ELECTRONICS I NOTES

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Textbook: Microelectronic Circuits by Sedra & Smith

Outline

1. Introduction to Electronics
2. Operational Amplifiers
3. Diodes
4. BJTs
5. FETs
6. Differential and Multistage amplifiers
7. Frequency Response of amplifiers

1. Introduction

Electronics: Study of electrical circuits for information processing

Microelectronics: integrated-circuit technology

Purpose: Design and analysis of electronic circuits.

1.1 Signals

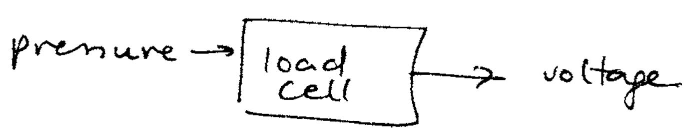
Signal: a physical variable that contain information.

voltage, current, pressure, temperature ...

a processing step is needed to extract the information from the signal.

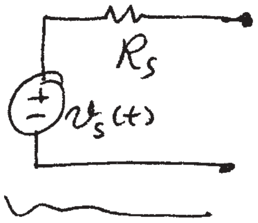
→ signal processing.

a transducer is needed to convert a physical signal into an electrical signal.

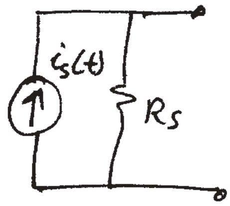


air pressure → [microphone] → voltage

The transducers are not our subject in this course. We will represent the transducer with an electrical equivalent:



Thévenin form

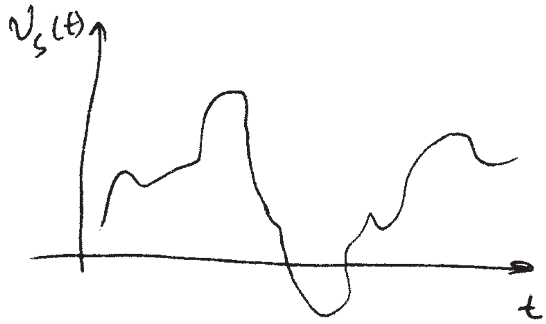


Norton form

signal source

signal → $v_s(t)$

signal $i_s(t)$



"arbitrary" in time

↑ this would be hard to characterize mathematically.

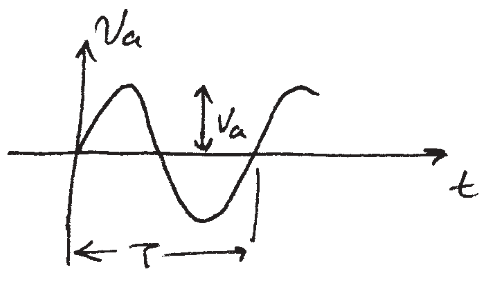
The signal processing equipment depends on the characteristics of the signal

1.2 Frequency Spectrum of Signals

an arbitrary signal $= \sum$ many sine wave signals

- Fourier series representation
- (Fourier transform)

⇒ Sinusoid is important



$v_a(t) = V_a \sin \omega t$

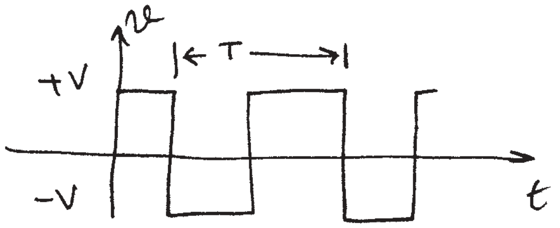
V_a: amplitude, peak value
ω: angular frequency (rad/s)

$\omega = 2\pi f$ rad/s $\quad f = \frac{1}{T}$ Hz $\quad$ T: period in seconds

There is also the phase of the sine-wave.
Here it is taken to be zero.

effective value (rms — root-mean-square) $= \frac{V_a}{\sqrt{2}}$

The power outlet in the house has the rms value 220 V. The peak value (amplitude) is $220\sqrt{2}$



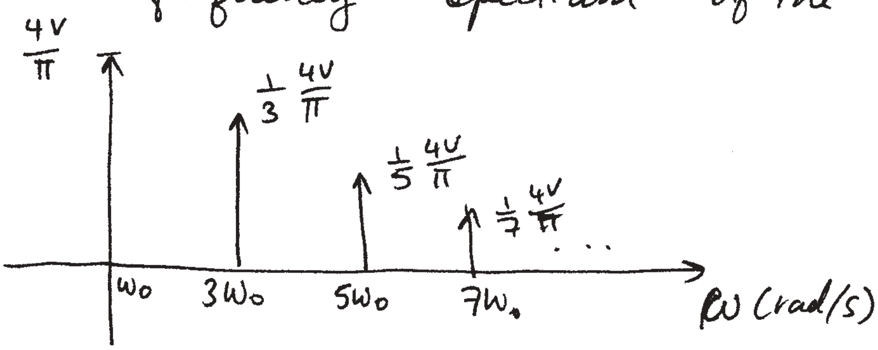
symmetrical square wave

harmonics

$$v(t) = \frac{4V}{\pi}\left(\sin\omega_0 t + \frac{1}{3}\sin 3\omega_0 t + \frac{1}{5}\sin 5\omega_0 t + \cdots\right)$$

