2.4.2 The Constant Voltage Model

This model assumes that the diode voltage is constant in the forward bias region at $V_\gamma = 0.7\,\mathrm{V}$.

2.5 Zener Diodes

A Zener diode is a diode that is designed to operate in the breakdown region.



For currents $I_Z > 0$, the characteristic curve of a Zener diode is almost vertical.

$$V_Z = V_{Z0} + r_z I_Z.$$

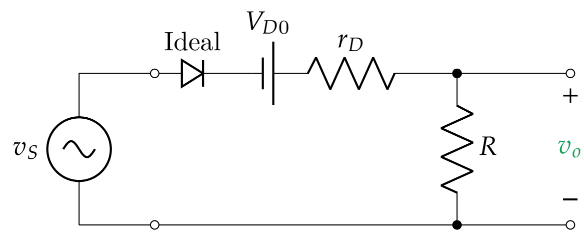
2.6 Diode Rectifiers

When selecting a diode for a rectifier, the following parameters should be considered:

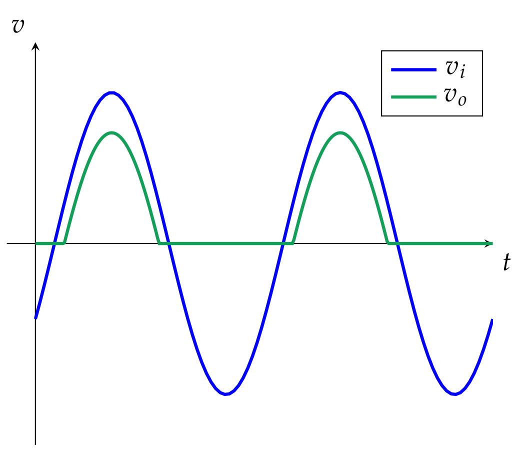
1. The current rating of the diode determined by the maximum current that the diode can handle.
2. The peak inverse voltage (PIV) rating of the diode determined by the maximum reverse voltage that the diode can handle.

2.6.1 The Half-Wave Rectifier

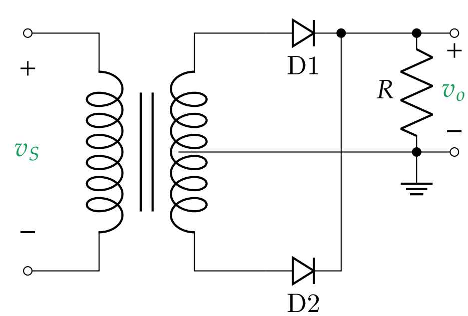
$$v_{\text{out}} = \begin{cases} v_{\text{in}} - V_{D0} & \text{if } v_{\text{in}} \geqslant V_{D0} \\ 0 & \text{if } v_{\text{in}} < V_{D0} \end{cases}.$$

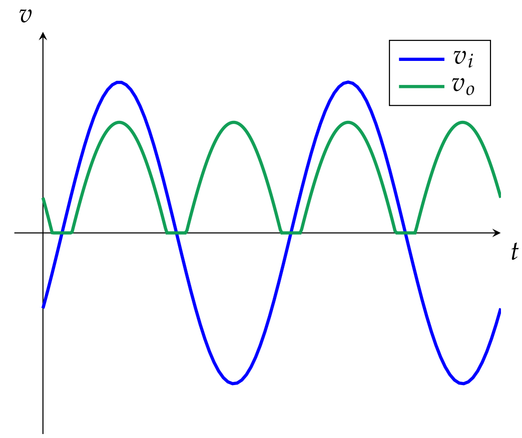


PIV = V_S (input voltage swing) and the diode breakdown voltage is selected to be 50 % higher.



