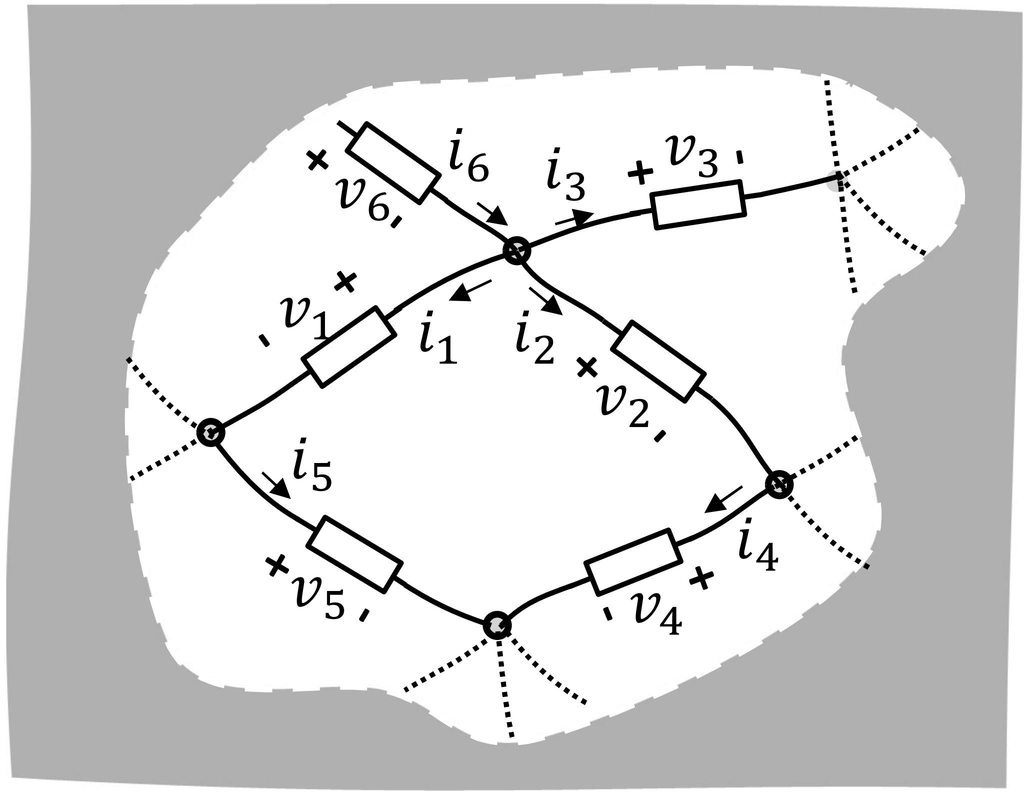
Week2 Electronics1

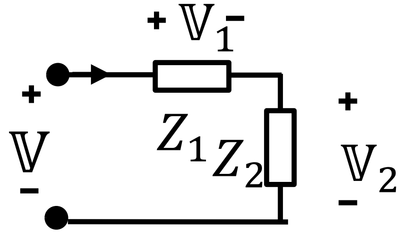
Reminders, Amplifiers

KVL , KCL



$$-\mathbb{V}_1+\mathbb{V}_2+\mathbb{V}_4-\mathbb{V}_5=0$$

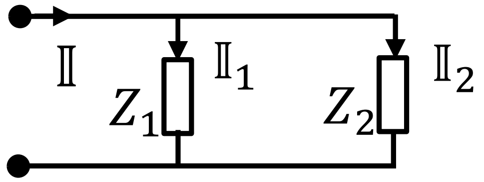
KVL $\sum_{i=1}^{n}\mathbb{V}_i=0$



$$\mathbb{V}_2=\frac{Z_2}{Z_1+Z_2}\mathbb{V}$$

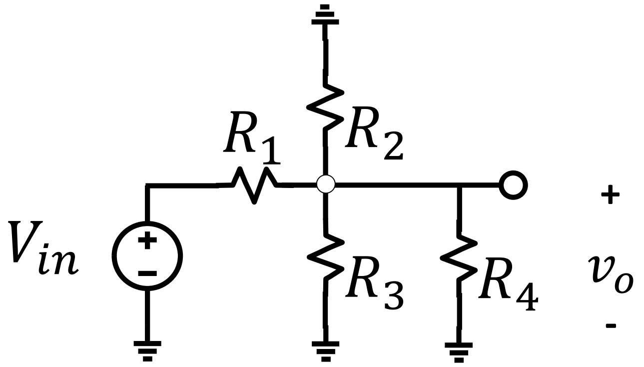
$$\mathbb{I}_1+\mathbb{I}_2+\mathbb{I}_3-\mathbb{I}_6=0$$

KCL $\sum_{i=1}^{m}\mathbb{I}_i=0$



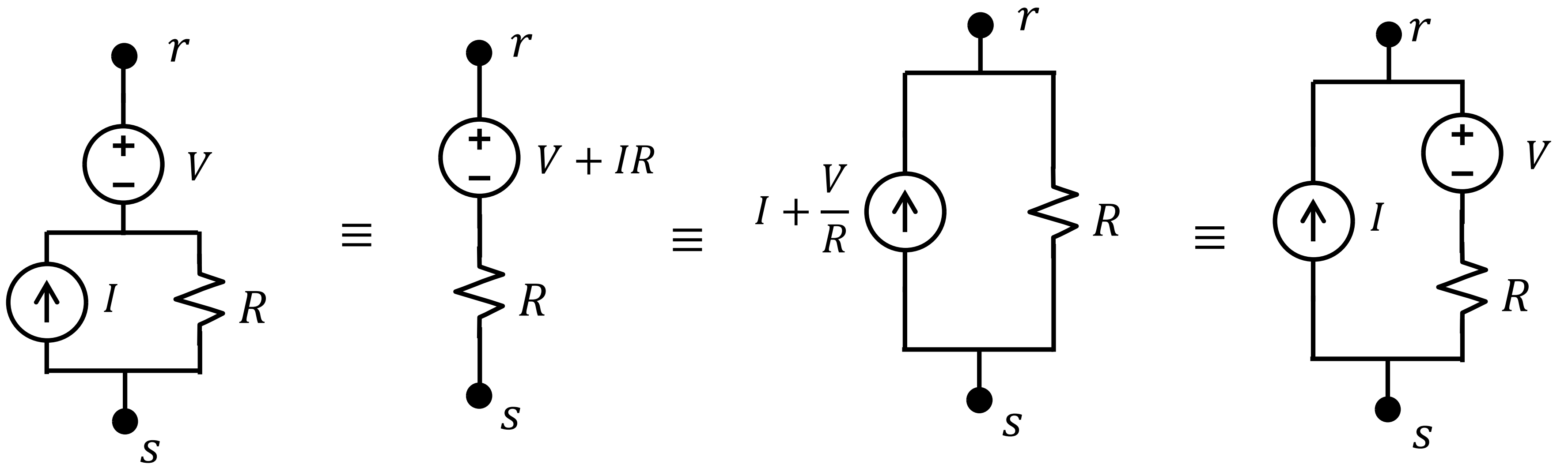
$$\mathbb{I}_2=\frac{Y_2}{Y_1+Y_2}\mathbb{I}$$

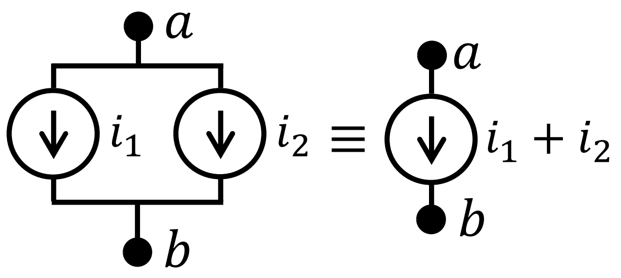
$$\mathbb{I}_2=\frac{Z_1}{Z_1+Z_2}\mathbb{I}$$