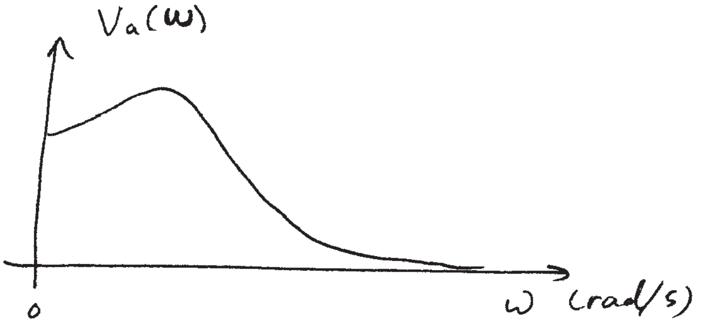
where $\omega_0 = \frac{2\pi}{T}$ fundamental frequency

The frequency spectrum of the square wave $v(t)$:



The amplitude of the harmonics diminish as the frequency increases.

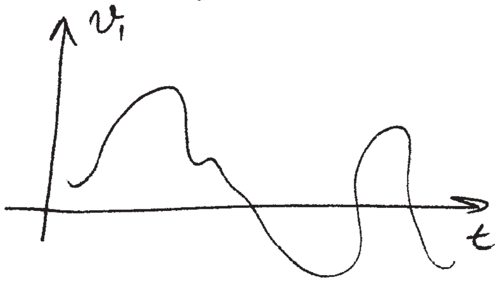
A non-periodic arbitrary signal may have a spectrum as follows:



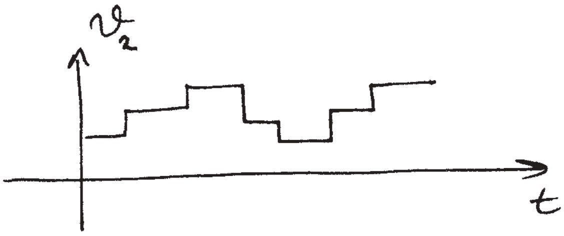
example:
audible sounds
20 Hz — 20 kHz
(audio band)

A signal may be represented as a time dependent function $v_s(t)$ (time domain) or as its frequency spectrum $V_s(\omega)$ (frequency domain)

1.3 Analog and Digital signals

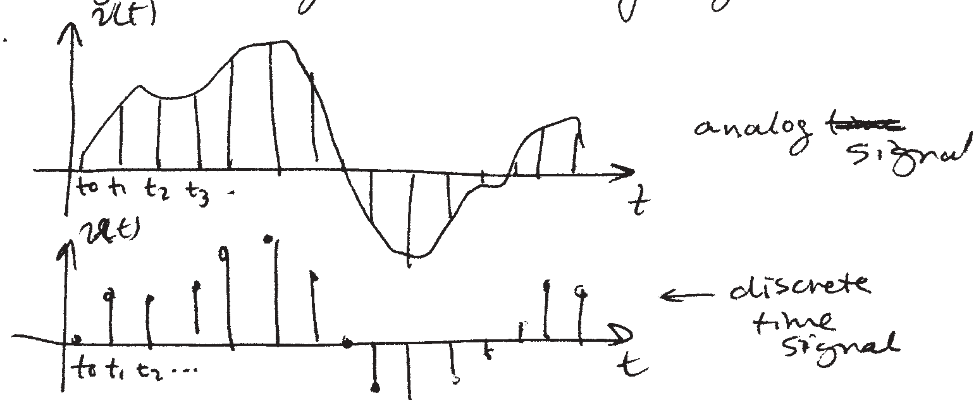


this is an analog signal. It can take <u>any</u> value. It is continuous



This is a "somehow" digital signal. It can take distinc values only.

To obtain a digital signal, analog signal is first sampled.



The magnitude of each sample canbe represented by a number with finite digits → quantized discretized, digitized signal.
→ sequence of number that represent the magnitudes of samples.

digital circuits process digital signals
digital computer

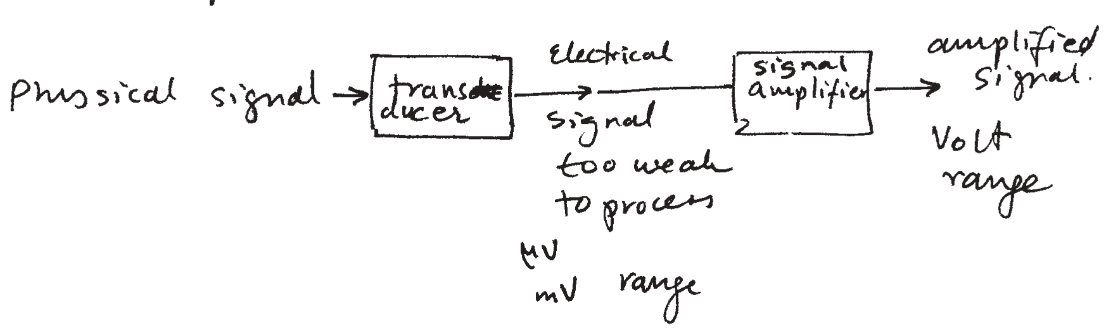
Digital signal processing → economical and reliable.
most signals in the physical world → analog.

Electronics engineers must be good in both type of signal processing.

1.4 Amplifiers

Signals usually have small magnitudes. They need to be amplified before they are used.

Signal amplification



Linearity of the amplifiers is needed.
An amplifier should not change the information content of the signal! — Nothing is added nothing is eliminated.

