EE105 – Fall 2015
Microelectronic Devices and Circuits

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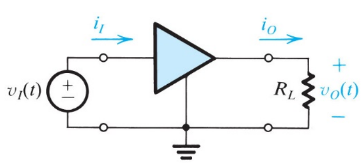
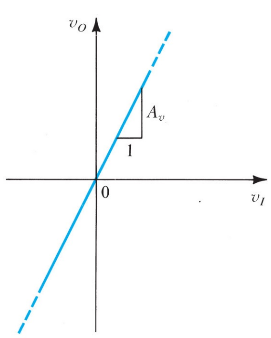
Amplifier Gain





Voltage Gain: $A_v = \dfrac{v_O}{v_I}$

Current Gain: $A_i = \dfrac{i_O}{i_I}$

Power Gain: $A_p = \dfrac{\text{load power}}{\text{input power}} = \dfrac{v_O i_O}{v_I i_I}$

Note: $A_p = A_v A_i$

Note: A_v and A_i can be positive, negative, or even complex numbers. Nagative gain means the output is 180° out of phase with input. However, power gain should always be a positive number.

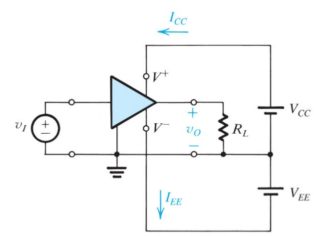
Gain is usually expressed in Decibel (dB):

$A_v(dB) = 10\log|A_v|^2 = 20\log|A_v|$

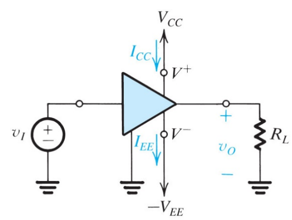
$A_i(dB) = 10\log|A_i|^2 = 20\log|A_i|$

$A_p(dB) = 10\log|A_p|$

Amplifier Power Supply and Dissipation



(a)



(b)

- Circuit needs dc power supplies (e.g., battery) to function.
- Typical power supplies are designated V_{CC} (more positive voltage supply) and $-V_{EE}$ (more negative supply).
- Total dc power dissipation of the amplifier

$$P_{dc} = V_{CC}I_{CC} + V_{EE}I_{EE}$$

- Power balance equation

$$P_{dc} + P_I = P_L + P_{dissipated}$$

P_I : power drawn from signal source

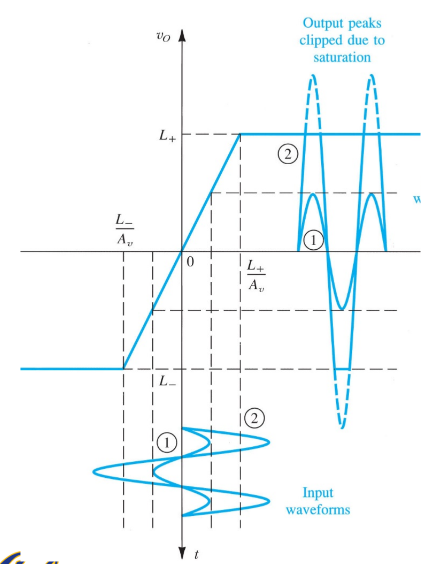
P_L : power delivered to the load (useful power)

$P_{dissipated}$: power dissipated in the amplifier circuit (not counting load)

- Amplifier power efficiency $\eta = \dfrac{P_L}{P_{dc}}$

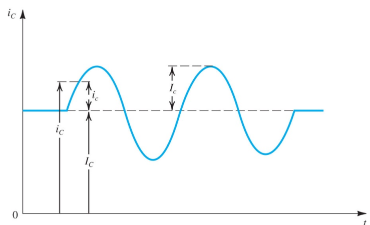
Power efficiency is important for "power amplifiers" such as output amplifiers for speakers or wireless transmitters.