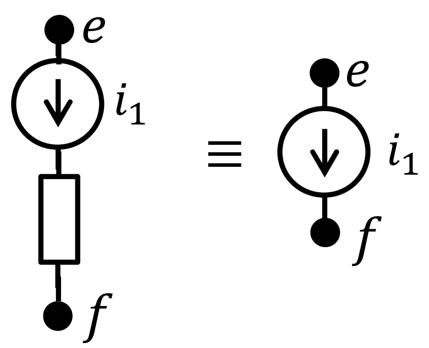


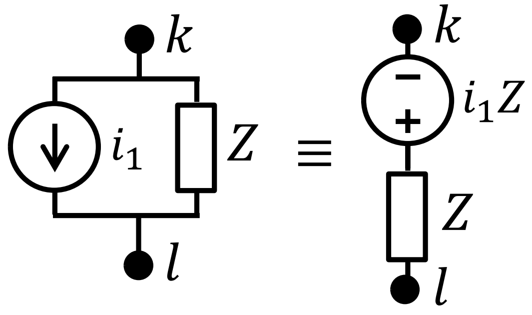
$$v_o=\frac{R_2\parallel R_3\parallel R_4}{R_1+(R_2\parallel R_3\parallel R_4)}V_{in}$$

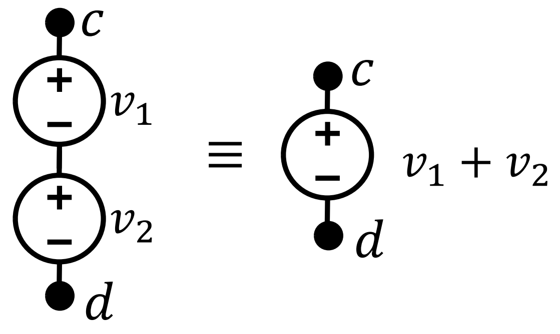
Source Transformation

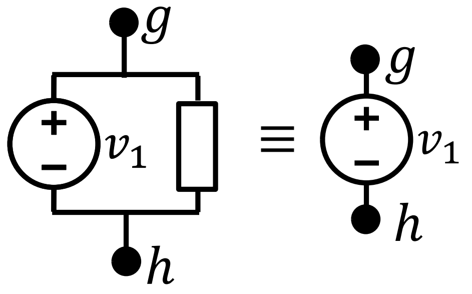




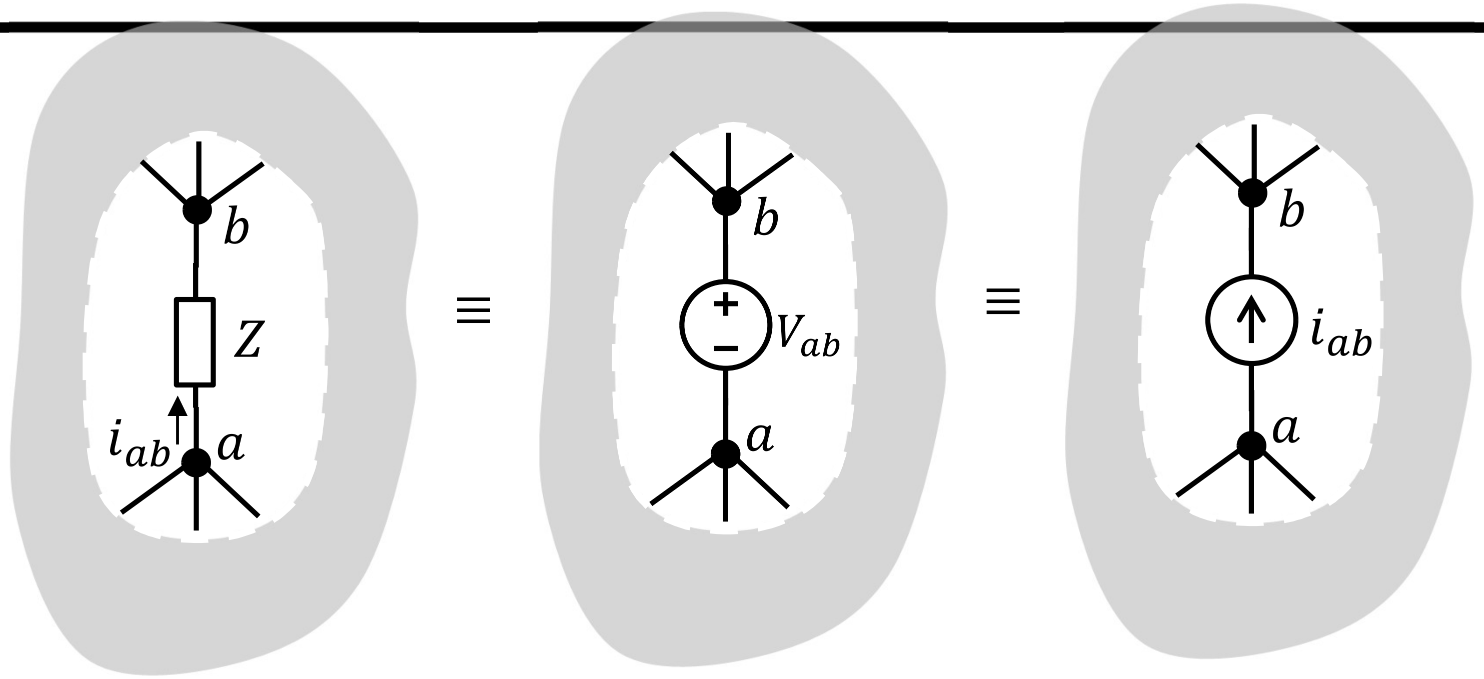


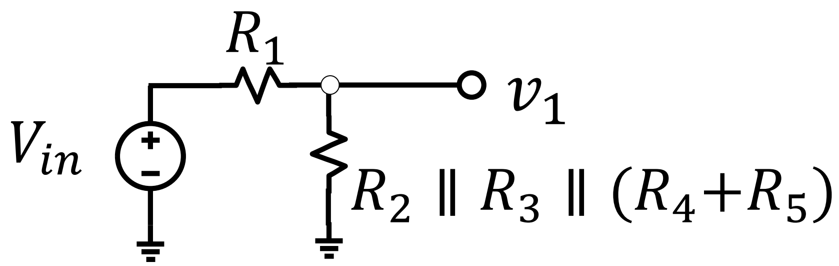


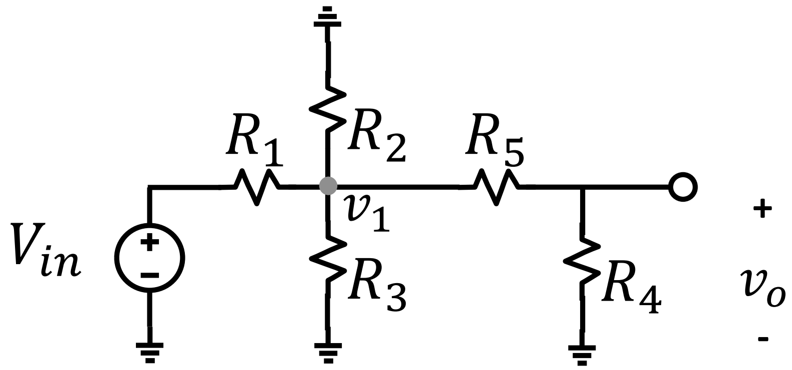


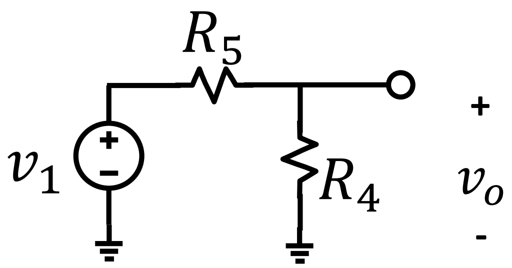


Replacement Theorem





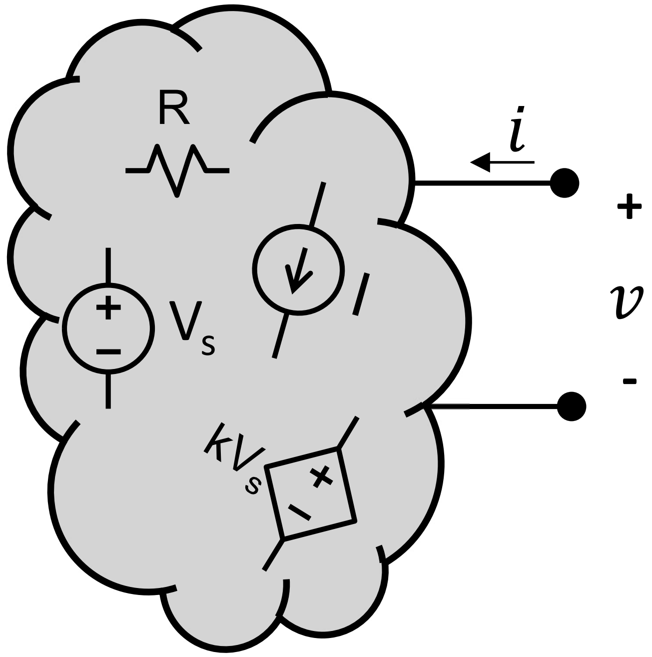


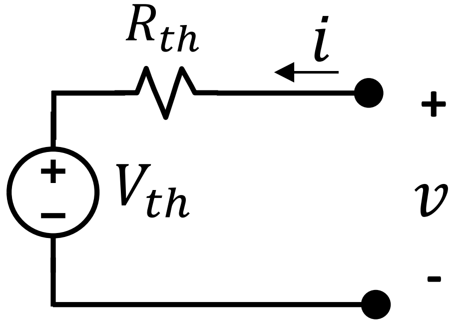


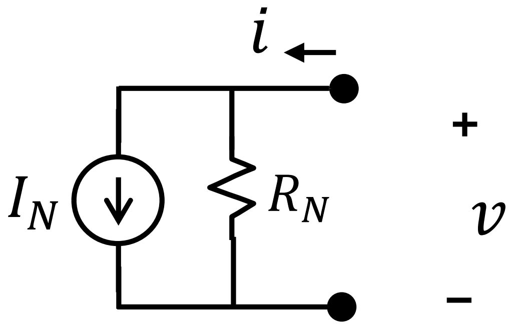
