Session 3: Analog Circuits

Ideal Amplifiers
voltage/current/power amplification
non-ideal amplifiers
biasing
types of amplifiers

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Outline

1. Lab
2. Power
3. Ser/Parl
4. Small sig.
5. Applic

- Amplifier

2

Amplifier

1. Lab
2. Power
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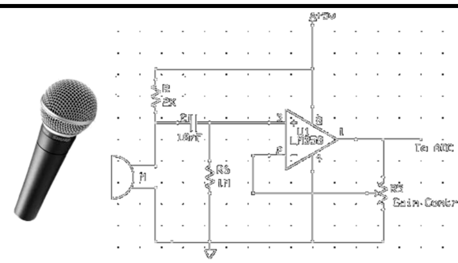
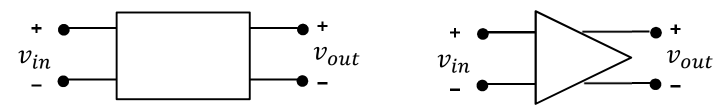
Audio Amplifier:



Output voltage of a sensor → Amplifier → Process

Amplifier ⇣ 2-port Network



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Amplifier

1. Lab
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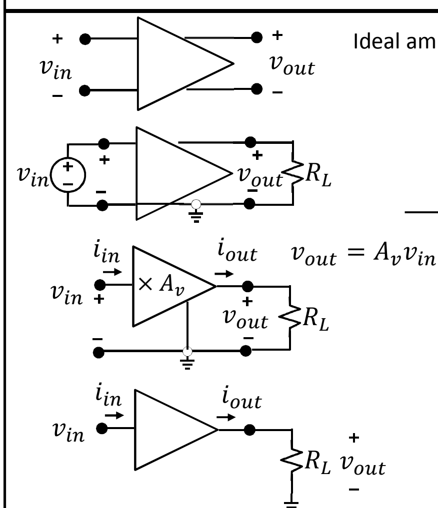
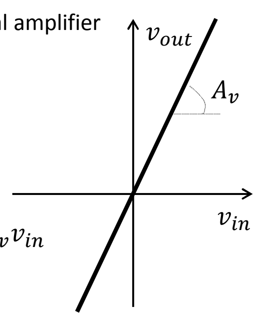


Ideal amplifier



$A_v = 10 = 20dB$

$A_v = 100 = 40dB$

$A_v = 1 = 0dB$

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

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

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

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

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

Note: There is a difference between Amplifier and Transformer

? Where is the source of this extra power?

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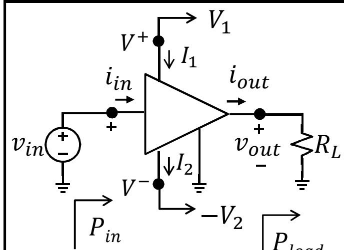
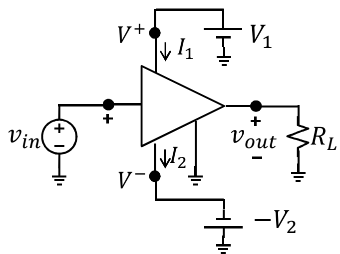
Amplifier - Efficiency

1. Lab
2. Power
3. Ser/Parl
4. Small sig.
5. Applic



$= v_{in} i_{in}$ $\quad$ $= v_{out} i_{out}$



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

Conservation of energy:

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

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

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

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Efficiency : Example

1. Lab
2. Power
3. Ser/Parl
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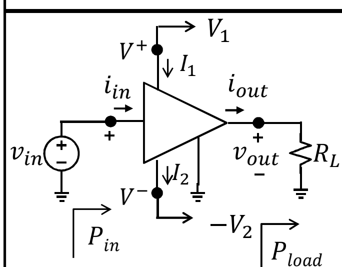
5. Applic



$$\begin{cases} V_{1,2} = \pm 10V \\ I_1 = 9.5mA \\ v_{in} = 1^V \sin\omega t \\ i_{in} = 0.1^{mA} \sin\omega t \end{cases}$$

