EEC 332 - Analog Integrated Circuits

Lecture 1
Introduction

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Microsoft Teams

1 Reference

Microelectronic Circuits, A Sedra, KC Smith, 8th Edition

2 Course Content

1) Signals and Amplifiers (Chapter 1)

2) MOS Field-Effect Transistors (MOSFETs) (Chapter 5)

3) Transistor Amplifiers (Chapter 7)

4) Building Blocks of Integrated Circuit Amplifiers (Chapter 8)

5) Differential and Multistage Amplifiers (Chapter 9)

3 AC signal

$\boldsymbol{V_a(t) = V_a \sin(\omega t)}$

for square wave we use the Fourier transform

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

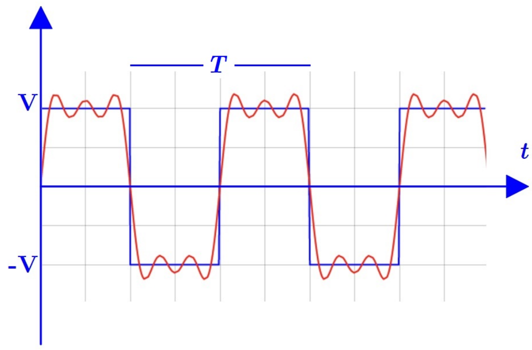

Figure 1: Converting square wave to a sum of sines

4 Analog to digital converting

$\boxed{\textbf{Sampling}} \rightarrow \boxed{\textbf{Quantization}} \rightarrow \boxed{\textbf{Encoding}}$

Note that $\boldsymbol{f_{\text{sampling}} \geq 2\omega}$

Where $\boldsymbol{\omega}$ **is the bandwidth of the signal**

Google **Nyquist rate**

Note that Quantization error occures if the quantization levels are not enough

5 Voltage, Current and Power Gain

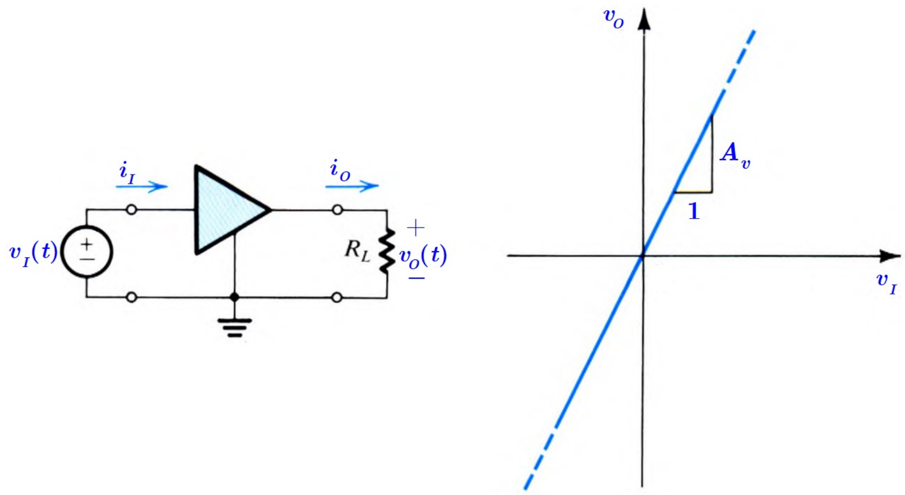

Figure 2: A voltage amplifier fed with a signal $v_L(t)$ and connected to a load resistance R_L. and the transfer characteristic of a linear voltage amplifier with voltage gain A_v .

$$\textbf{Voltage gain } (A_v) \equiv \frac{v_o}{v_i} \tag{2}$$

$$\textbf{Current gain } (A_i) \equiv \frac{i_o}{i_i} \tag{3}$$

$$\begin{aligned} \textbf{Power gain } (A_p) &\equiv \frac{\textbf{load power } (P_L)}{\textbf{input power } (P_I)} \\ &= \frac{v_o i_o}{v_i i_i l} \end{aligned} \tag{4}$$

$$A_p = A_v A_i \tag{5}$$

Note that in figure 2:

Slope of Transfer Characteristics $= A_V$

6 Decibel Gain

$$\begin{aligned} \text{Voltage gain in decibels} &= 20\log|A_v| \quad \text{dB} && (6)\\ \text{Current gain in decibels} &= 20\log|A_i| \quad \text{dB} && (7)\\ \text{Power gain in decibels} &= 10\log A_p \quad \text{dB} && (8)\\ & && (9) \end{aligned}$$

Why the absolute value ?