$$v_1 = \frac{R_2 \parallel R_3 \parallel (R_4+R_5)}{R_1 + (R_2 \parallel R_3 \parallel (R_4+R_5))} V_{in}$$

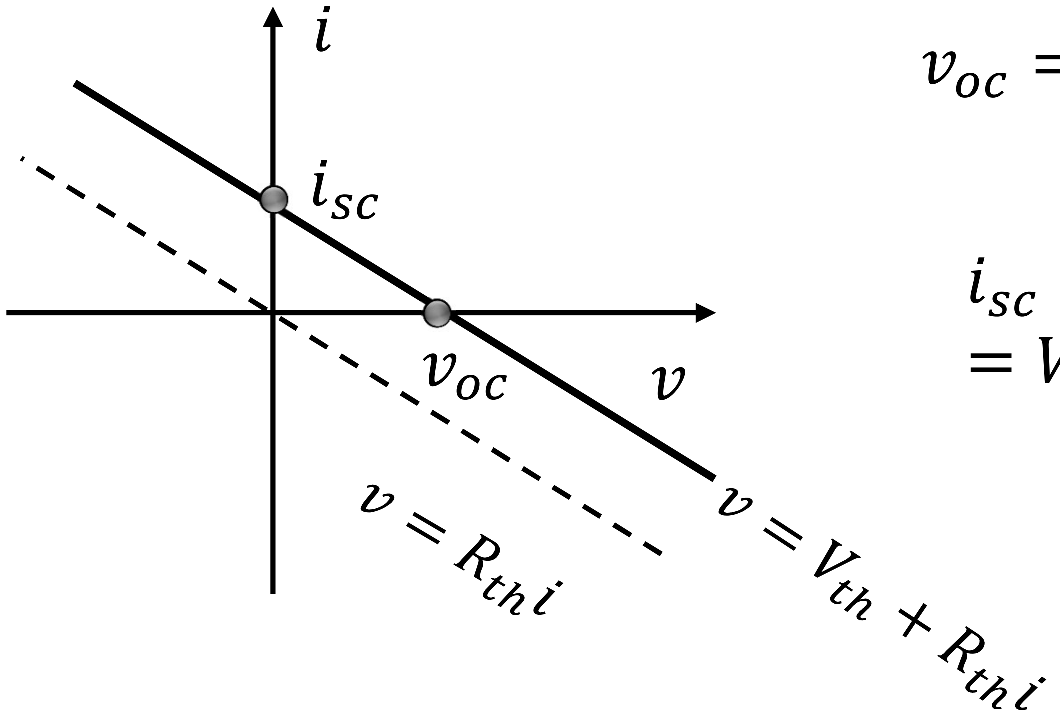
$$v_o = \frac{R_4}{R_4 + R_5} \frac{R_2 \parallel R_3 \parallel (R_4+R_5) V_{in}}{R_1 + (R_2 \parallel R_3 \parallel (R_4+R_5))}$$

Thevenin / Norton Equivalent





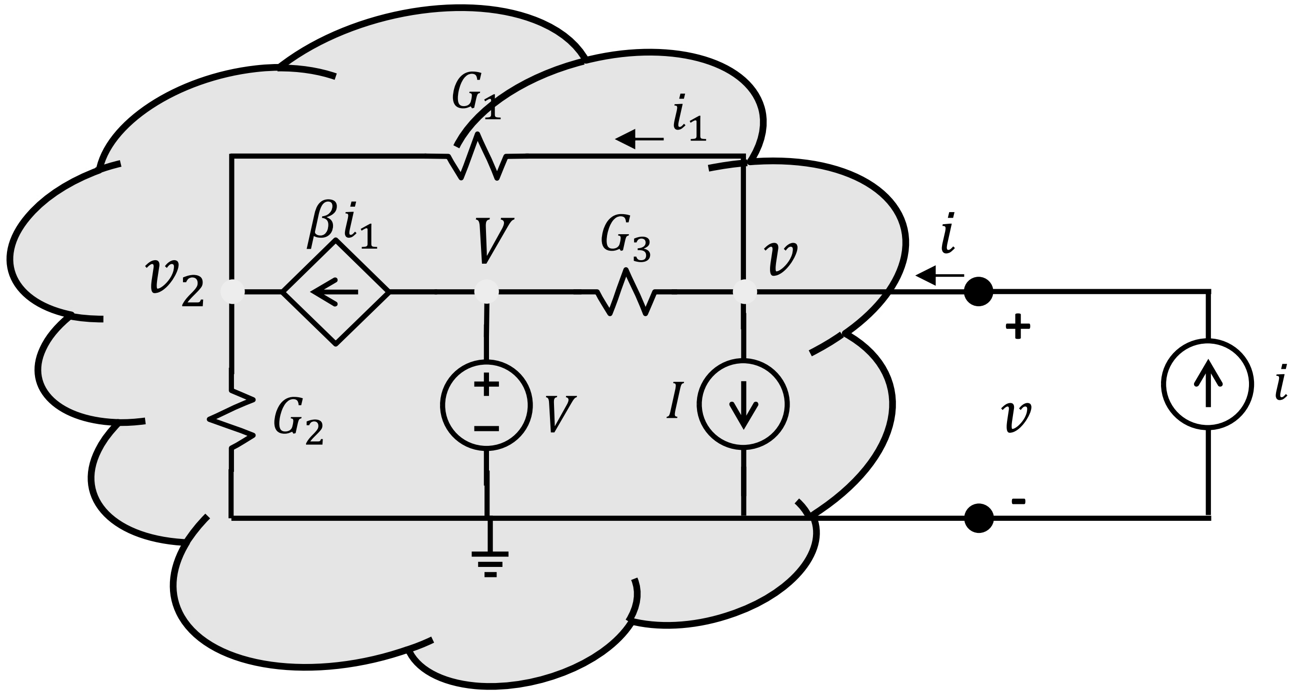




$$v_{oc} = V_{th}$$

$$i_{sc} = I_N$$
$$= V_{th}/R_{th}$$

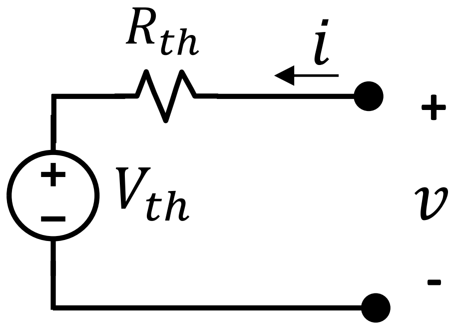
Thevenin / Norton Equivalent



$$\begin{cases} \boxed{v}: & G_1(v - v_2) + G_3(v - V) + I - i = 0 \\ \boxed{v_2}: & G_1(v_2 - v) + G_2 v_2 - \beta G_1(v - v_2) = 0 \end{cases}$$