2.6.2 Full-Wave Rectifier

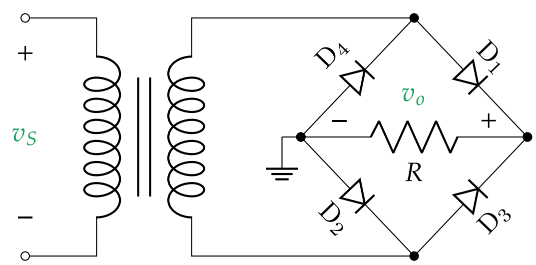


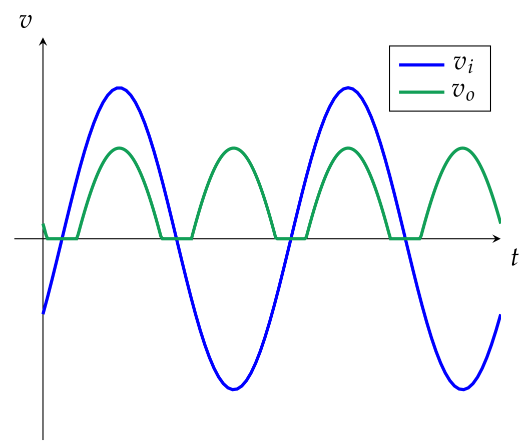


$$\text{PIV} = 2V_S - V_D.$$

2.6.3 The Bridge Rectifier

The difference between the bridge rectifier and the full-wave rectifier is that the bridge rectifier does not require a center-tapped transformer and requires more turn on voltage $2V_D$.



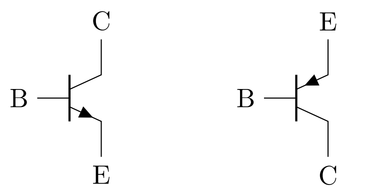


$$\text{PIV} = V_S - V_D.$$

Chapter 3

BJTs

A BJT is a Bipolar Junction Transistor. It is a current controlled device. It has three terminals: the base, the collector, and the emitter. The BJT is a three-layer, two-junction semiconductor device.



npn BJT pnp BJT

3.1 BJT Current-Voltage Relationships in the Active Mode

npn Transistor	pnp Transistor	Global
$i_C = I_S e^{v_{BE}/V_T}$	$i_C = I_S e^{v_{EB}/V_T}$	$i_E = i_C + i_B$
$i_B = \dfrac{i_C}{\beta}$	$i_B = \dfrac{i_C}{\beta}$	$\alpha = \dfrac{\beta}{\beta + 1}$
$i_E = \dfrac{i_C}{\alpha}$	$i_E = \dfrac{i_C}{\alpha}$	$\beta = \dfrac{\alpha}{1 - \alpha}$

3.2 BJT in DC

1. Cut-off mode:
   - $i_E = i_C = i_B = 0$
   - $v_{BE} < 0.5\,\mathrm{V}$ and $v_{BC} < 0.4\,\mathrm{V}$
2. Saturation mode:
   - $v_{BE} = 0.7\,\mathrm{V}$ and $i_B : i_C : i_E = 1 : \beta : \beta + 1$
   - $v_{CE} > 0.3\,\mathrm{V}$
3. Active mode:
   - $v_{BE} = 0.7\,\mathrm{V}$ and $v_{CE} = 0.2\,\mathrm{V}$
   - ${}^{i_C}/_{i_B} = \beta_{\text{forced}} < \beta$

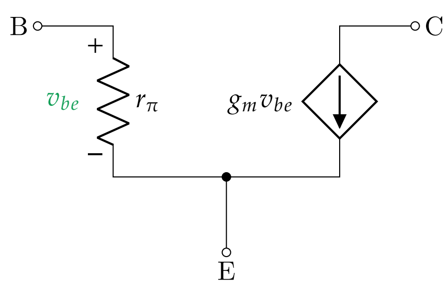
3.3 Small Signal Model of a BJT

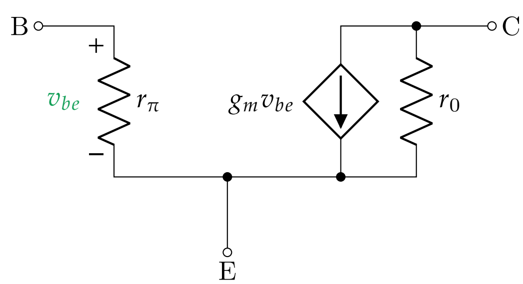
The transconductance of a BJT is given by