Any change in the form of the signal is called "distortion."

$$v_O(t) = A\, v_i(t)$$ (output signal: $v_O(t)$; input signal: $v_i(t)$) — linear amplifier

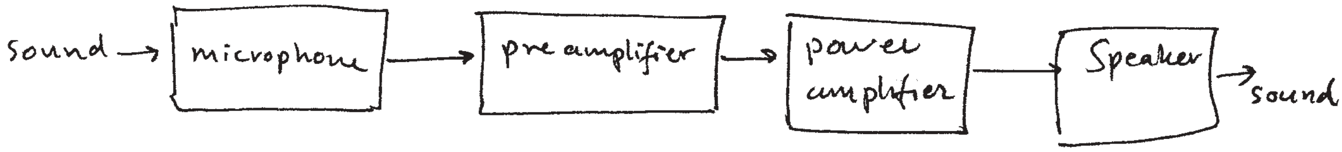
A: Constant, amplifier gain

if v_O contains higher powers of $v_i(t)$, the amplifier exhibits nonlinear distortion.

The amplitude of the signal is made larger.

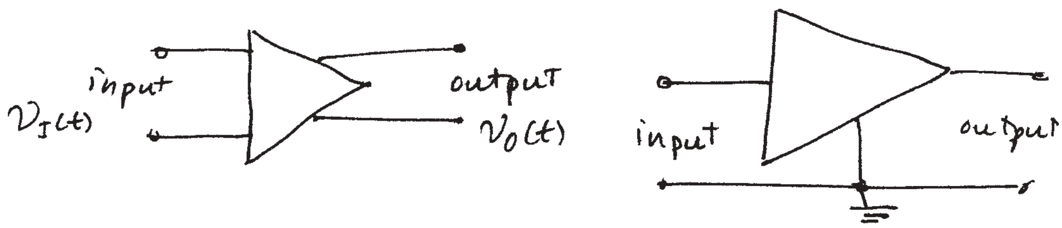
→ voltage amplifier

- Preamplifier
- Power amplifier



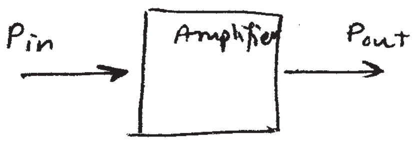
Amplifier Circuit Symbol:

a two-terminal circuit

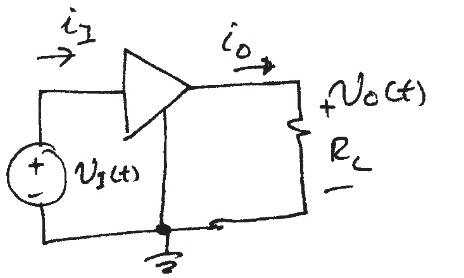


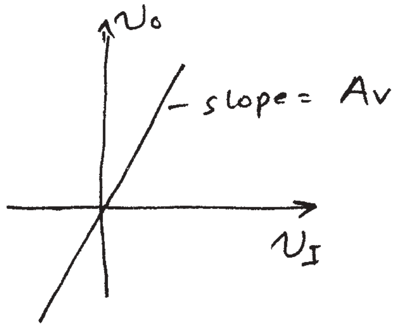
$$\text{Voltage gain} \equiv A_v \equiv \frac{v_O(t)}{v_I(t)}$$

Power gain



Pout > Pin the difference comes from the power supply.





$$A_p = \text{Power gain} \equiv \frac{\text{Load power}}{\text{input power}} = \frac{v_o i_o}{v_I i_I}$$

$$i_o = \frac{v_o}{R_L}, \qquad \text{current gain} \equiv \frac{i_o}{i_I} = A_i$$

$$A_p = \frac{v_o}{v_I} \cdot \frac{i_o}{i_I} = A_v \cdot A_i$$

decibel unit is used to expres the gain.

$20 \log|A_v|$ dB
$20 \log|A_i|$ dB
$10 \log|A_p|$ dB

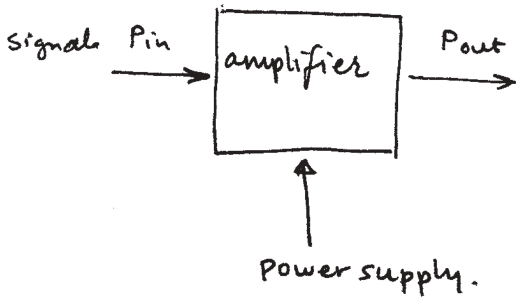
if the input resistance of the amplifier is R_L
then $i_I = \frac{v_I}{R_L}$, $i_o = \frac{v_o}{R_L}$

$$A_i = \frac{i_o}{i_I} = \frac{v_o}{R_L} \Big/ \frac{v_I}{R_L} = \frac{v_o}{v_I} = A_v$$