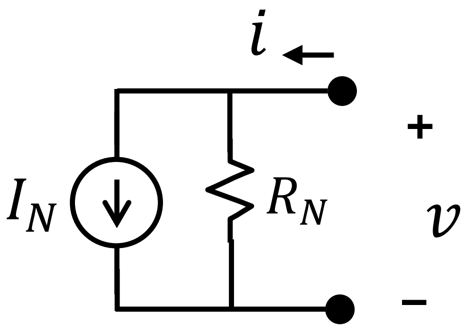
$$\begin{pmatrix} G_1 + G_3 & -G_1 \\ -G_1 - \beta G_1 & G_1 + G_2 + \beta G_1 \end{pmatrix} \begin{pmatrix} v \\ v_2 \end{pmatrix} = \begin{pmatrix} i - I + G_3 V \\ 0 \end{pmatrix}$$

$$\begin{pmatrix} v \\ v_2 \end{pmatrix} = [G]^{-1} \begin{pmatrix} i \\ 0 \end{pmatrix} + [G]^{-1} \begin{pmatrix} G_3 V - I \\ 0 \end{pmatrix}$$



$$v = R_{th} i + V_{th}$$

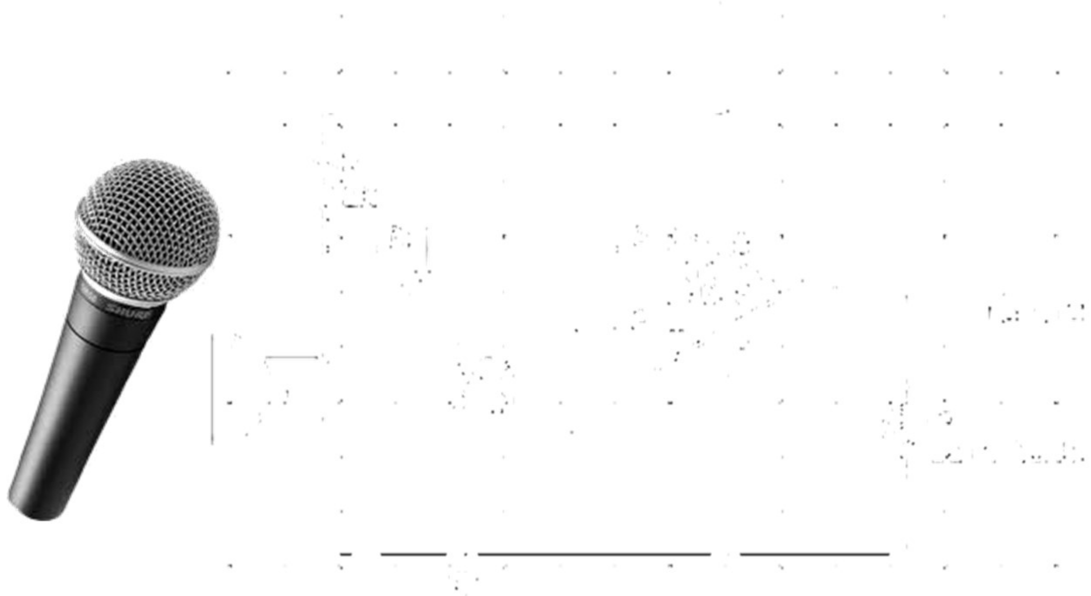
$$v_{oc} = V_{th}$$

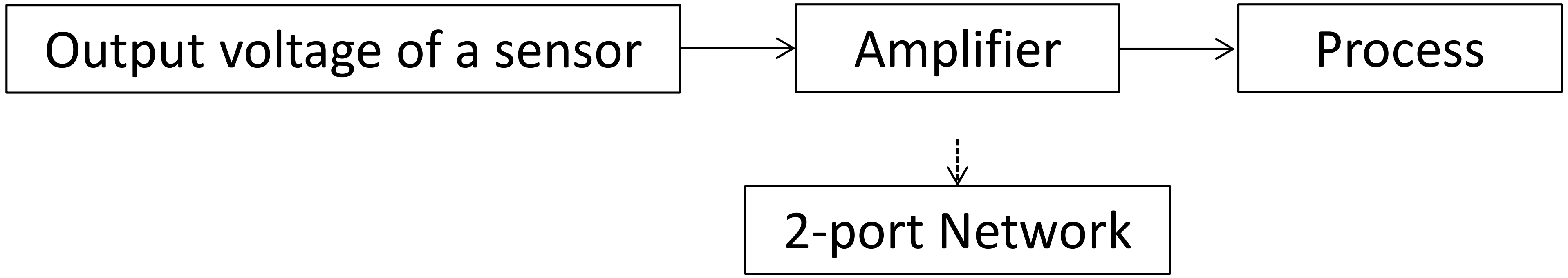


$$i_{sc} = I_N$$
$$= V_{th}/R_{th}$$

Amplifier

Audio Amplifier:



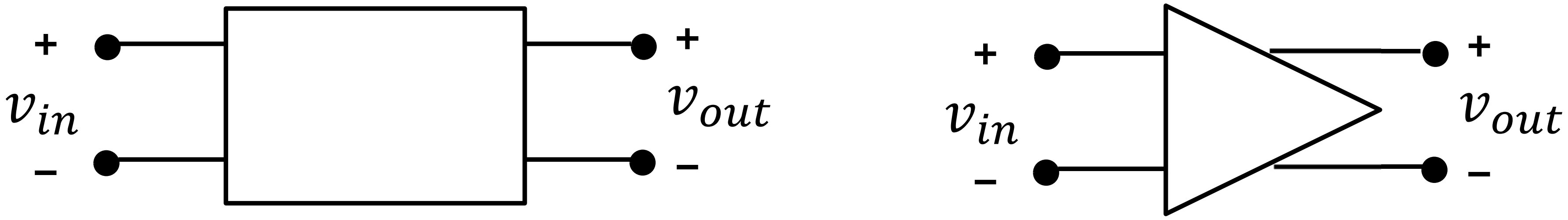


Output voltage of a sensor

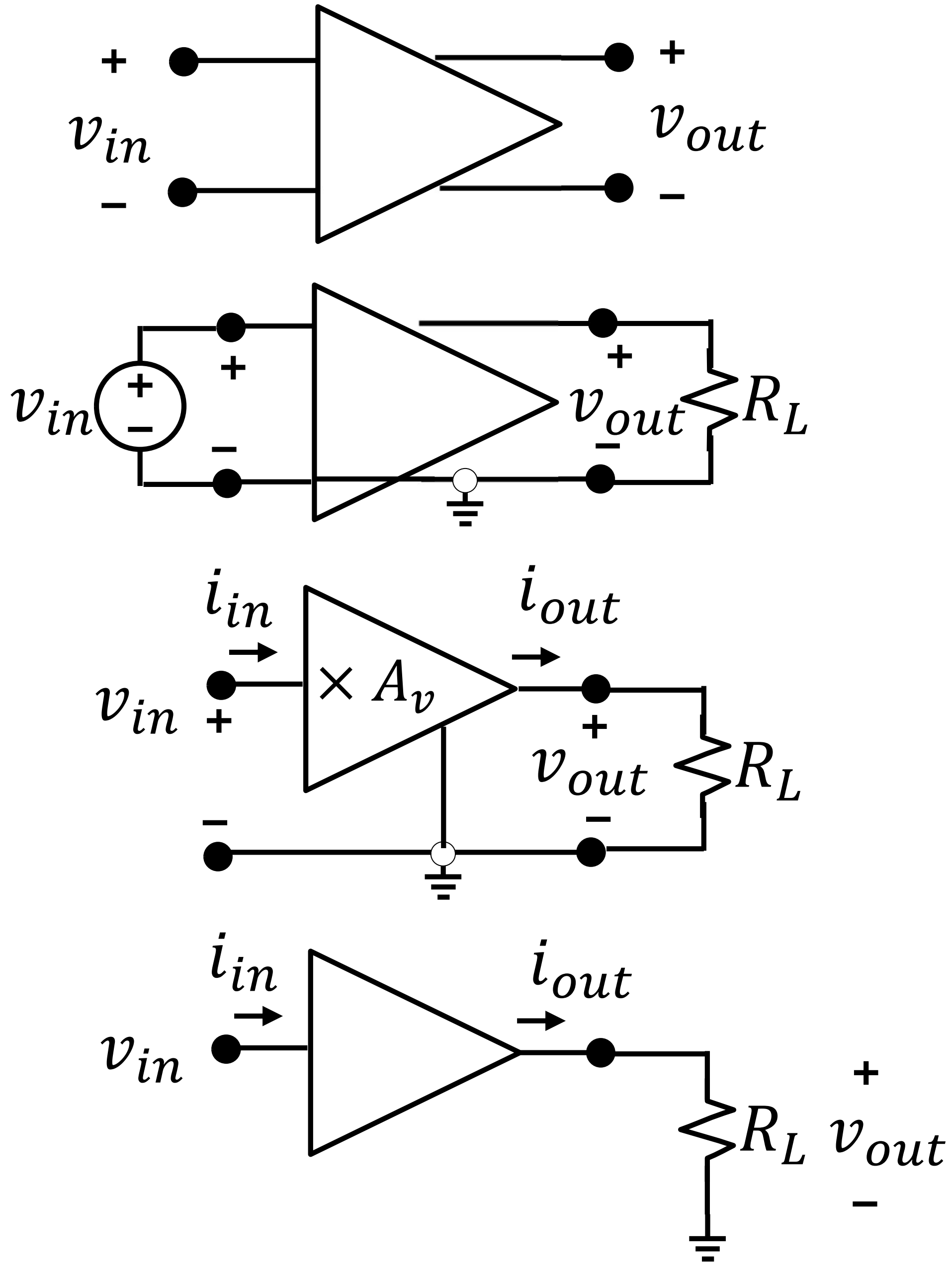
Amplifier

Process

2-port Network



Amplifier

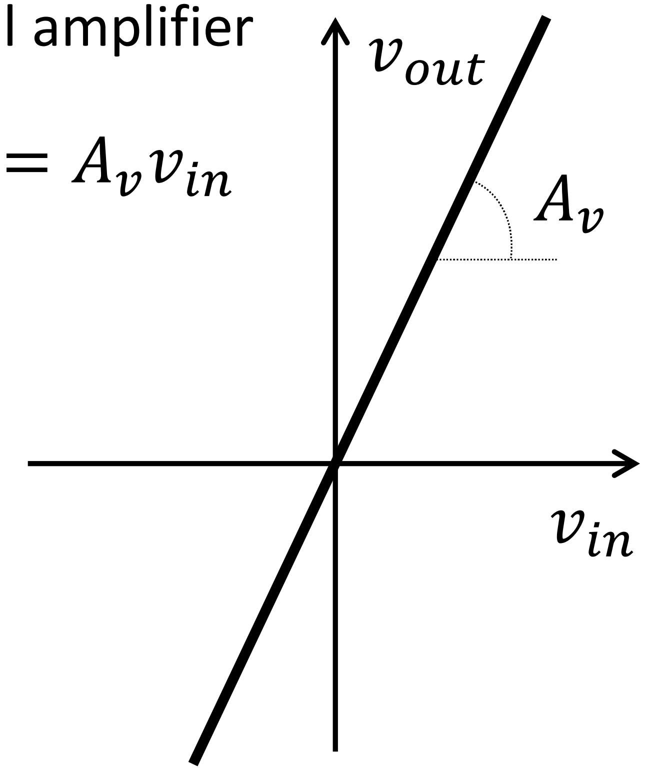


Note: There is a difference between Amplifier and Transformer

? Where is the source of this extra power?

Ideal amplifier

$$v_{out} = A_v v_{in}$$



$$A_v = 10 = 20dB$$

$$A_v = 100 = 40dB$$

$$A_v = 1 = 0dB$$

$$A_v = \frac{1}{\sqrt{2}} = -3dB$$

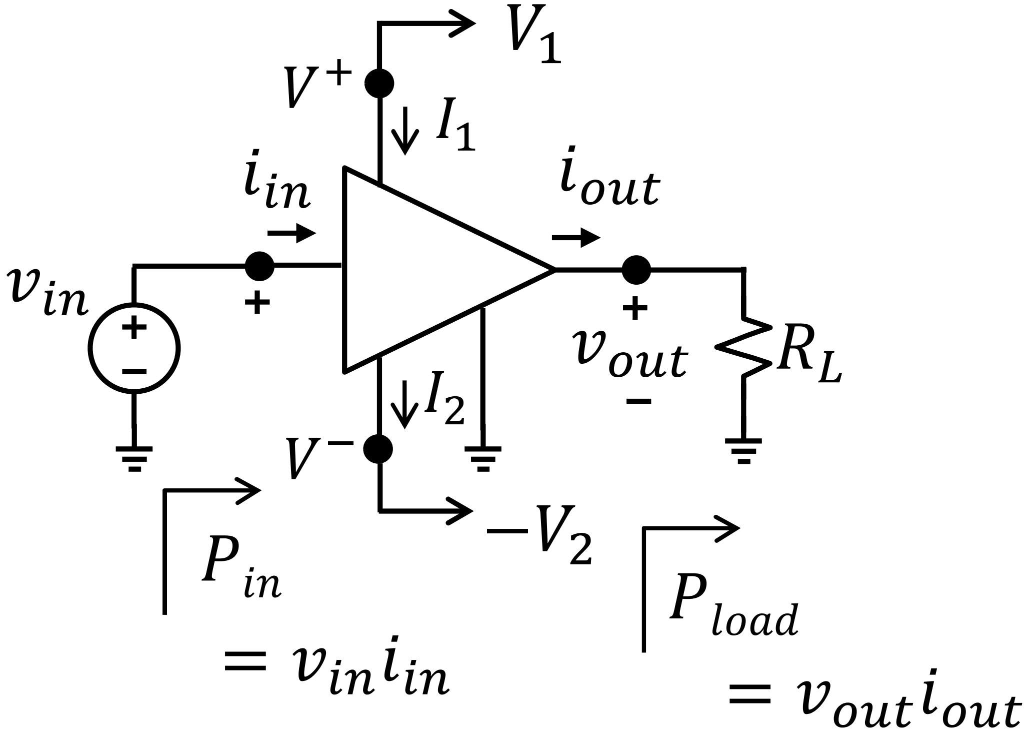
$$A_P = \frac{1}{2} = -3dB$$

$$A_P \triangleq \frac{P_{out}}{P_{in}} \rightarrow 10\log_{10} A_P \quad in\ \ dB$$

$$A_v \triangleq \frac{v_{out}}{v_{in}} \rightarrow 20\log_{10} A_v \quad in\ \ dB$$