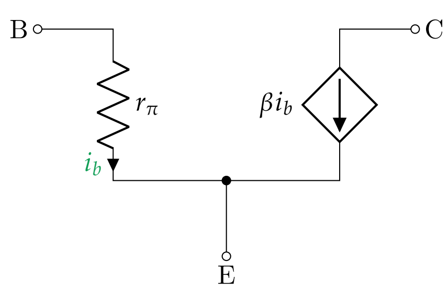
$$g_m = \left.\frac{\partial i_C}{\partial v_{BE}}\right|_{i_C = I_C} = \frac{I_C}{V_T}.$$

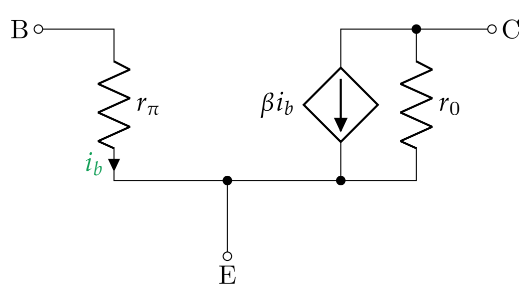
$$\begin{aligned} r_\pi &= \frac{\beta}{g_m} = \frac{V_T}{I_B} \\ r_e &= \frac{\alpha}{g_m} = \frac{V_T}{I_E} \\ r_0 &= \frac{V_A}{I_C} \end{aligned}$$

3.3.1 The Hybrid-π Model

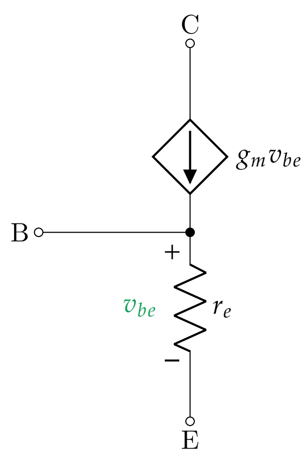


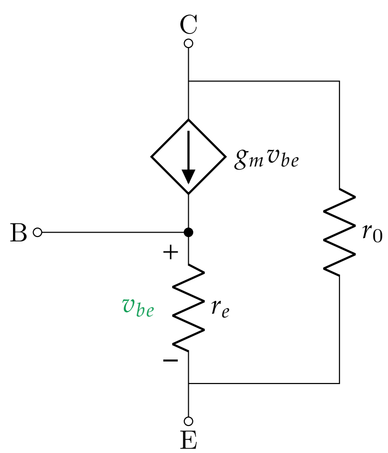


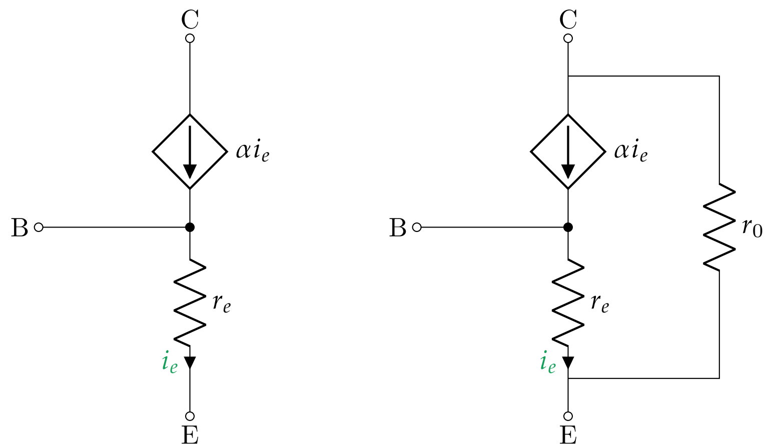




3.3.2 The T Model



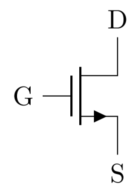



C
αi_e
B
r_e
i_e
E
C
αi_e
B
r_0
r_e
i_e
E

Chapter 4

MOSFETs

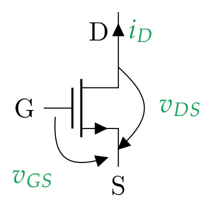
A MOSFET is a Metal Oxide Semiconductor Field Effect Transistor. It is a voltage controlled device. It has three terminals: the gate, the source, and the drain.



4.1 MOSFET Modes of Operation

Note:-

$$k_n = \mu_n C_{ox} \frac{W}{L}.$$



4.1.1 Cut-off

In this mode, the MOSFET is off ($i_D = 0$). The MOSFET is in cut-off when $v_{GS} \leqslant V_{th}$. Where V_{th} is the threshold voltage of the MOSFET.