Amplifier Saturation



- Amplifier transfer characteristics is linear only over a limited range of input and output voltages
- Beyond linear range, the output voltage (or current) waveforms saturates, resulting in distortions
  - Lose fidelity in stereo
  - Cause interference in wireless system

Symbol Convention



$i_C(t) = I_C + i_c(t)$

$i_C(t)$: total instantaneous current

I_C: dc current

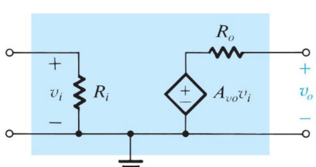
$i_c(t)$: small signal current

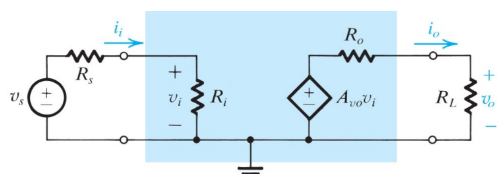
Usually $i_c(t) = I_c \sin \omega t$

Please note case of the symbol:
lowercase-uppercase: total current
lowercase-lowercase: small signal ac component
uppercase-uppercase: dc component
uppercase-lowercase: amplitude of ac component

Similarly for voltage expressions.
These expressions are widely adopted, though occasionally you will find different convention. You should check carefully whenever you read a new book or paper.

Circuit Model of Voltage Amplifiers (Two-Port Model)





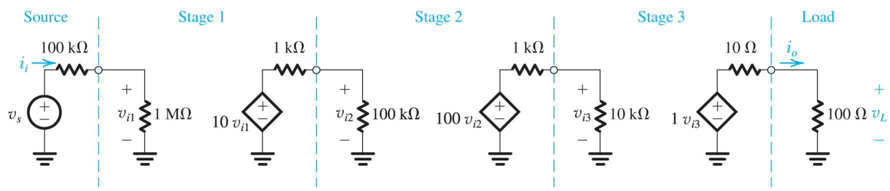
$$v_i = v_s \frac{R_i}{R_i + R_s}$$

$$v_o = A_{v0} v_i \frac{R_L}{R_L + R_o} = A_{v0} v_s \frac{R_i}{R_i + R_s} \frac{R_L}{R_L + R_o}$$

Overall voltage gain: $A_v = \frac{v_o}{v_s} = A_{v0} \frac{R_i}{R_i + R_s} \frac{R_L}{R_L + R_o}$

A_{v0}: open-circuit voltage gain (or voltage gain of "unloaded" amplifier)
R_i: input resistance of the amplifier
R_o: output resistance of the amplifier
R_s: source resistance
R_L: load resistance

Cascaded Amplifier



For most practical applications, multiple stages of amplifiers are cascaded to

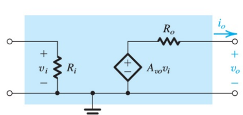
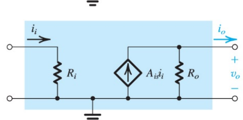
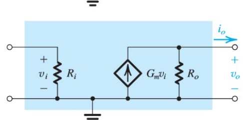
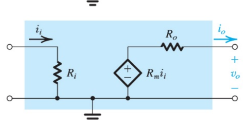
- provide suffiicent gain
- provide adequate input and output resistances

For example, in a voltage amplifier

- the input stage is designed to have high input impedance
- the output stage is designed to have low output impedance
- middle stage(s) provide the necessary gain

Amplifier Types

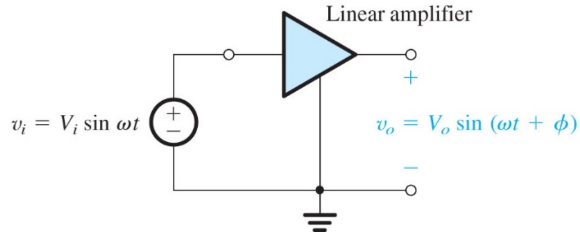
Table 1.1 The Four Amplifier Types

Type	Circuit Model	Gain Parameter	Ideal Characteristics
Voltage Amplifier		Open-Circuit Voltage Gain $A_{vo} \equiv \frac{v_o}{v_i}\Big\vert_{i_o=0}$ (V/V)	$R_i = \infty$ $R_o = 0$
Current Amplifier		Short-Circuit Current Gain $A_{is} \equiv \frac{i_o}{i_i}\Big\vert_{v_o=0}$ (A/A)	$R_i = 0$ $R_o = \infty$
Transconductance Amplifier		Short-Circuit Transconductance $G_m \equiv \frac{i_o}{v_i}\Big\vert_{v_o=0}$ (A/V)	$R_i = \infty$ $R_o = \infty$
Transresistance Amplifier		Open-Circuit Transresistance $R_m \equiv \frac{v_o}{i_i}\Big\vert_{i_o=0}$ (V/A)	$R_i = 0$ $R_o = 0$