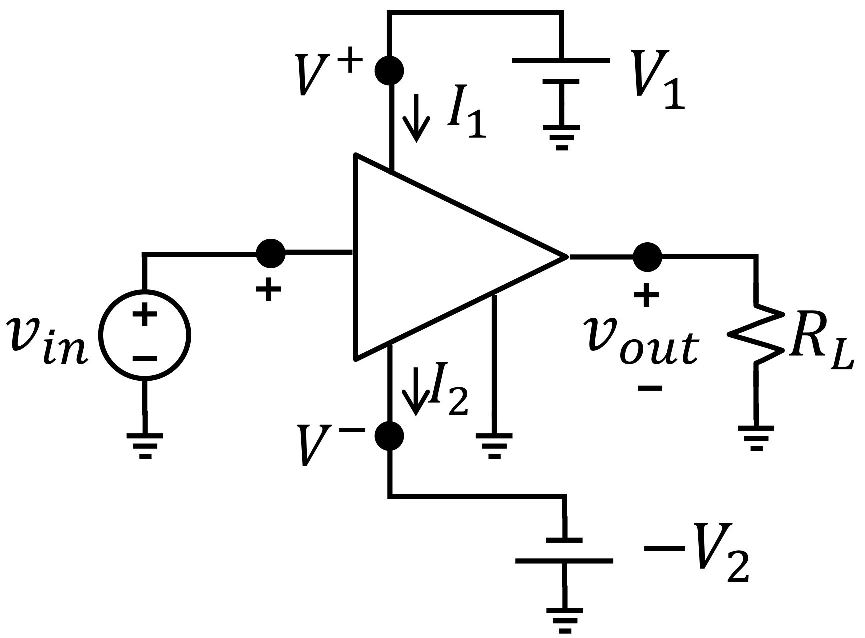
$$A_i \triangleq \frac{i_{out}}{i_{in}} \rightarrow 20\log_{10} A_i \quad in\ \ dB$$

Amplifier - Efficiency



$P_{in} = v_{in} i_{in}$

$P_{load} = v_{out} i_{out}$



$$P_{dc} = P_{supply} = V^+ I_1 - V^- I_2$$
$$= V_1 I_1 + V_2 I_2$$

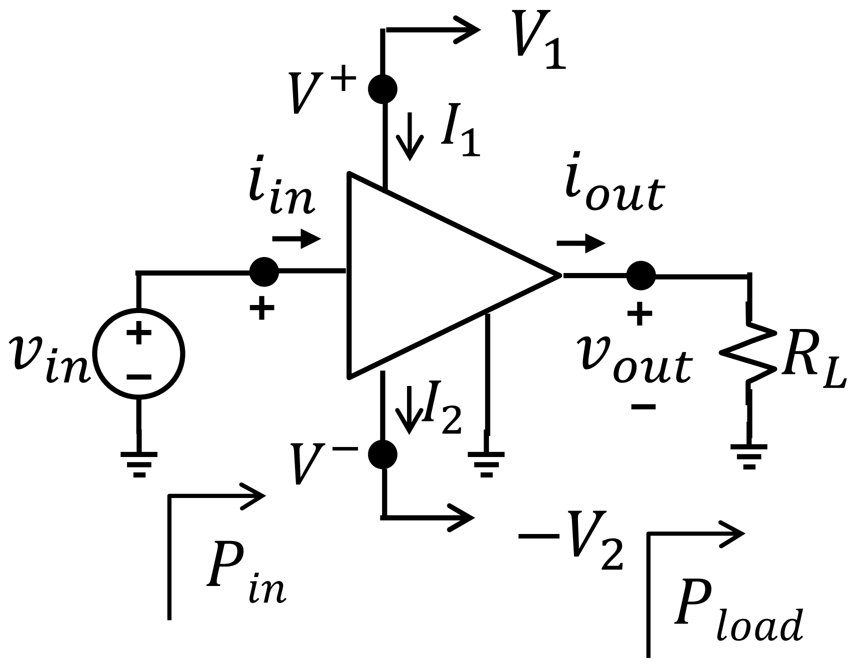
Conservation of energy:

$$P_{in} + P_{dc} = P_{load} + P_{dissipated}$$

$$\eta \equiv \frac{P_{load}}{P_{dc}} \quad \text{Efficiency}$$

$$= \frac{P_{load}}{P_{dc}} \times 100\%$$

Efficiency : Example



$$\begin{cases} V_{1,2} = \pm 10V \\ I_1 = 9.5mA \quad I_2 = 9.5mA \\ v_{in} = 1^V \sin\omega t \quad v_{out} = 9^V \sin\omega t \\ i_{in} = 0.1^{mA} \sin\omega t \quad R_L = 1^{k\Omega} \end{cases}$$

$$A_v = 9 = 19.1^{dB}$$

$$i_{out} = \frac{v_{out}}{R_L} = 9^{mA} \sin\omega t \qquad A_i = \frac{i_{out}}{i_{in}} = 90 = 39.1^{dB}$$

$$P_{load} = v_{orms} i_{orms} = \frac{9 \times 9^m}{\sqrt{2}\sqrt{2}} = 40.5^{mW}$$

$$A_P = 810 = 29.1^{dB}$$

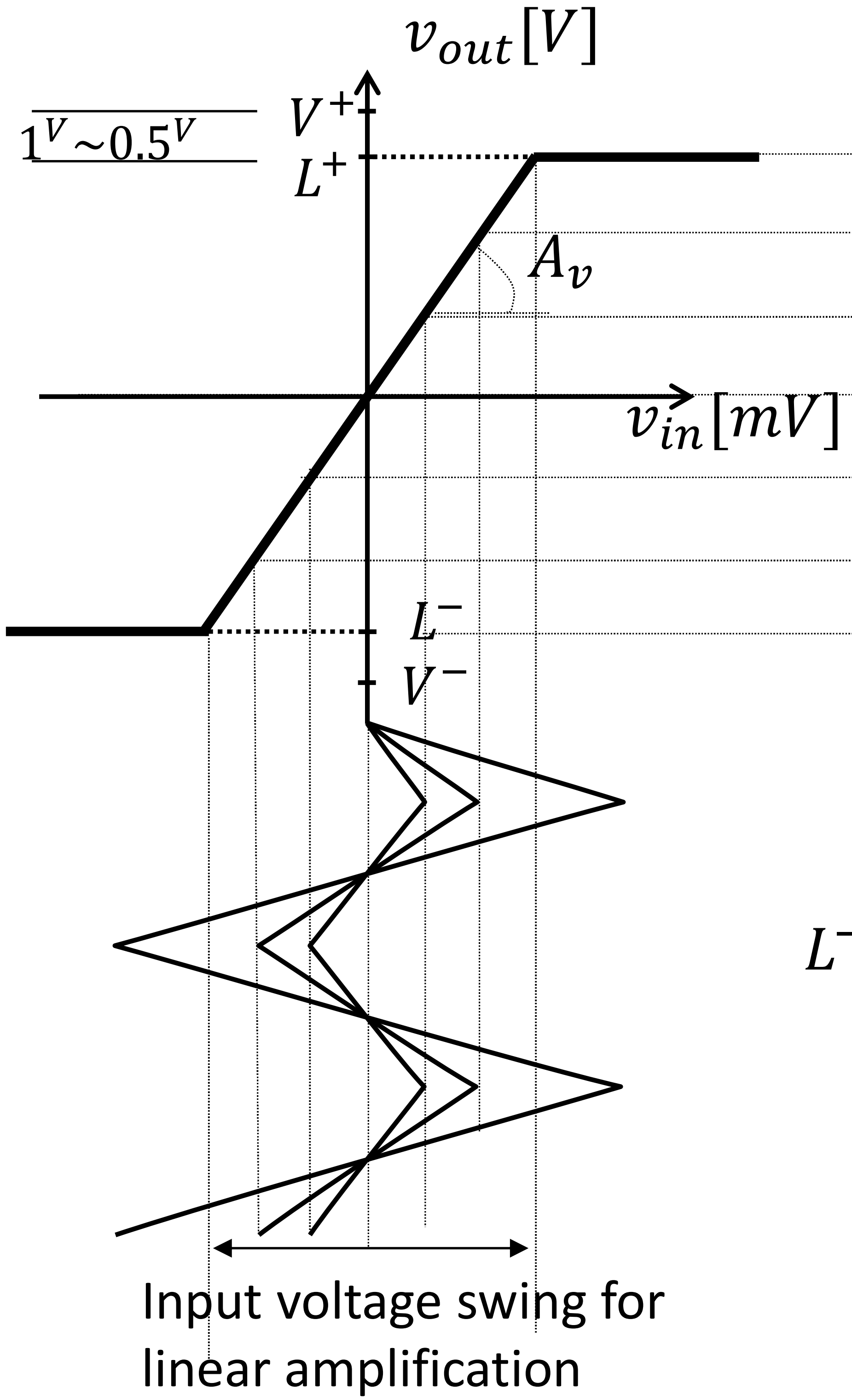
$$P_{in} = v_{irms} i_{irms} = \frac{1 \times 0.1^m}{\sqrt{2}\sqrt{2}} = 0.05^{mW}$$