$I_2 = 9.5mA$

$v_{out} = 9^V \sin\omega t$

$R_L = 1^{k\Omega}$

$A_v = 9 = 19.1^{dB}$

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

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

$A_P = 810 = 29.1^{dB}$

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

$$P_{dc} = 10 \times 9.5 \times 2 = 0.05^{mW}$$

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

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

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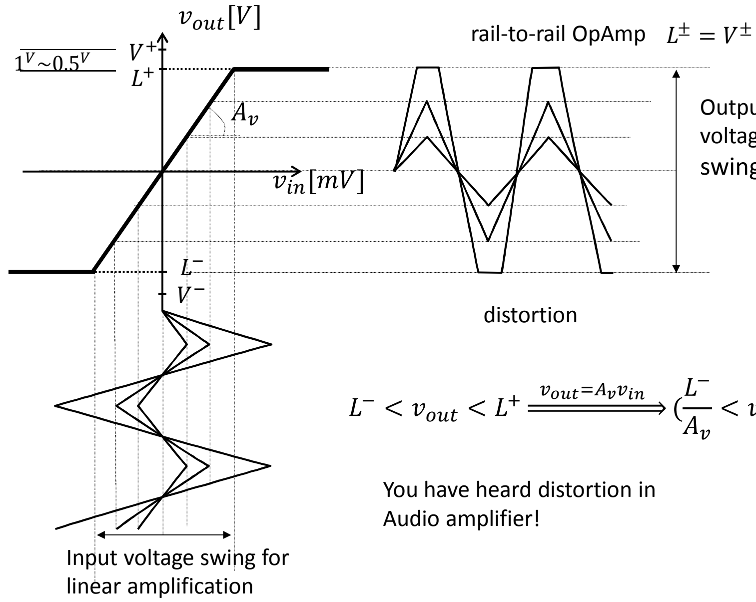
Non-ideal Amplifier

1. Lab
2. Power
3. Ser/Parl
4. Small sig.
5. Applic



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

You have heard distortion in Audio amplifier!

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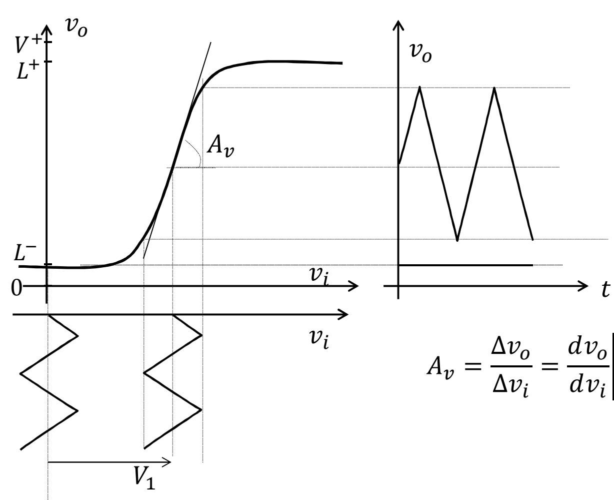
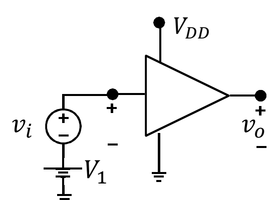
Nonlinear Transfer Function Biasing

1. Lab
2. Power
3. Ser/Parl
4. Small sig.
5. Applic





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

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Nonlinear Transfer Function Biasing

1. Lab
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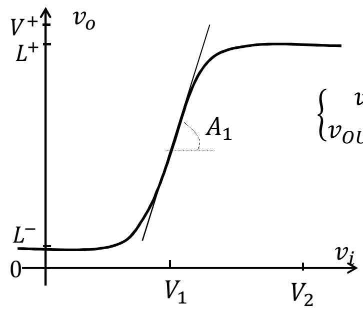
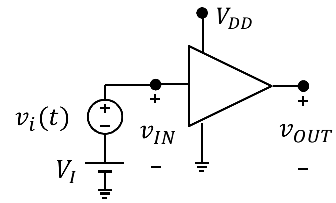


$$\begin{cases} v_{IN} = V_I + v_i(t) \\ v_{OUT} = V_O + A_v v_i(t) \end{cases}$$