This means $A_p = A_i \cdot A_v = A_v^2$

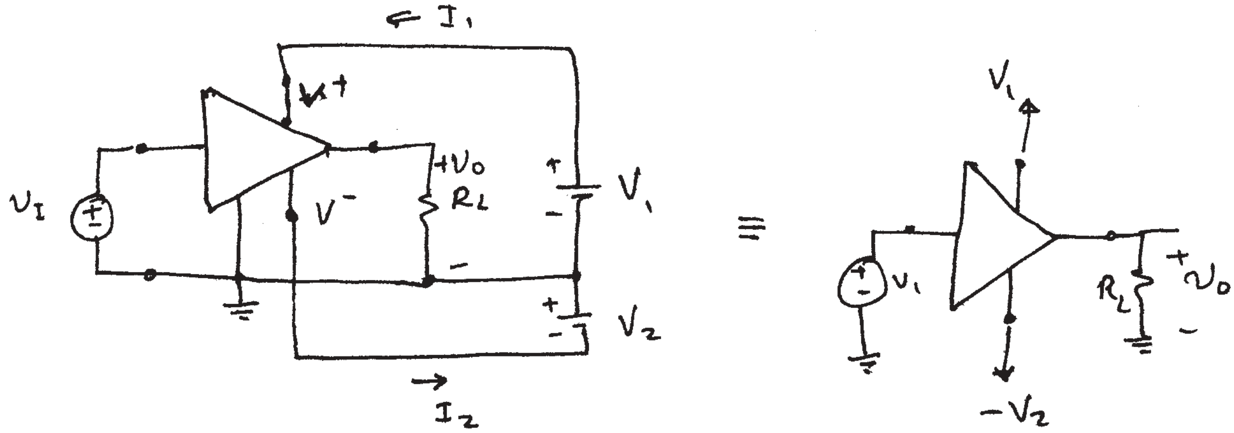
$$10 \log A_p = 10 \log (A_v^2)$$
$$10 \log A_p = 20 \log|A_v|$$

$A_p = 1 \Rightarrow$ 0 dB gain
$|A_p| < 1 \Rightarrow$ negative gain $\rightarrow$ loss
$|A_p| > 1 \Rightarrow$ positive gain



$P_{out} > P_{in}$

where does the difference come from?



DC power delivered to the amplifier $P_{dc} = V_1 I_1 + V_2 I_2$

Power balance equation

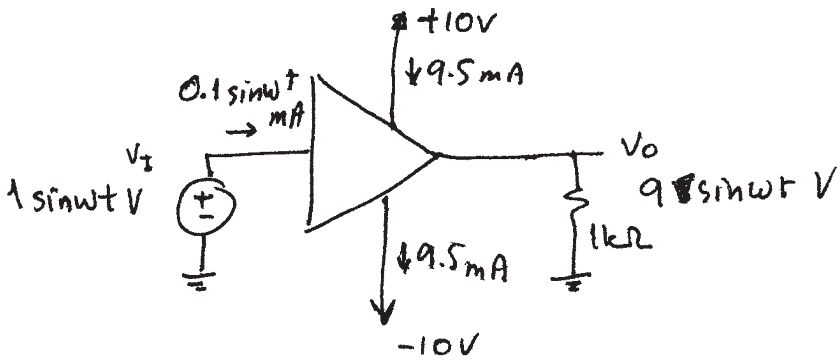
$$P_{dc} + P_I = P_L + P_{dis}$$

P_I ↑ usually small

P_{dis} ↑ power dissipated in the amplifier.

Efficiency $\eta \equiv \dfrac{P_L}{P_{dc}}$ (%) ← This is important for large powers

Example:



find A_v, A_i, A_p, P_{dc}, P_{dis}, η

$$A_v = \frac{9 \sin\omega t}{1 \sin\omega t} = 9 \qquad A_i = \frac{9 \sin\omega t^{V} / 1k\Omega}{0.1 \sin\omega t \ mA} = 90$$

$$20 \log 9 = 19.1\,dB \qquad 20 \log 90 = 39.1\,dB$$

$$P_L = V_{o\,rms} I_{o\,rms} = \frac{9}{\sqrt{2}} \cdot \frac{9}{\sqrt{2}} = 40.5\ mW$$

$$P_I = V_{i\,rms} I_{i\,rms} = \frac{1}{\sqrt{2}} \times \frac{0.1}{\sqrt{2}} = 0.05\ mW$$

$$A_p = \frac{40.5}{0.05} = 810 \rightarrow 10 \log 810 = 29.1\,dB$$

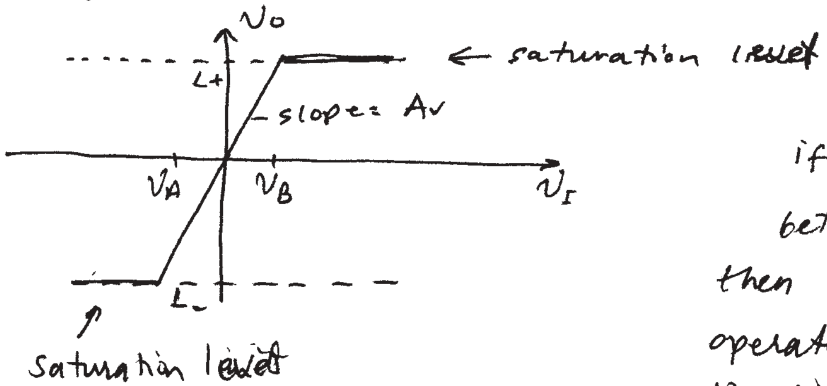
$$P_{dc} = 10 \times 9.5 + 10 \times 9.5 = 190\ mW$$