$$P_{dc} = 10 \times 9.5 \times 2 = 190^{mW}$$

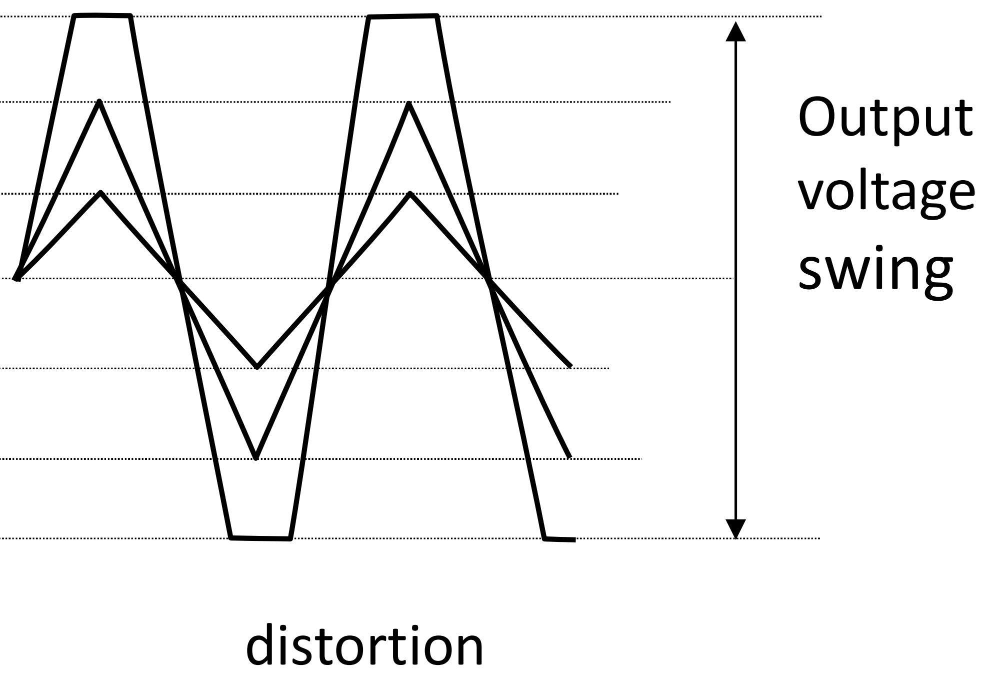
$$\eta = \frac{P_{load}}{P_{dc}} \times 100\% = 21.3\%$$

$$P_{diss} = P_{dc} + P_{in} - P_{load} = 149.6^{mW}$$

Non-ideal Amplifier



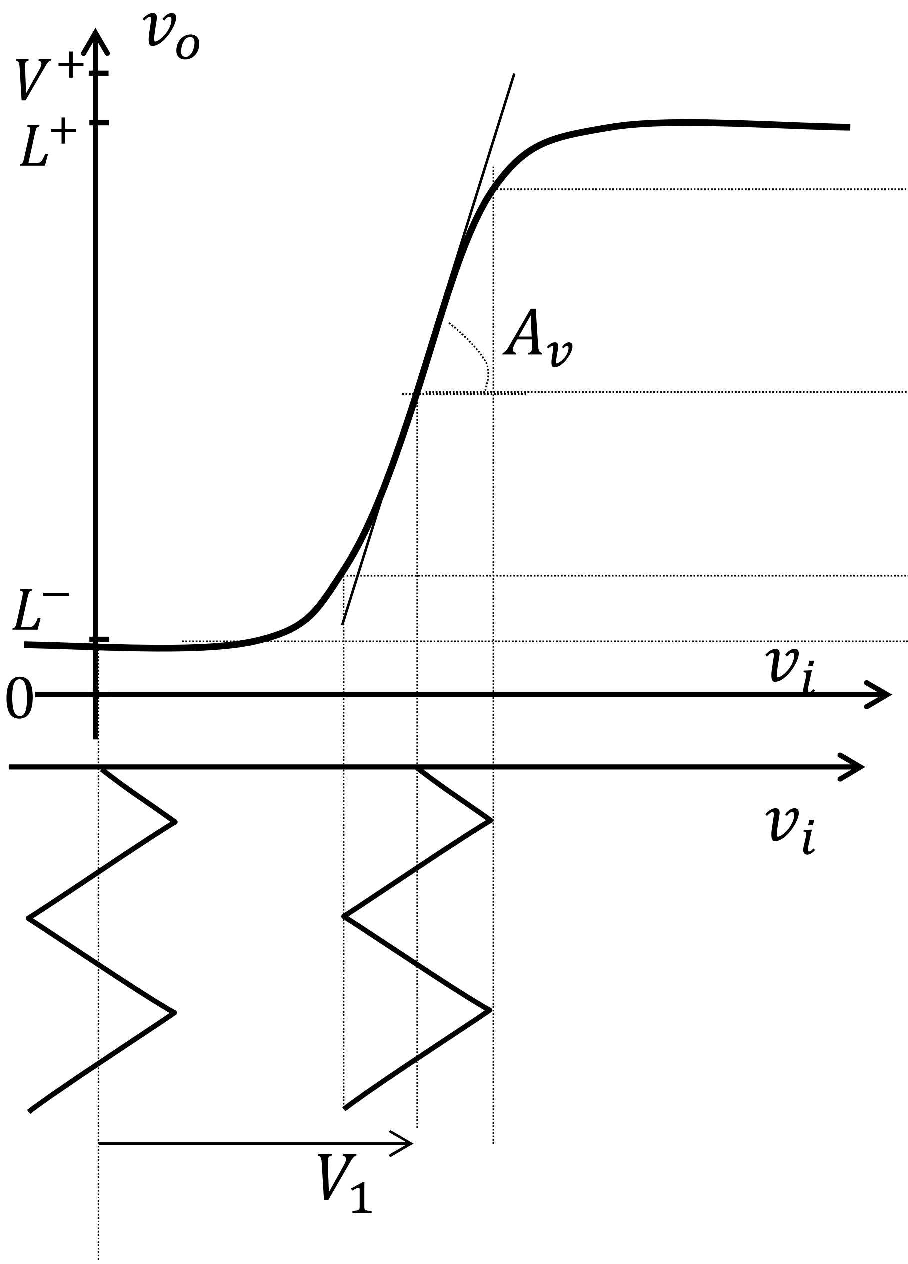
rail-to-rail OpAmp $L^{\pm} = V^{\pm}$

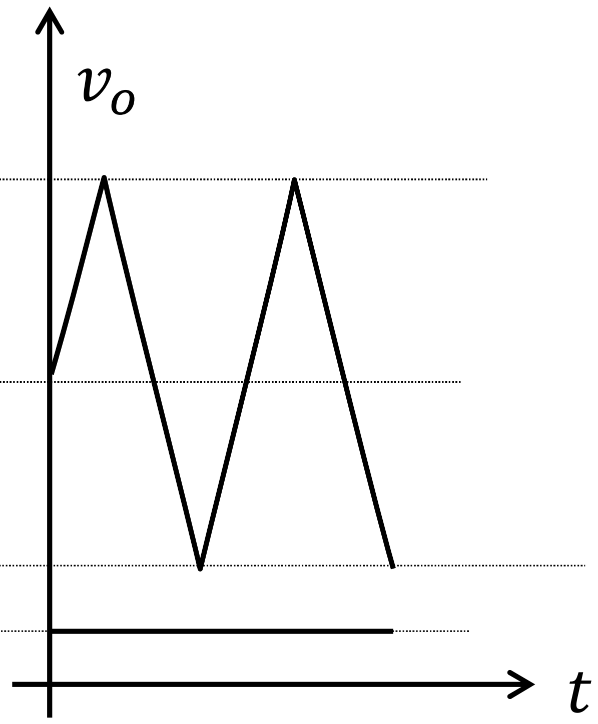


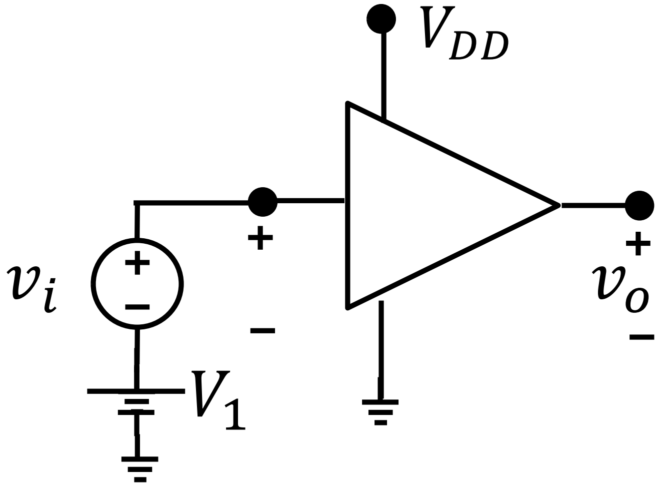
$$L^- < v_{out} < L^+ \xRightarrow{v_{out}=A_v v_{in}} \left(\frac{L^-}{A_v} < v_{in} < \frac{L^+}{A_v}\right)$$