Note that the gain may be positive or negative, real or imaginary :

negative gain refers to a 180° (inversion)[1]

imaginary gain refers to any other phase shift

So the absolute value is used

Note that there are no need for absolute value in power gain in dB, because it is proportional to the square of the voltage (or current)

7 The Amplifier Power Supplies

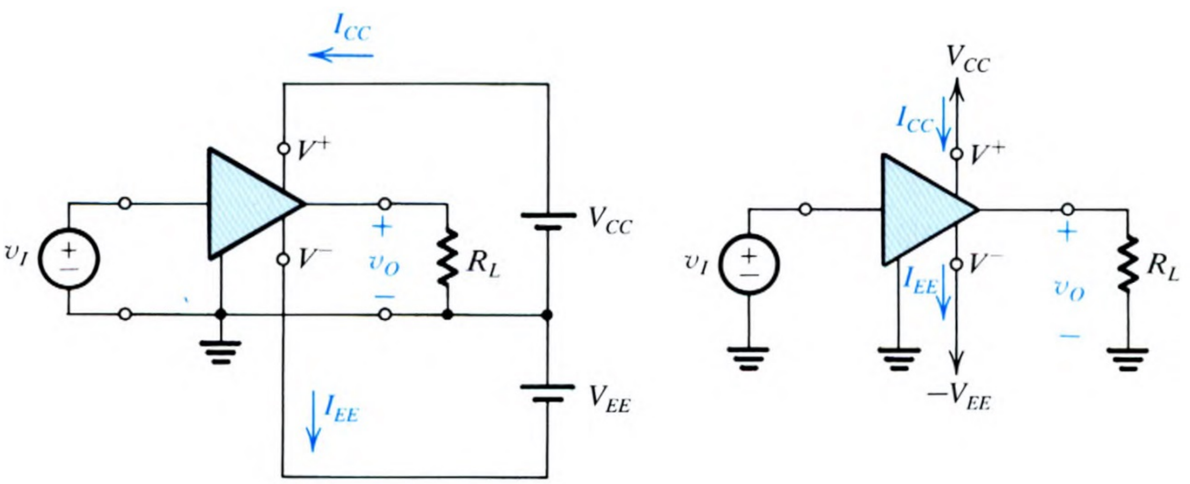

Figure 3: An amplifier that requires two dc supplies (shown as batteries) for operation.

The input power

[1] Note atenuation, attenuation happens when the gain < 1 (i.e. $A_v = 0.1V/V$)

$$\begin{aligned} P_I &= V_{i\ \text{rms}} I_{i\ \text{rms}} && (10) \\ &= \frac{V_{i\ \text{peak}} I_{i\ \text{peak}}}{\sqrt{2} \times \sqrt{2}} && (11) \\ &= \frac{V_{i\ \text{peak}} I_{i\ \text{peak}}}{2} && (12) \end{aligned}$$

Note that : $V_{\text{rms}} = \dfrac{V_{\text{peak}}}{\sqrt{2}}$

The load power :

$$\begin{aligned} P_{\text{load}} &= V_{o\ \text{rms}} I_{o\ \text{rms}} && (13) \\ &= I^2_{o\ \text{rms}} \times R_L && (14) \\ &= \frac{V^2_{o\ \text{rms}}}{R_L} && (15) \end{aligned}$$

the dc power delivered to the amplifier

$$P_{\text{dc}} = V_{CC} I_{CC} + V_{EE} I_{EE} \tag{16}$$

$$\tag{17}$$

, the power-balance equation for the amplifier (conservation of power)

$$P_{\text{dc}} + P_I = P_L + P_{\text{dissipated}} \tag{18}$$

the amplifier power efficiency [2]

$$\eta \equiv \frac{P_L}{P_{\text{dc}}} \times 100 \tag{19}$$

8 Example

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1. Q Consider a microphone producing a sinusoidal signal that is 400-mV peak. It delivers 10- μA peak sinusoidal current to an amplifier that operates from $\pm$1-V

[2] It should be $\eta \equiv \frac{P_L}{P_{\text{dc}}+P_I} \times 100$ but P_I is so small that it can be ignored

power supplies. The amplifier delivers a $0.8-\mathrm{V}$ peak sinusoid to a speaker load with $32-\Omega$ resistance. The amplifier draws a current of 30 mA from each of its two power supplies. Find the voltage gain, the current gain, the power gain, the power drawn from the dc supplies, the power dissipated in the amplifier, and the amplifier efficiency.