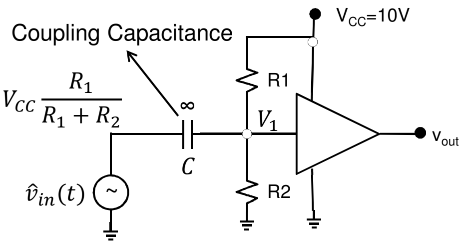


$V_I = 0 \;\rightarrow A_v = 0$

$V_I = V_1 \;\rightarrow A_v = A_1$

$V_I = V_2 \;\rightarrow A_v = 0$

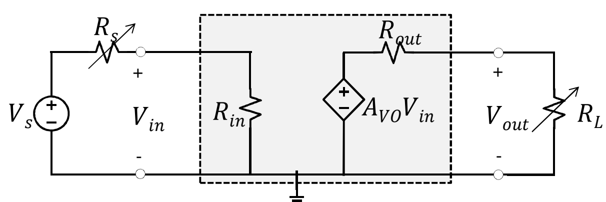
$$V_1 = V_{CC}\frac{R_1}{R_1 + R_2}$$

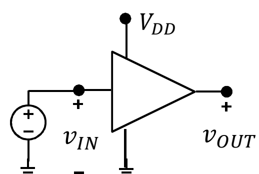


$$v_{out}(t) = V_{out} + A_v \hat{v}_{in}(t)$$

Voltage Amplifier

1. Lab
2. Power
3. Ser/Parl
4. Small sig.
5. Applic





Open circuit: $R_L = \infty \;\rightarrow \dfrac{V_{out}}{V_{in}} = A_{VO} \quad \left[\dfrac{V}{V}\right]$ open circuit voltage gain

$V_{in} = \dfrac{R_{in}}{R_{in} + R_s}.V_s$ $\quad V_{in} = V_s \quad \forall R_s$ $\quad$ if $R_{in} = \infty$ Ideal case

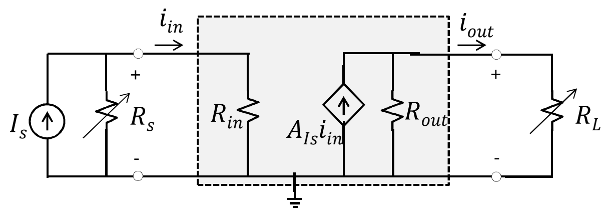
$V_{out} = A_{Vo}V_{in}\dfrac{R_L}{R_L + R_{out}}$ $\quad V_{out} = A_{Vo}V_{in} \quad \forall R_L$ $\quad$ if $R_{out} = 0$ Ideal case

Generally: $\dfrac{V_{out}}{V_s} = A_{Vo}(\dfrac{R_L}{R_L + R_{out}})(\dfrac{R_{in}}{R_{in} + R_s})$

Ideal case: $\dfrac{V_{out}}{V_s} = A_{Vo}$

Current Amplifier

1. Lab
2. Power
3. Ser/Parl
4. Small sig.
5. Applic



Short circuit: $R_L = 0 \rightarrow \frac{i_{out}}{i_{in}} = A_{Is}$ $\left[\frac{A}{A}\right]$ short circuit current gain

$i_{in} = \frac{R_S}{R_{in} + R_s} . I_s$ $i_{in} = I_s \quad \forall R_s$ if $R_{in} = 0$ Ideal case

$i_{out} = A_{Is} i_{in} \frac{R_{out}}{R_L + R_{out}}$ $i_{out} = A_{Is} i_{in} \quad \forall R_L$ if $R_{out} = \infty$ Ideal case

Generally: $\frac{i_{out}}{I_s} = A_{Is}(\frac{R_{out}}{R_L + R_{out}})(\frac{R_S}{R_{in} + R_s})$

Ideal case: $\frac{i_{out}}{I_s} = A_{Is}$

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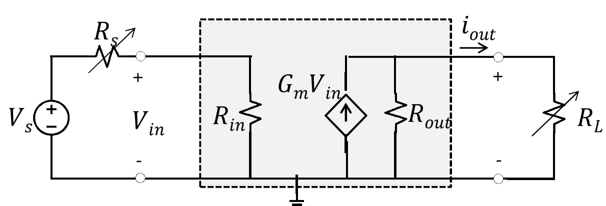
Trance-Conductance Amplifier

1. Lab
2. Power
3. Ser/Parl
4. Small sig.
5. Applic



Short circuit: $R_L = 0 \rightarrow \frac{i_{out}}{V_{in}} = G_m$ $\left[\frac{A}{V} = \Omega^{-1}\right]$ short circuit Trance-conductance