You have heard distortion in Audio amplifier!

Nonlinear Transfer Function
Biasing



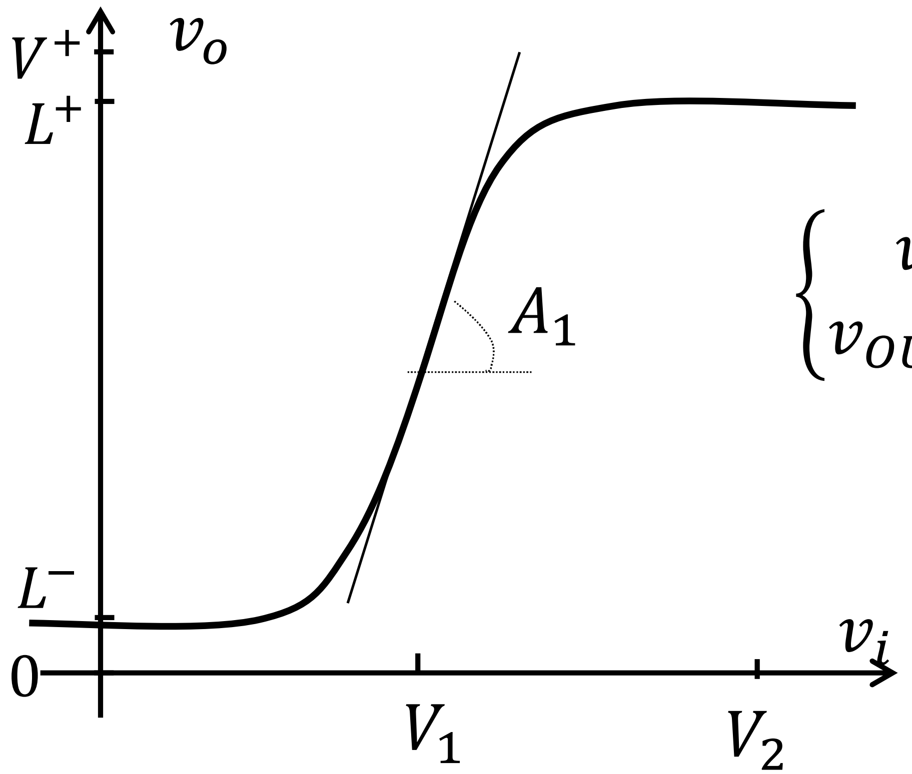




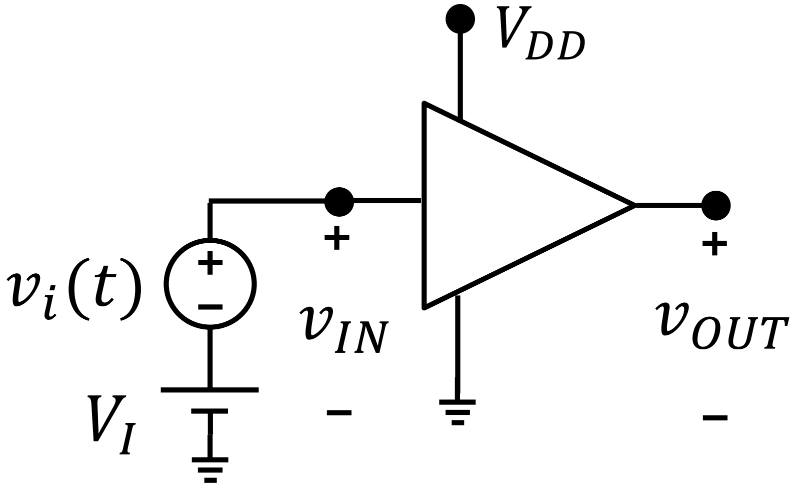
$$A_v = \frac{\Delta v_o}{\Delta v_i} = \left.\frac{dv_o}{dv_i}\right|_Q$$

bias point

Nonlinear Transfer Function
Biasing



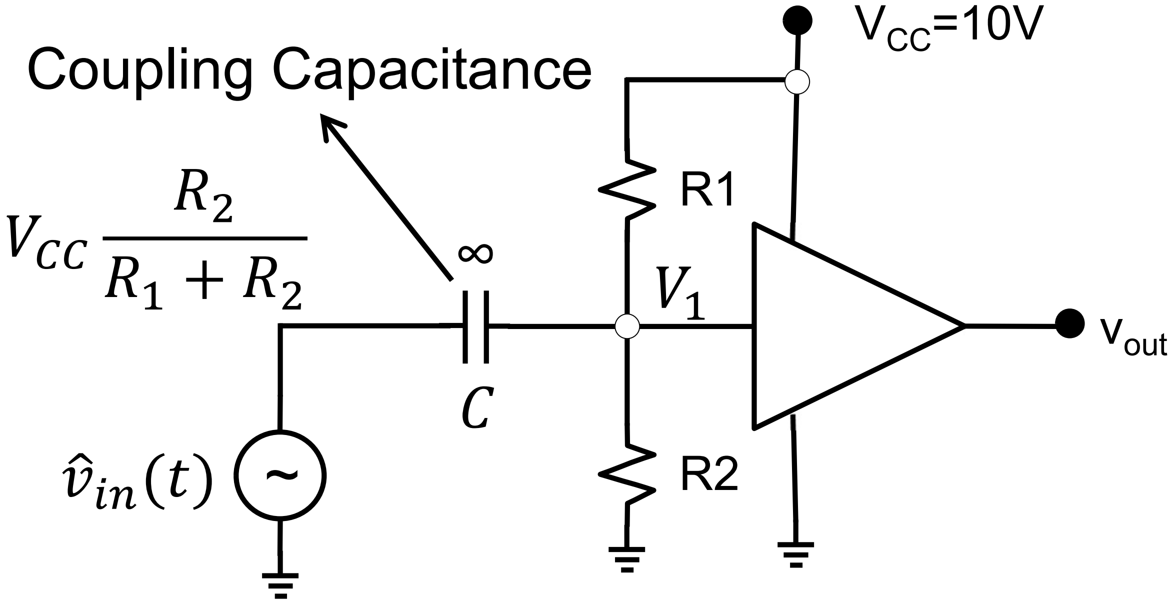
$$\begin{cases} v_{IN} = V_I + v_i(t) \\ v_{OUT} = V_O + A_v v_i(t) \end{cases}$$



$V_I = 0 \rightarrow A_v = 0$

$V_I = V_1 \rightarrow A_v = A_1$

$V_I = V_2 \rightarrow A_v = 0$



$$V_1 = V_{CC}\frac{R_2}{R_1 + R_2}$$

$$v_{out}(t) = V_{out} + A_v \hat{v}_{in}(t)$$

Summary

KVL, KCL: voltage division

Source Transformation

Replacement Theorem

Thevenin / Norton Equivalent

Amplifier, ideal / non-ideal

Amplifier - Efficiency

Output voltage swing

Nonlinear Transfer Function
Biasing