$\boxed{\text{1. A}}$

$$
\begin{aligned}
A_v &= \frac{0.8\ \mathrm{V}}{0.4\ \mathrm{V}} = 2\ \mathrm{V/V},\ \text{ or } A_v = 20\log 2 = 6\ \mathrm{dB} \\
I_o &= \frac{0.8\ \mathrm{V}}{32\Omega} = 25\ \mathrm{mA} \\
A_i &= \frac{I_o}{I_i} = \frac{25\ \mathrm{mA}}{0.01\ \mathrm{mA}} = 2500\ \mathrm{A/A},\ \text{ or } A_i = 20\log 2500 = 68\ \mathrm{dB} \\
P_L &= V_{o_{\mathrm{rms}}} I_{o_{\mathrm{rms}}} = \frac{0.8\ \mathrm{V}}{\sqrt{2}}\frac{25\ \mathrm{mA}}{\sqrt{2}} = 10\ \mathrm{mW} \\
P_I &= V_{i_{\mathrm{rms}}} I_{i_{\mathrm{rms}}} = \frac{0.4\ \mathrm{V}}{\sqrt{2}}\frac{0.01\ \mathrm{mA}}{\sqrt{2}} = 2\ \mu\mathrm{W} \\
A_p &= \frac{P_L}{P_I} = \frac{10\ \mathrm{mW}}{2\mu\mathrm{W}} = 5000\ \mathrm{W/W},\ \text{ or } A_p = 10\log 5000 = 37\ \mathrm{dB} \\
P_{\mathrm{dc}} &= 1\ \mathrm{V} \times 30\ \mathrm{mA} + 1\ \mathrm{V} \times 30\ \mathrm{mA} = 60\ \mathrm{mW} \\
P_{\mathrm{dissipated}} &= P_{\mathrm{dc}} + P_I - P_L \\
&= 60\ \mathrm{mW} + 0.002\ \mathrm{mW} - 10\ \mathrm{mW} \simeq 50\ \mathrm{mW} \\
\eta &= \frac{P_L}{P_{\mathrm{dc}}} \times 100 = 16.7\%
\end{aligned}
$$

9 Saturation

In order to avoid distorting the output signal waveform, the input signal swing must be kept within the linear range of operation.

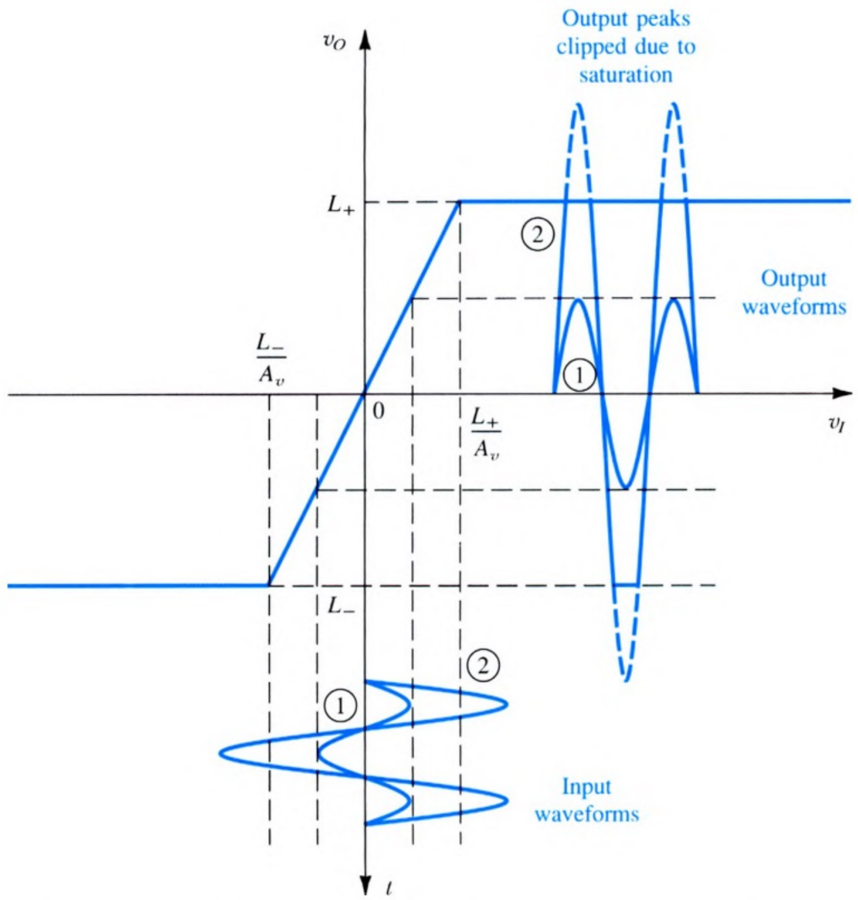

Figure 4: An amplifier transfer characteristic that is linear except for output saturation.