$$P_{dissipated} = P_{dc} + P_I - P_L = 190 + 0.05 - 40.5 = 149.6\ mW$$

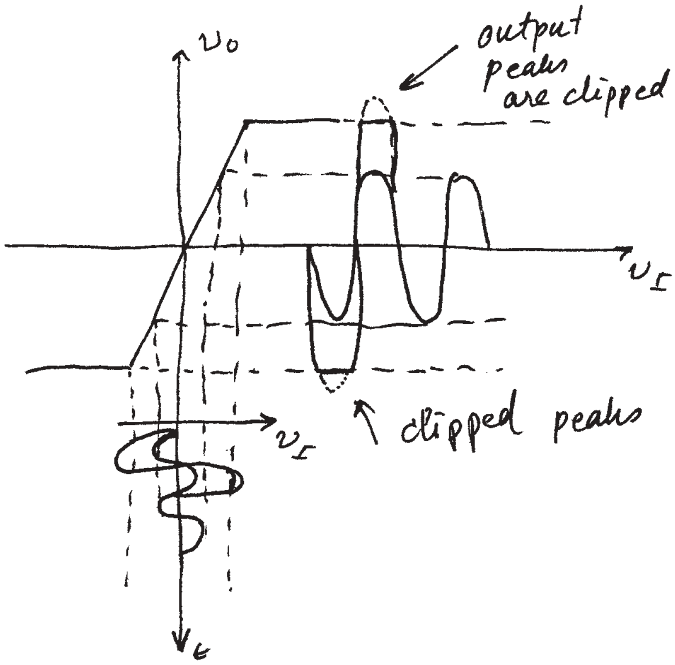
$$\eta = \frac{P_L}{P_{dc}} = \frac{40.5}{190} = 0.213 = 21.3\%$$

Amplifier Saturation

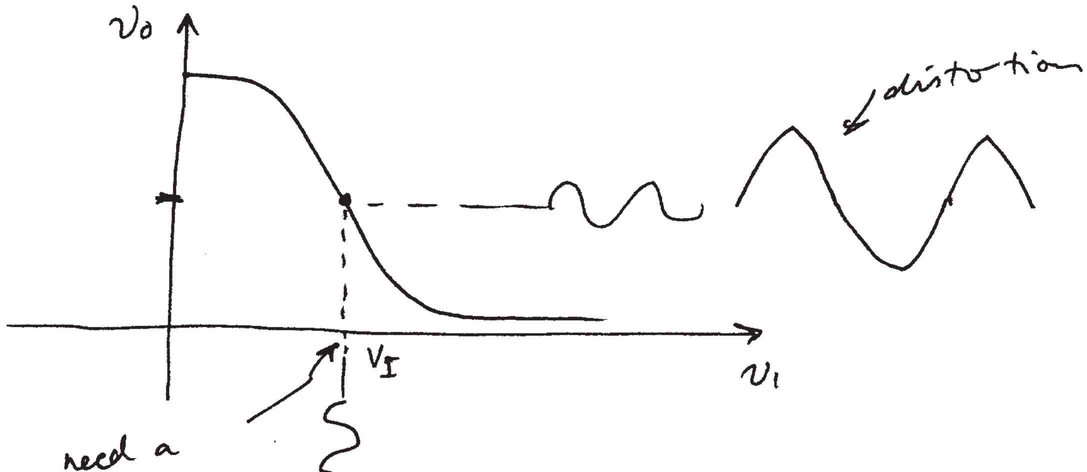
The output voltage of an amplifier may not assume infinetely large values. It has limits $L+$, $L-$ in positive and negative voltages, respectively.

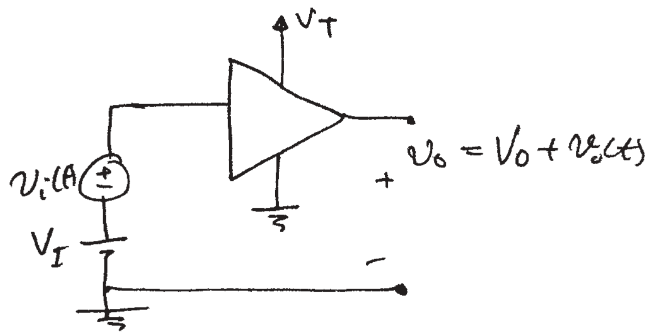


if v_I is between v_A and v_B, then amplifier operates linearly otherwise - nonlinear.



Often the characteristics of the amplifier is not linear:





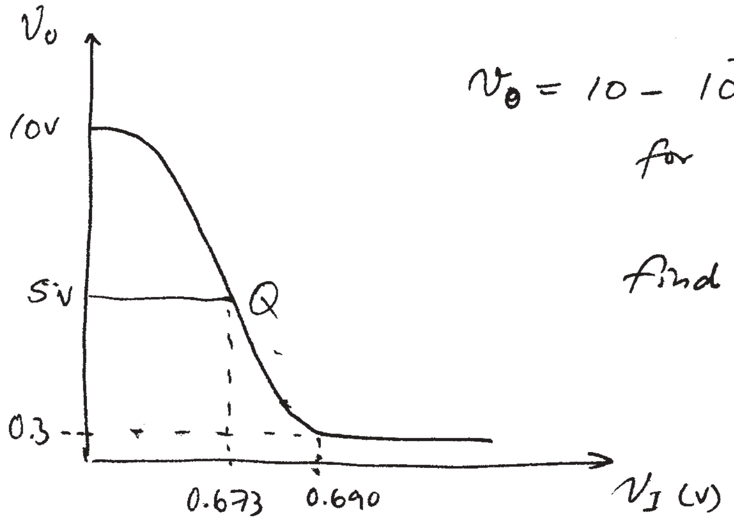
$$v_I(t) = V_I + v_i(t)$$

$$v_O(t) = V_O + v_o(t)$$

total — bias — signal

$$A_v = \left.\frac{dv_O}{dv_I}\right|_Q$$

Example: A transistor amplifier



$$v_O = 10 - 10^{-11} e^{40 v_I}$$

for $v_I > 0$, $v_O \geq 0.3V$

find L_+ and L_- limits

$L_+ = 10V$

$L_- = 0.3V$

Substitute $v_O = 0.3V$ and solve for V_I, $\rightarrow v_I = 0.690V$

To bias it at $V_O = 5V$,

$V_I = 0.673$ is found.