Depending on the nature of the source signals and output loads, different types of amplifiers are needed

- Voltage amplifier
- Current amplifier
- Transconductance amp
  - Converts voltage to current
- Transimpedance amp
  - Converts current to voltage
- The 4 models here are interchangeable, though one is usually more convenient than others for analysis

Amplifier Frequency Response



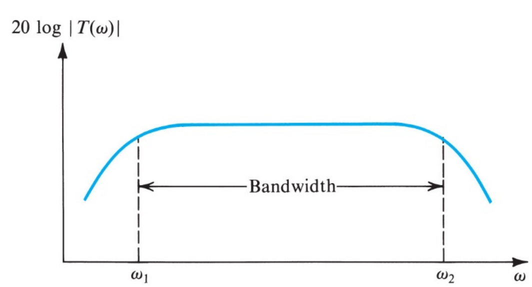
When a sinusoidal signal is applied to a linear circuit, the output is sinusoidal
- with the same frequency as the input
- but different amplitude and phase

Transfer function: $T(\omega) = \dfrac{V_o(\omega)}{V_i(\omega)}$

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

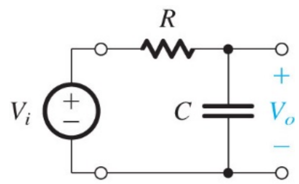
Phase response: $\angle T(\omega) = \phi$

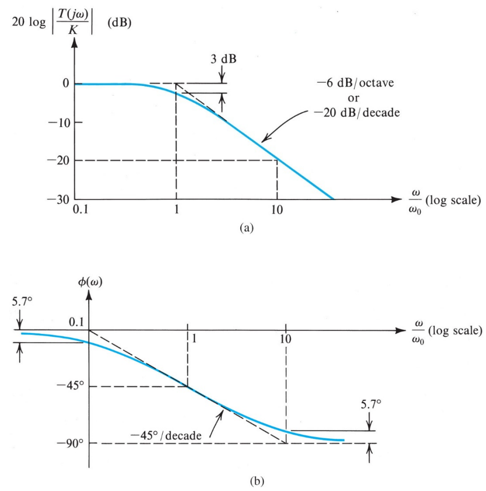
Frequency Response



- **Log-log plot of the transfer function versus angular frequency, ω**
  - **Vertical axis: 20 log |T(ω)|**
  - **Horizontal axis: 10 log ω**
- **This is called Bode Plot**
- **Bandwidth**
  - **Band of frequencies over which the gain response falls by 3dB**

Frequency Response of Low-Pass Filters





$$T(\omega)=\frac{\frac{1}{j\omega C}}{R+\frac{1}{j\omega C}}=\frac{1}{1+j\omega RC}=\frac{1}{1+j\omega/\omega_0}$$

$$\omega_0=\frac{1}{RC}$$

$$|T(\omega)|=\frac{1}{\sqrt{1+(\omega/\omega_0)^2}}$$

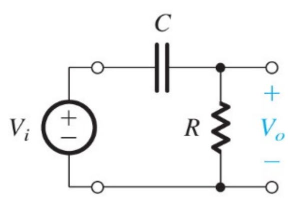
$$\angle T(\omega)=-\tan^{-1}(\omega/\omega_0)$$

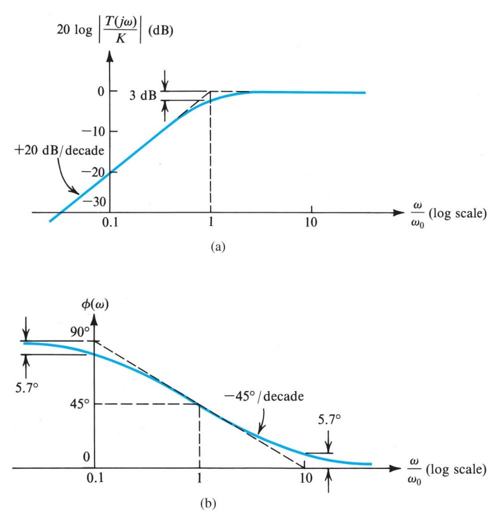
$$\omega_{3dB}=\omega_0 \qquad \text{[rad/sec]}$$