$V_{in} = \frac{R_{in}}{R_{in} + R_s} . V_s$ $V_{in} = V_s \quad \forall R_s$ if $R_{in} = \infty$ Ideal case

$i_{out} = G_m V_{in} \frac{R_{out}}{R_L + R_{out}}$ $i_{out} = G_m V_{in} \quad \forall R_L$ if $R_{out} = \infty$ Ideal case

Generally: $\frac{i_{out}}{V_s} = G_m(\frac{R_{out}}{R_L + R_{out}})(\frac{R_{in}}{R_{in} + R_s})$

Ideal case: $\frac{i_{out}}{V_s} = G_m$

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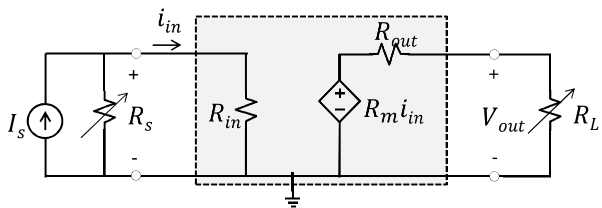
Trance-Resistance Amplifier

1. Lab
2. Power
3. Ser/Parl
4. Small sig.
5. Applic



Short circuit: $R_L = \infty \rightarrow \frac{V_{out}}{i_{in}} = R_m \quad \left[\frac{V}{A} = \Omega\right]$ open circuit Trans-resistance

$i_{in} = \frac{R_S}{R_{in} + R_s} . I_s \qquad i_{in} = I_s \quad \forall R_s \qquad$ if $R_{in} = 0$ Ideal case

$V_{out} = R_m i_{in} \frac{R_L}{R_L + R_{out}} \qquad V_{out} = R_m i_{in} \quad \forall R_L \qquad$ if $R_{out} = 0$ Ideal case

Generally: $\frac{V_{out}}{I_s} = R_m (\frac{R_L}{R_L + R_{out}})(\frac{R_S}{R_{in} + R_s})$

Ideal case: $\frac{V_{out}}{I_s} = R_m$

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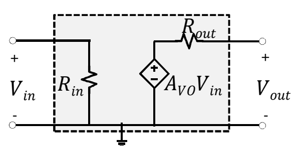
Amplifiers

1. Lab
2. Power
3. Ser/Parl
4. Small sig.
5. Applic

Ideal:

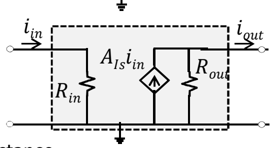
Voltage Amplifier



$A_{Vo} = \left.\frac{V_{out}}{V_{in}}\right|_{i_{out}=0}$ $\qquad R_{in} = \infty$, $R_{out} = 0$

open circuit voltage gain

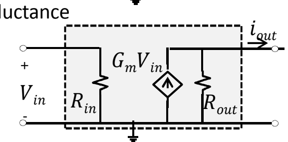
Current Amplifier



$A_{Is} = \left.\frac{i_{out}}{i_{in}}\right|_{V_{out}=0}$ $\qquad R_{in} = 0$, $R_{out} = \infty$

short circuit current gain

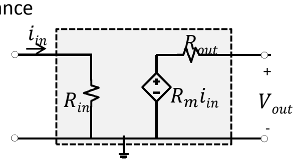
Trance-Conductance Amplifier



$G_m = \left.\frac{i_{out}}{V_{in}}\right|_{V_{out}=0}$ $\qquad R_{in} = \infty$, $R_{out} = \infty$

short circuit Trans-conductance

Trance-Resistance Amplifier



$R_m = \left.\frac{V_{out}}{i_{in}}\right|_{i_{out}=0}$ $\qquad R_{in} = 0$, $R_{out} = 0$