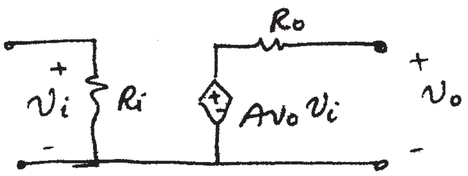
gain at the Q-point $\rightarrow$ $A_v = \left.\dfrac{dv_O}{dv_I}\right|_Q = -200$

if the signal components are small, $\rightarrow$ linear operation assumption is valid.

1.5 Circuit Models for Amplifiers

The amplifier may be modeled in one of the following 4 ways:

a) Voltage amplifier

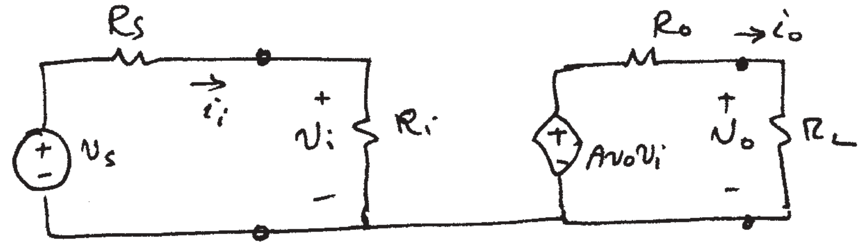


A_{vo} : voltage gain w/o a load. (open ckt voltage gain)

R_i = input resistance

R_o = output resistance

In the presence of a load, the source voltage is divided by the load and the output resistance. There may be a similar voltage division at the input:

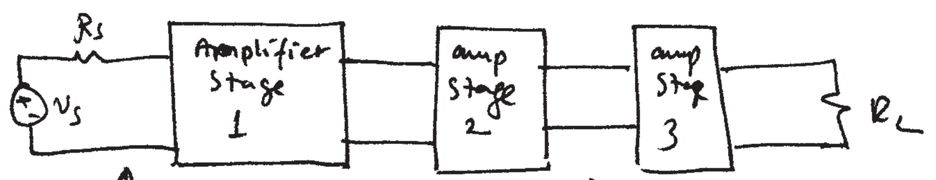


$$v_i = v_s \frac{R_i}{R_s + R_i} \qquad v_o = A_{vo} v_i \frac{R_L}{R_o + R_L}$$

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

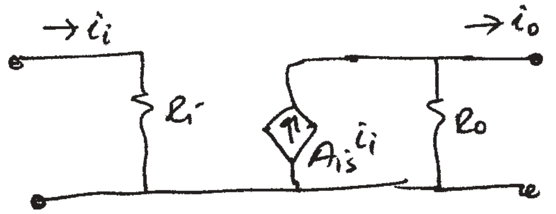
- A_{vo}: Open ckt Voltage gain
- $\frac{R_i}{R_s + R_i}$: loading @ input
- $\frac{R_L}{R_L + R_o}$: Loading @ output

ideal voltage amplifier has $R_i \to \infty$, $R_o \to 0$

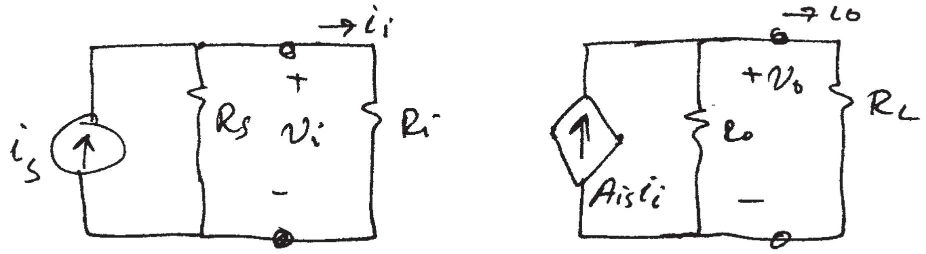


Loading factors exist here

b) current amplifier



with the source and load:

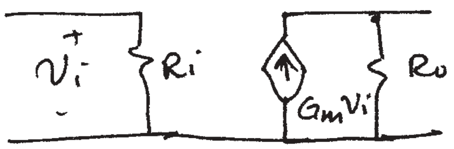


$v_i = i_s \, R_s || R_i$, $i_i = \frac{v_i}{R_i} = i_s \frac{R_s}{R_i + R_s}$

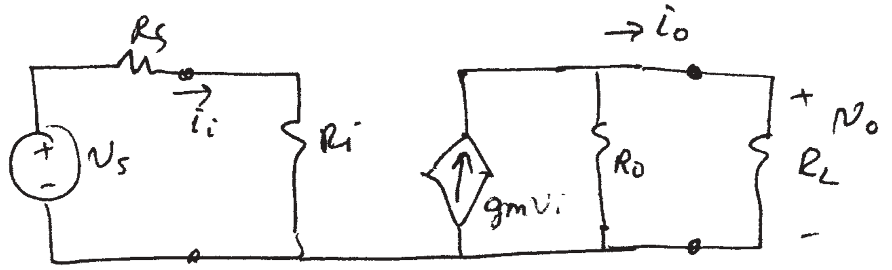
$v_o = A_{is} i_i \, (R_o || R_L)$, $i_o = \frac{v_o}{R_L}$

A_v , A_i, A_p can be calculated.