$$f_{3dB}=\frac{\omega_0}{2\pi} \qquad \text{[Hz]}$$

Cal BSAC

Frequency Response of High-Pass Filters





$$T(\omega)=\frac{R}{R+\frac{1}{j\omega C}}=\frac{1}{1+\frac{1}{j\omega RC}}=\frac{1}{1-j\omega_0/\omega}$$

$$\omega_0=\frac{1}{RC}$$

$$|T(\omega)|=\frac{1}{\sqrt{1+(\omega_0/\omega)^2}}$$

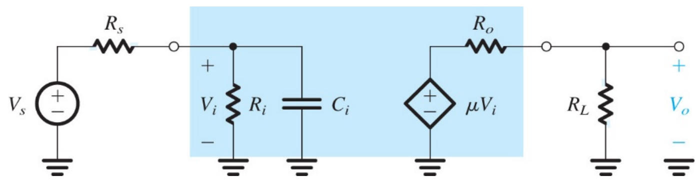
$$\angle T(\omega)=\tan^{-1}(\omega_0/\omega)$$

$$\omega_{3dB}=\omega_0 \qquad \text{[rad/sec]}$$

$$f_{3dB}=\frac{\omega_0}{2\pi} \qquad \text{[Hz]}$$

Cal BSAC

Example: Amplifier Frequency Response



$$V_i = V_s \frac{Z_i}{R_s + Z_i}$$

$$Z_i = \frac{R_i / (j\omega C_i)}{R_i + 1/(j\omega C_i)} = \frac{R_i}{1 + j\omega R_i C_i}$$

$$\frac{V_i}{V_s} = \frac{R_i}{R_s + R_i + j\omega R_i R_s C_i} = \frac{R_i}{R_s + R_i} \frac{1}{1 + j\omega R_\parallel C_i}$$

$$R_\parallel = R_s \parallel R_i = \frac{R_s R_i}{R_s + R_i}$$

$$T(\omega) = \frac{V_o}{V_s} = \frac{V_o}{V_i}\frac{V_i}{V_s}$$

$$= \mu \frac{R_L}{R_o + R_L} \frac{R_i}{R_s + R_i} \frac{1}{1 + j\omega R_\parallel C_i}$$

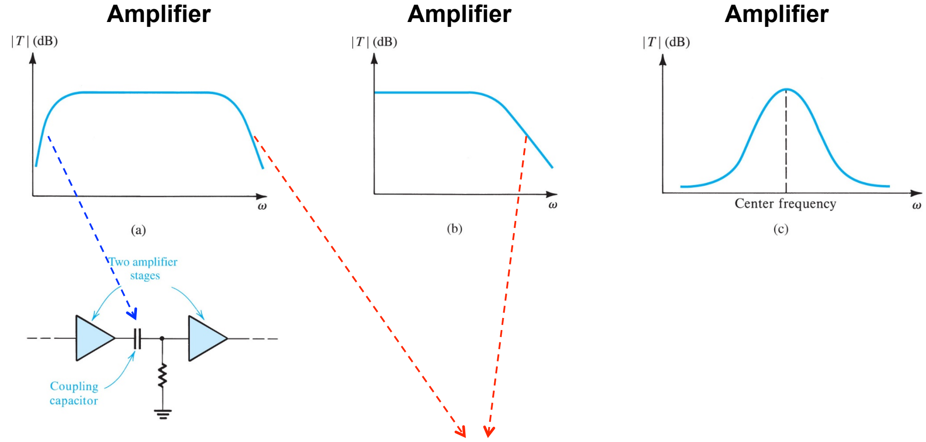
$$= \frac{K}{1 + j\left(\omega / \omega_0\right)}$$

$$\omega_0 = \frac{1}{R_\parallel C}$$

$$K = \mu \frac{R_L}{R_o + R_L} \frac{R_i}{R_s + R_i}$$

Typical Frequency Responses

Capacitively Coupled Amplifier | **Direct-Coupled Amplifier** | **Bandpass Amplifier**



Low frequency roll-off due to coupling capacitor

High frequency cut-off due to intrinsic capacitors of the transistors