4.1.2 Triode

In this mode, the MOSFET is on ($i_D \neq 0$). The MOSFET conducts current from the drain to the source. The MOSFET is in triode when $v_{GS} > V_{th}$ and $v_{DS} < v_{GS} - V_{th}$.

$$i_D = \mu_n C_{ox} \frac{W}{L} \left[(v_{GS} - V_{th}) v_{DS} - \frac{v_{DS}^2}{2} \right].$$

4.1.3 Saturation

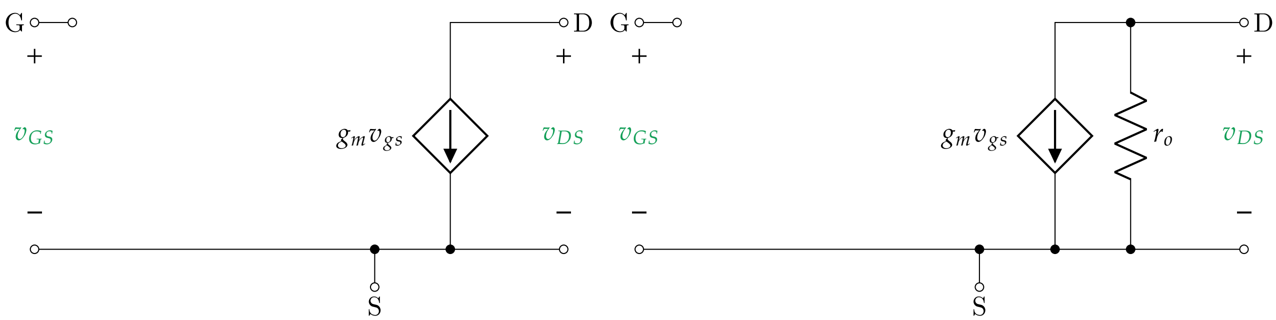
In this mode, the MOSFET is on ($i_D \neq 0$). The MOSFET conducts current from the drain to the source. The MOSFET is in saturation when $v_{GS} > V_{th}$ and $v_{DS} > v_{GS} - V_{th}$.

$$i_D = \frac{1}{2}\mu_n C_{ox}\frac{W}{L}(v_{GS} - V_{th})^2.$$

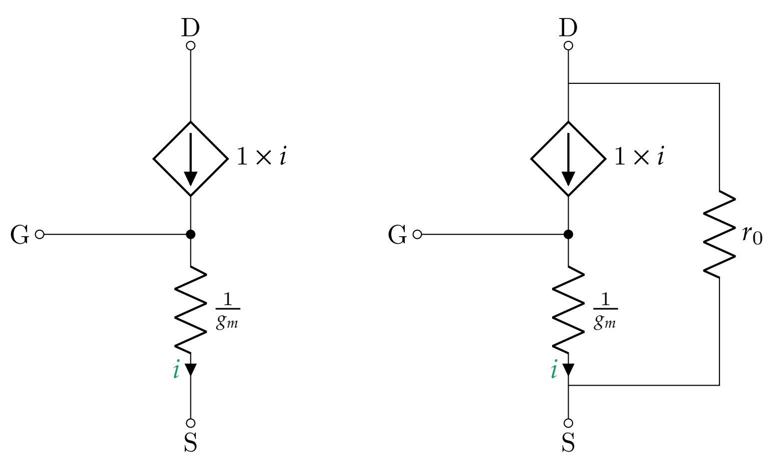
4.2 Small Signal Model of a MOSFET

$$g_m = \frac{2I_D}{V_{GS} - V_{th}}$$
$$r_o = \frac{V_A}{I_D} = \frac{1}{\lambda I_D}$$