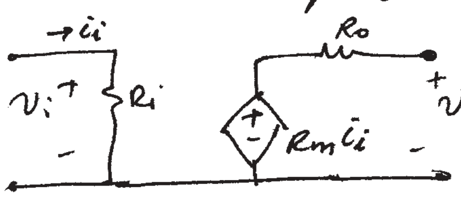
c) Transconductance amplifier



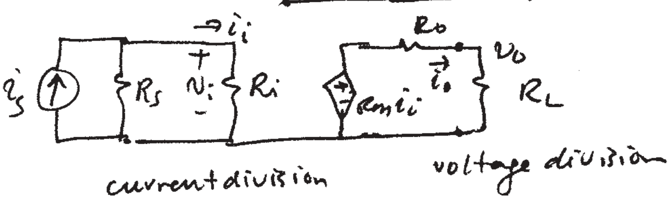
G_m: short circuit transconductance



d) Transadmittance Amplifier



R_m: open-ckt transresistance



An amplifier can be represented by any of the models. It can be shown that

$$A_{vo} = A_{is}\left(\frac{R_o}{R_i}\right)$$

$$A_{vo} = G_m R_o$$

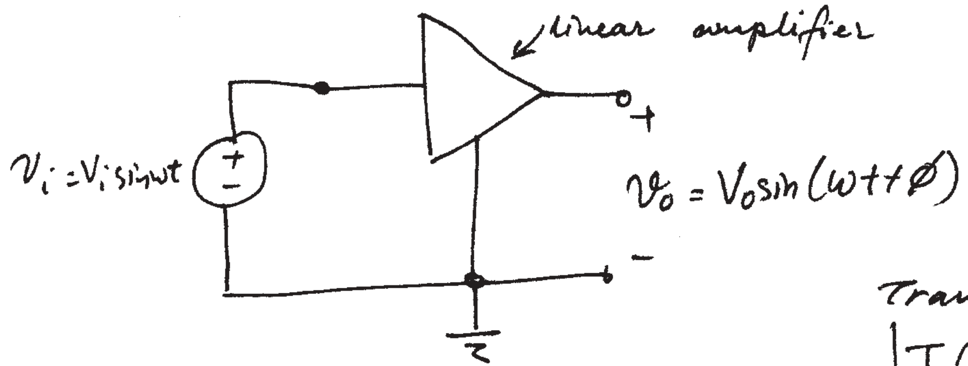
$$A_{vo} = \frac{R_m}{R_i}$$

All of these models are UNILATERAL signal flow ⟶ into one direction.

[Study examples 1.4 and 1.5 on pp. 25 – 28]

1.6 Frequency Response of Amplifiers

How the gain of the amplifier changes with frequency?

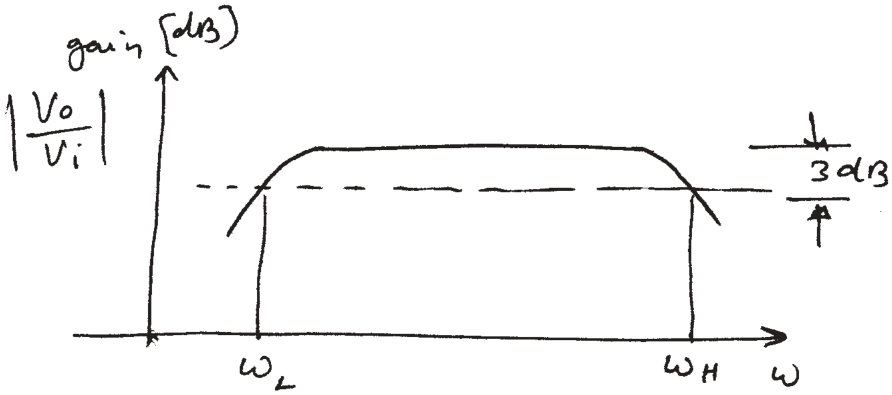


Transfer function

$$|T(\omega)| = \left|\frac{V_o}{V_i}\right|$$

Magnitude + Phase

$$\angle T(\omega) = \phi$$



Bandwidth: $\omega_H - \omega_L$

Half-power frequencies $\rightarrow \omega_L, \omega_H$

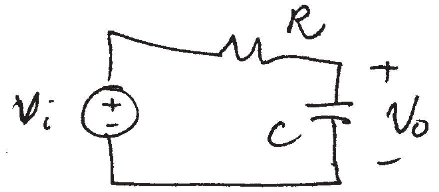
Lower 3-dB cutoff freq $= \omega_L$

Higher 3-dB " " $= \omega_H$

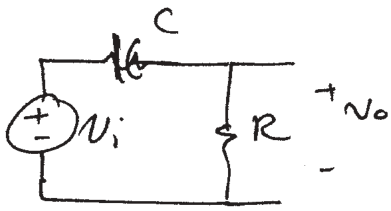
non-flat sections of the amplifier response cause <u>distortion</u>.