$$\frac{L_-}{A_v} \leq v_I \leq \frac{L_+}{A_v} \tag{20}$$

10 Symbol convention

instantaneous current $i_C(t)$ is the sum of the dc current I_C and the signal current $i_c(t)$,

$$i_C(t) = I_C + i_c(t) \tag{21}$$

where the signal current is given by

$$i_c(t) = I_c \sin \omega t \tag{22}$$

11 Circuit Models for Amplifiers

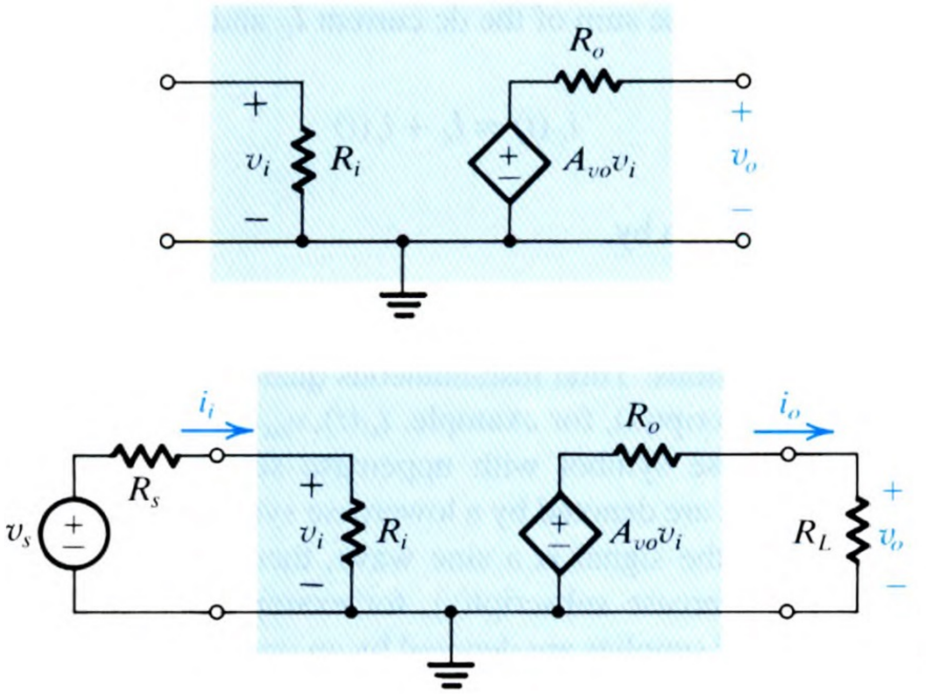

Figure 5: Circuit model for the voltage amplifier with and without source and load

Note that :

$\boldsymbol{R_i}$ **: input resistance (ideally ∞)**

$\boldsymbol{R_o}$ **: output resistance (ideally 0)**

$\boldsymbol{A_v}$ **: voltage gain**

$\boldsymbol{A_{vo}}$ **: Open circuit voltage gain**

Note : $\boldsymbol{A_v < A_{vo}}$

$$\boldsymbol{v_o = A_{vo}v_i} \tag{23}$$

$$\boldsymbol{= A_{vo}v_s(\text{in case of no } R_s)} \tag{24}$$

$$\boldsymbol{v_o = A_{vo} v_i \frac{R_L}{R_L + R_o}} \tag{25}$$

$$\boldsymbol{v_i = v_s \frac{R_i}{R_i + R_s}} \tag{26}$$

$$\boldsymbol{A_v \equiv \frac{v_o}{v_i} = A_{vo} \frac{R_L}{R_L + R_o}} \tag{27}$$

(overall voltage gain:) (28)

$$\boldsymbol{\frac{v_o}{v_s} = A_{vo} \frac{R_i}{R_i + R_s} \frac{R_L}{R_L + R_o} = A_v \frac{R_i}{R_i + R_s}} \tag{29}$$