open circuit Trans-resistance

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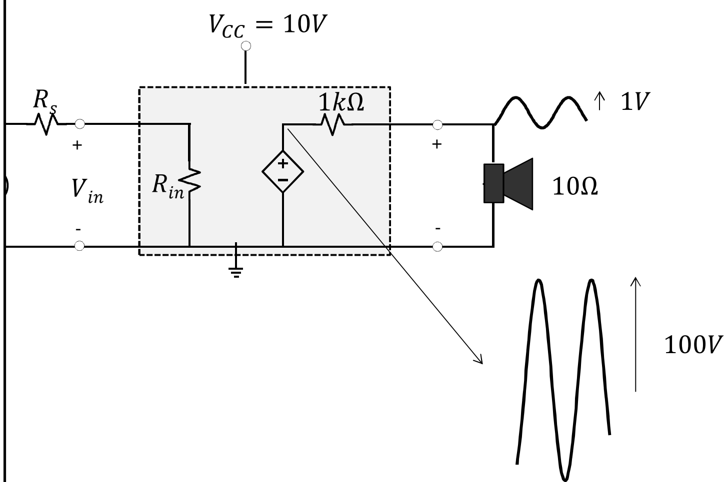
Practical Consideration

1. Lab
2. Power
3. Ser/Parl
4. Small sig.
5. Applic



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Practical Consideration: Input / Output Resistance

1. Lab
2. Power
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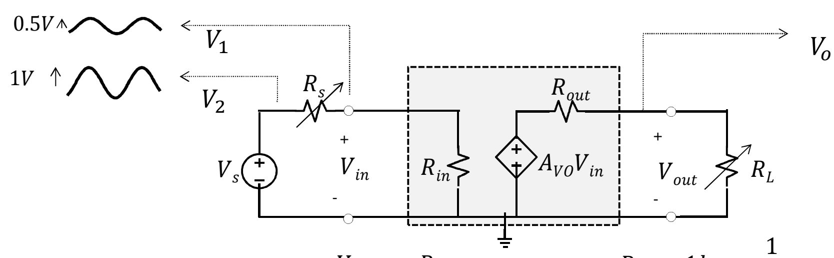
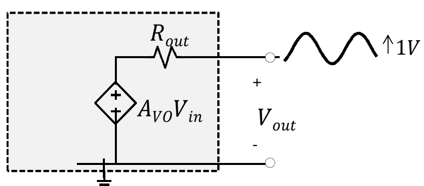
4. Small sig.
5. Applic

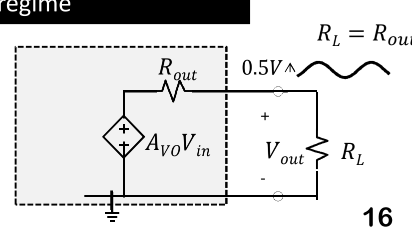


$$R_S = 1k\Omega \;\rightarrow\; \frac{V_1}{V_2} = \frac{R_{in}}{R_{in} + 1k} \qquad R_{in} = 1k \times \frac{1}{\frac{V_2}{V_1} - 1}$$

How about R_{out}?

Point: You need to make sure circuit is in its linear operation regime





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Amplifier Frequency Response

1. Lab
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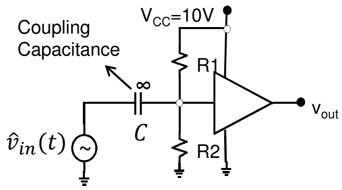
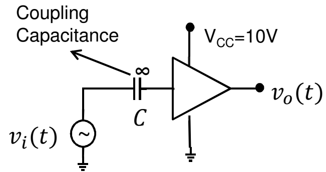
5. Applic





$v_i(t) = V_i \sin \omega t$ $\quad$ $v_o(t) = V_o \sin(\omega t + \varphi)$

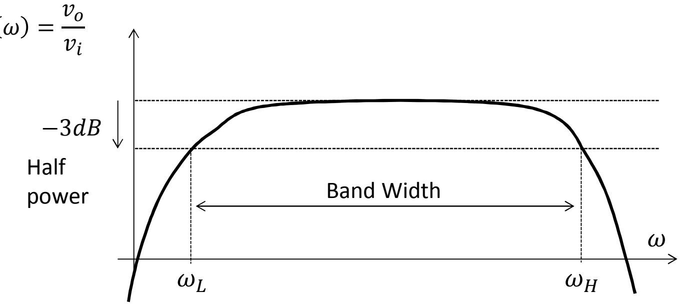
Transfer Function: $T(\omega) = \dfrac{v_o}{v_i}$

$|T(\omega)| = \dfrac{V_o}{V_i}$

Amplitude in dB

$\measuredangle T(\omega) = \varphi$

Phase



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