single-time-constant networks: (STC networks)

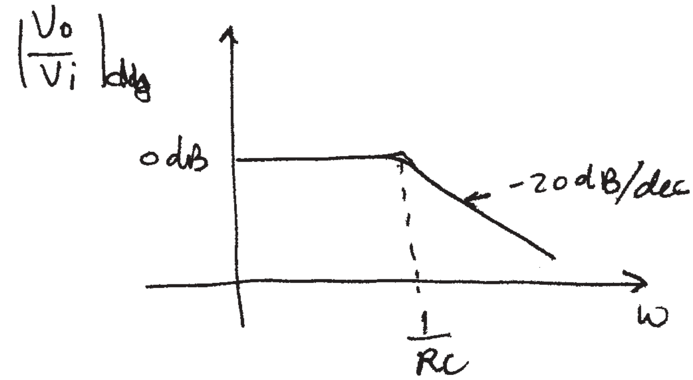
a circuit that has a resistive and a reactive components



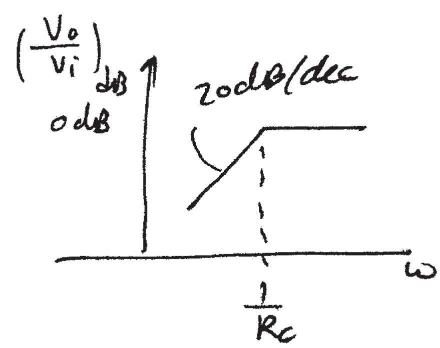
(Low pass filter)



(High pass filter)



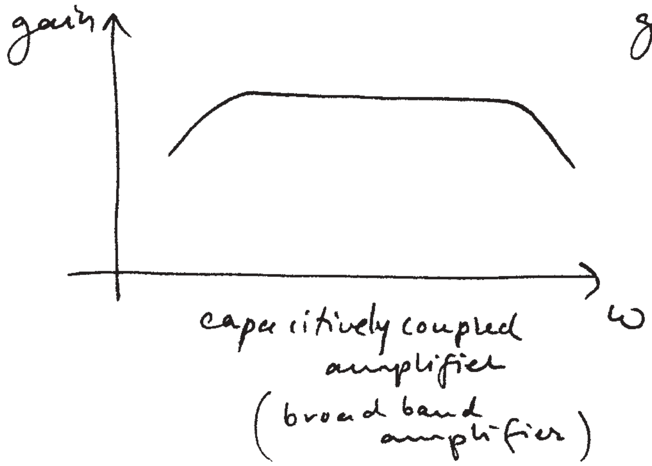
corner frequency

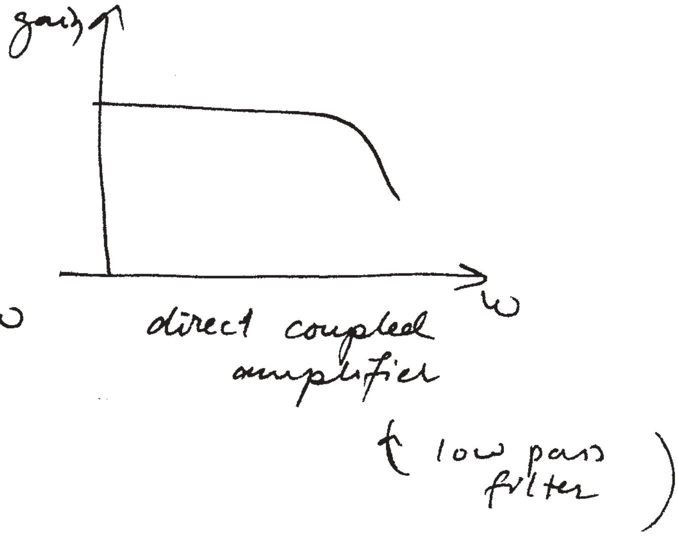


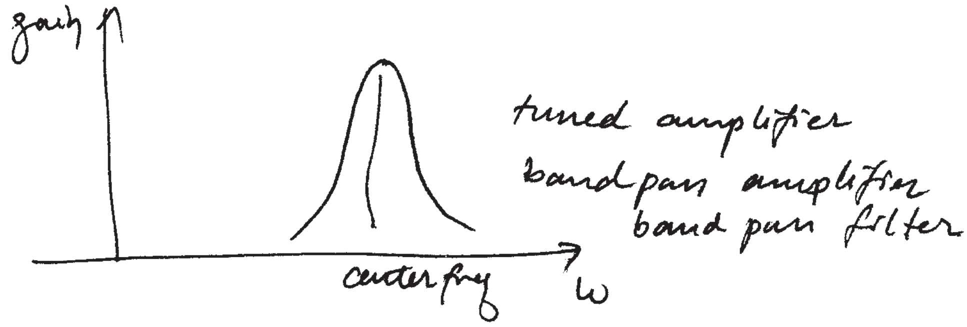
break frequency

[study example 1.6 on pp. 33 – 37]

Classification of Amplifiers:







Homework: # 1.4 # 1.11 a, b, c # 1.23 ?

1.9 # 1.12