4.2.1 The Hybrid-π Model



4.2.2 The T Model

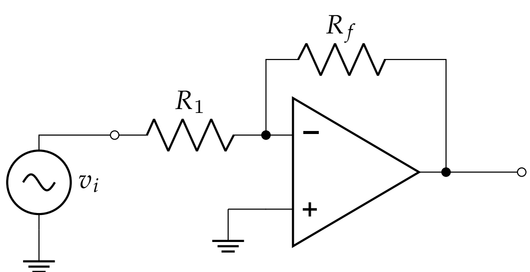


Chapter 5

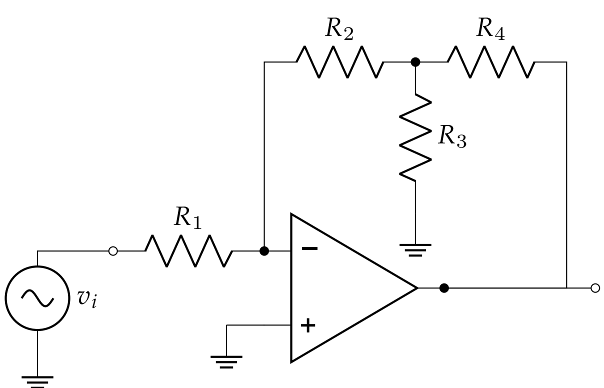
Operational Amplifiers

An operational amplifier is a high gain differential amplifier. It has two inputs: the inverting input and the non-inverting input. It has one output.

5.1 Inverting Configuration

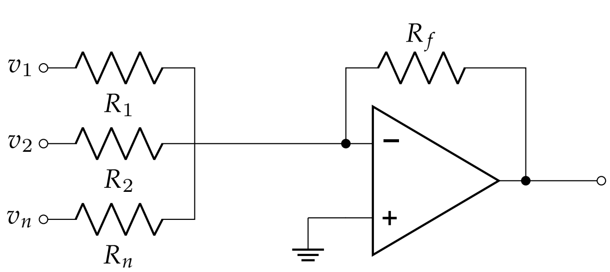


$$v_o = -\frac{R_f}{R_1} v_i$$



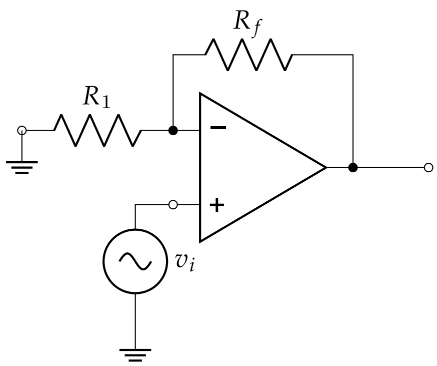
$$v_o = -\frac{R_2}{R_1}\left(1 + \frac{R_4}{R_2} + \frac{R_4}{R_3}\right) v_i$$

5.1.1 The Summing Amplifier



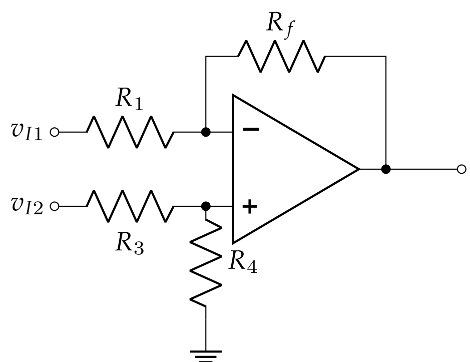
$$v_o = -R_f\left(\frac{1}{R_1}v_1 + \frac{1}{R_2}v_2 + \cdots + \frac{1}{R_n}v_n\right)$$

5.2 Non-Inverting Configuration



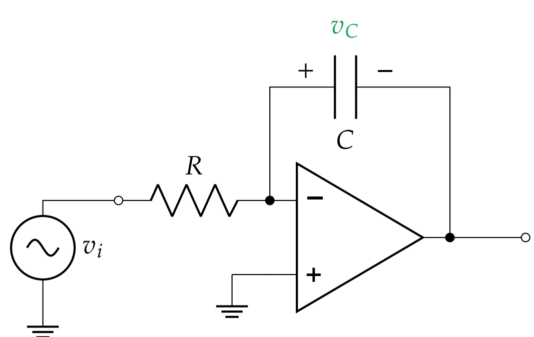
$$v_o = \left(1 + \frac{R_f}{R_1}\right) v_i$$

5.3 Difference Amplifier



$$v_o = \left(1 + \frac{R_f}{R_1}\right) v_i$$

5.4 Integrator



$$v_o = -\frac{1}{RC} \int_0^t v_i(t)\, \mathrm{d}t - V_C$$

5.5 Differentiator