Basic BJT and MOS Amplifier Topologies
CE/CS, CC/CD, CB/CG
Amplifier Circuit Analysis

- We studied the small-signal method for analyzing circuits that contain nonlinear devices such as transistors and diodes.

- We will now utilize this method to analyze the most popular amplifier topologies.

- There are 3 fundamental amplifier topologies we will discuss:
  - Common Emitter (BJT-based) and Common Source (MOS-based) topologies
    - A variation of these topologies are CE/CS with emitter/source resistance
  - Common Collector (BJT-based) and Common Drain (MOS-based)
    - Topologies
  - Common Base (BJT-based) and Common Gate (MOS-based) topologies
Amplifier Circuit Analysis

- We used the small-signal Y-parameters to represent each transistor in a given circuit → We can do the same thing to represent the entire circuit in terms of its Y-parameters.

- Note that the Y-parameters of the entire circuit are not the same Y-parameters of the individual devices.

- However, we can compute the Y-parameters of the full circuit as a function of the Y-parameters for the individual devices.

- Since we linearized all the devices in the circuit, obtaining the Y-parameters for the entire circuit is rather easy.
Amplifier Circuit Analysis

\[ i_1 = y_{11} \cdot v_1 + y_{12} \cdot v_2 \]

\[ i_2 = y_{21} \cdot v_1 + y_{22} \cdot v_2 \]

- \textbf{Y-parameters characterization is popular for characterizing individual device, but not very popular for characterizing amplifier circuits}
Amplifier Circuit Analysis

- An alternative method is to use Input Impedance \( (r_{in}) \), Output Impedance \( (r_{out}) \), Forward Gain \( (A_{v0}) \), and Reverse Gain \( (A_{vr}) \) → essentially a Thevenin transformation of the Y-parameters

\[
\begin{align*}
 i_1 &= y_{11} \cdot v_1 + y_{12} \cdot v_2 \\
 i_2 &= y_{21} \cdot v_1 + y_{22} \cdot v_2
\end{align*}
\]

\[
\begin{align*}
 v_1 &= i_1 \cdot r_{in} + A_{VR} \cdot v_2 \\
 v_2 &= i_2 \cdot r_{out} + A_{V0} \cdot v_1
\end{align*}
\]
**Amplifier Circuit Analysis**

- Depending on \( A_{VR} \), the amplifier is termed unilateral if \( A_{VR} = 0 \), otherwise the amplifier is termed bilateral.

If \( A_{VR} \neq 0 \)

\[
v_1 = i_1 \cdot r_{in} + A_{VR} \cdot v_2
\]

\[
v_2 = i_2 \cdot r_{out} + A_{V0} \cdot v_1
\]

If \( A_{VR} = 0 \)

\[
v_1 = i_1 \cdot r_{in}
\]

\[
v_2 = i_2 \cdot r_{out} + A_{V0} \cdot v_1
\]
Amplifier Circuit Analysis

why is this form popular in amplifiers?

It is very common that we have different source and load impedances but the same amplifier → we don’t want to re-analyze the amplifier every time.
Amplifier Circuit Analysis

Why is this form popular in amplifiers?

\[ v_{out} = \frac{R_L}{r_{out} + R_L} \cdot A_{V0} \cdot v_1 = \frac{R_L}{r_{out} + R_L} \cdot A_{V0} \cdot \frac{r_{in}}{r_{in} + R_s} \cdot v_{in} \]

\[ A_V = \frac{v_{out}}{v_{in}} = \left( \frac{R_L}{r_{out} + R_L} \right) \cdot \left( \frac{r_{in}}{r_{in} + R_s} \right) \cdot A_{V0} \]
Amplifier Circuit Analysis

Why is this form popular in amplifiers?

It is very common that we cascade amplifiers to increase gain.
Amplifier Circuit Analysis

Why is this form popular in amplifiers?

\[
V_{\text{out}} = \left( \frac{R_L}{r_{\text{out}3} + R_L} \right) \cdot A_{V03} \cdot V_{13}
\]

\[
= \left( \frac{R_L}{r_{\text{out}3} + R_L} \right) \cdot A_{V03} \cdot \left( \frac{r_{\text{in}3}}{r_{\text{in}3} + r_{\text{out}2}} \right) \cdot A_{V02} \cdot V_{12}
\]

\[
= \left( \frac{R_L}{r_{\text{out}3} + R_L} \right) \cdot A_{V03} \cdot \left( \frac{r_{\text{in}3}}{r_{\text{in}3} + r_{\text{out}2}} \right) \cdot A_{V02} \cdot \left( \frac{r_{\text{in}2}}{r_{\text{in}2} + r_{\text{out}1}} \right) \cdot A_{V01} \cdot V_{11}
\]

\[
= \left( \frac{R_L}{r_{\text{out}3} + R_L} \right) \cdot A_{V03} \cdot \left( \frac{r_{\text{in}3}}{r_{\text{in}3} + r_{\text{out}2}} \right) \cdot A_{V02} \cdot \left( \frac{r_{\text{in}2}}{r_{\text{in}2} + r_{\text{out}1}} \right) \cdot A_{V01} \cdot \left( \frac{r_{\text{in}1}}{r_{\text{in}1} + R_s} \right) \cdot V_{\text{in}}
\]
Amplifier Circuit Analysis

Why is this form popular in amplifiers?

\[ A_{V03} = \frac{v_{out}}{v_{in}} = \left(\frac{R_L}{r_{out3} + R_L}\right) \cdot \left(\frac{r_{in3}}{r_{in3} + r_{out2}}\right) \cdot \left(\frac{r_{in2}}{r_{in2} + r_{out1}}\right) \cdot \left(\frac{r_{in1}}{r_{in1} + R_s}\right) \cdot A_{V03} \cdot A_{V02} \cdot A_{V01} \]
Amplifier Circuit Analysis

- How do we obtain $r_{in}$, $r_{out}$, $A_{V0}$, and $A_{VR}$?
- Mathematical $\Rightarrow$ we can solve the circuit and write the equations in the standard form $\Rightarrow$ tedious and not very intuitive

$$v_1 = i_1 \cdot r_{in} + A_{VR} \cdot v_2$$
$$v_2 = i_2 \cdot r_{out} + A_{V0} \cdot v_1$$

- Circuit level $\Rightarrow$ we can use Thevenin and Norton equivalent circuits to manipulate the circuit and put it in a structure that looks like the standard equivalent circuit $\Rightarrow$ tedious if the circuit is big
A better method is to use the $V_{\text{TEST}} : i_{\text{TEST}}$ method → intuitive, easy, and can be done straight on the circuit without having to manipulate equations into standard form.
Amplifier Circuit Analysis

◆ The $V_{TEST} : i_{TEST}$ method

$$A_{V0} = \frac{v_{OUT-TEST}}{v_{TEST}}$$

$$A_{VR} = \frac{v_{OUT-TEST}}{v_{TEST}}$$
Amplifier Circuit Analysis

◆ The $V_{\text{TEST}} : i_{\text{TEST}}$ method

\[ r_{\text{in}} = \frac{V_{\text{TEST}}}{i_{\text{TEST}}} \]

\[ r_{\text{out}} = \frac{V_{\text{TEST}}}{i_{\text{TEST}}} \]
Amplifier topologies are categorized based on which terminal in the transistor is common to both the input and output signals.

- Common Emitter
- Common Source
- Common Base
- Common Gate
- Common Collector
- Common Drain
Since the MOS case is just a special case of the BJT case that can be obtained by setting $r_{\pi}$ to infinity, we will analyze the BJT case for generality.
CE/CS Amplifier Topology

- In a CE/CS topology, the input signal is applied to the base/gate of the transistor, while the output is taken at the collector/drain.

- Consider the BJT case, let's obtain the amplifier equivalent circuit.

\[ V_1 \rightarrow V_2 \]

\[ + \quad + \quad - \quad - \]

Common Emitter

\[ \begin{align*}
V_1 & \quad V_{be} \quad r_\pi \\
\quad & \quad & \quad g_m V_{be} \\
\quad & \quad & \quad r_o \\
\quad & \quad & \quad V_{ce}
\end{align*} \]

\[ + \quad + \quad - \quad - \]
We can obtain the 2-port equivalent circuit in two ways:

- Manipulate the circuit to put it in the desired form.

CE/CS topology is unilateral:
- Gain is high and inverting.
- High input and output impedance.
We can obtain the 2-port equivalent circuit in two ways

Use the $V_{\text{TEST}} : i_{\text{TEST}}$ method

$$v_{\text{OUT-TEST}} = -g_m \cdot v_{\text{TEST}} \cdot r_o$$

$$A_{V0} = \frac{v_{\text{OUT-TEST}}}{v_{\text{TEST}}} = -g_m \cdot r_o$$
We can obtain the 2-port equivalent circuit in two ways

Use the $V_{\text{TEST}} : i_{\text{TEST}}$ method

$V_{\text{OUT-TEST}} = 0$

$A_{VR} = 0$

CE/CS topology is unilateral
We can obtain the 2-port equivalent circuit in two ways:

Use the $V_{\text{TEST}} : i_{\text{TEST}}$ method.

\[
\begin{align*}
\text{B} & \quad + & \quad \text{C} \\
V_1 & \quad \text{r}_\pi & \quad g_m V_1 & \quad \text{r}_o & \quad V_2 \\
& \quad - & \quad & \quad - & \quad \\
V_{\text{TEST}} & \quad + & \quad V_1 & \quad \text{r}_\pi & \quad g_m V_1 & \quad \text{r}_o & \quad V_2 \\
& \quad - & \quad & \quad - & \quad \\
i_{\text{TEST}} & \quad = & \quad \frac{V_{\text{TEST}}}{r_\pi} & \quad r_{\text{in}} & \quad = & \quad r_\pi
\end{align*}
\]
CE/CS Amplifier Topology

- We can obtain the 2-port equivalent circuit in two ways
- Use the $V_{\text{TEST}} : i_{\text{TEST}}$ method

\[ i_{\text{TEST}} = \frac{v_{\text{TEST}}}{r_o} \]

\[ r_{out} = r_o \]