EE 330
Lecture 31

Basic amplifier architectures
These circuits considered previously have a terminal (emitter or source) common to the input and output in the small-signal equivalent circuit.
Amplifiers using these devices generally have one terminal common and use remaining terminals as input and output.

Since devices are unilateral, designation of input and output terminals is uniquely determined.

Three different ways to designate the common terminal:

- Source or Emitter
- Gate or Base
- Drain or Collector

Terms:
- Common Source or Common Emitter
- Common Gate or Common Base
- Common Drain or Common Collector
Review from Last Time

Basic Amplifier Structures

<table>
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<th>Common Source or Common Emitter</th>
<th>MOS</th>
<th>BJT</th>
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<tr>
<td>Common Input</td>
<td>S</td>
<td>E</td>
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<tr>
<td>Common Output</td>
<td>G</td>
<td>B</td>
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<tr>
<td>Common Drain or Common Collector</td>
<td>D</td>
<td>C</td>
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Can analyze the BJT structures and then obtain the characteristics of The MOS structure by setting $g_{m}=0$
Basic Amplifier Structures

Review from Last Time

Common Emitter Amplifier

Common Source Amplifier

Can include or exclude R and R₁ (included here)

The CE and CS amplifiers are themselves two-ports!
Observe that the small-signal equivalent of any 3-terminal network is a two-port.

Thus to characterize any of the 3 basic amplifier structures, it suffices to determine the two-port equivalent network.

How should the two-port characterization be done?

Why is the two-port characterization useful?
Two-Port Characterization of 3-terminal devices

Small Signal Transistor Models as 3-terminal Devices

y-parameter characterization of 3-terminal network

\[ i_1 = y_{11}v_1 + y_{12}v_2 \]
\[ i_2 = y_{21}v_1 + y_{22}v_2 \]

- If unilateral, \( y_{12} = 0 \)
- \( y \) = parameters not widely used
Two-Port characterization of unilateral 3-terminal devices

Widely used characterization strategy
Model parameters are \( \{R_{iX}, A_{V0} \text{ and } R_{0X}\} \)
Two-Port characterization of non-unilateral 3-terminal devices

Widely used characterization strategy
Model parameters are \( \{R_{iX}, A_{V0}, A_{VR} \text{ and } R_{0X}\} \)
The three basic amplifier types for both MOS and bipolar processes

- Common Emitter
- Common Base
- Common Collector
- Common Source
- Common Gate
- Common Drain

How can the two-port parameters be obtained for these or any other linear two-port networks?
Determination of two-port unilateral model parameters

A method of obtaining $R_{in}$

Terminate the output in an open-circuit

$$i_1 = v_1 \left( \frac{1}{R_{in}} \right)$$

$$i_2 = v_1 \left( \frac{-A_v}{R_0} \right) + v_2 \left( \frac{1}{R_0} \right)$$

$$R_{in} = \frac{v_{test}}{i_{test}}$$
Two-port model for Common Emitter Configuration

It can be readily shown that the common-emitter configuration is unilateral

Thus is is characterized by the parameters \( \{R_{\text{in}}, A_V, R_0\} \)
Two-port model for Common Emitter Configuration

\[ \begin{align*}
    &\text{Common Emitter} \\
    &\begin{array}{ccc}
        + & \text{v}_{be} & - \\
        & g_T & \\
        & g_m v_{be} & g_O
    \end{array} \\
    \end{align*} \]

\[ \begin{align*}
    i_1 & \rightarrow R_{ix} A_{v0} v_1 & R_{ox} \\
    - & \rightarrow v_1 & + \\
    + & \rightarrow v_2 & - \\
    \end{align*} \]

\{R_{ix}, A_{v0} and R_{ox}\}
Two-port model for Common Emitter Configuration

To obtain $R_{in}$

\[ R_{iX} = \frac{V_{test}}{i_{test}} \]

\[ R_{iX} = \frac{1}{g_\pi} \]

$\{R_{inX}, A_{V0}$ and $R_{0X}\}$
Two-port model for Common Emitter Configuration

To obtain $A_{V0}$

$$A_{V0} = \frac{V_{out-test}}{V_{test}}$$

$$v_{out-test} = v_{test} \left(-\frac{g_m}{g_0}\right)$$

$$A_{V0} = -\frac{g_m}{g_0}$$

$\{R_{inX}, A_{V0} \text{ and } R_{0X}\}$
Two-port model for Common Emitter Configuration

To obtain $g_0$

$$\{R_{inX}, A_{V0} \text{ and } R_{0X}\}$$
Two-port model for Common Emitter Configuration

- Input impedance is mid-range
- Voltage Gain is Large and Inverting
- Output impedance is large
- Widely used to build voltage amplifiers
Consider the following CE application

(this will also generate a two-port model for this CE application)

$$\mathbf{v}_{\text{out}} \left(g_C + g_0\right) = g_0 A V_0 \mathbf{v}_{\text{in}}$$

$$A_V = \frac{\mathbf{v}_{\text{out}}}{\mathbf{v}_{\text{in}}} = \frac{g_0 A V_0}{g_0 + g_C} = \frac{-g_m}{g_0 + g_C} \approx -g_m R_C$$

$$R_{\text{in}} = R_{iX} = r_{\pi}$$

$$R_{\text{out}} = R_{oX}/R_C \quad \Rightarrow \quad R_{\text{out}} = R_{oX}/R_C = \frac{1}{g_0 + g_C} \approx R_C$$
Common Emitter Configuration

Consider the following CE application

(this will also a two-port model for this CE application)

This circuit can also be analyzed directly without using 2-port model for CE configuration

\[ V_{out} = -g_m V_{in} \left( \frac{1}{g_0 + g_C} \right) \]

\[ A_v = \frac{V_{out}}{V_{in}} = -\left( \frac{g_m}{g_0 + g_C} \right) \approx -g_m R_C \]

\[ R_{in} = r_{\pi} \]

\[ R_{out} = \frac{1}{g_0 + g_C} \approx R_C \]
Consider the following CE application
(this is also a two-port model for this CE application)

\[ A_v \approx -g_m R_C \]

\[ R_{out} = \frac{1}{g_0 + g_C} \approx R_C \]

\[ R_{in} = r_{\pi} \]

- Input impedance is mid-range
- Voltage Gain is Large and Inverting
- Output impedance is mid-range
- Widely used as a voltage amplifier
Two-port model for Common Collector Configuration

It can be readily shown that the common-collector and the common base configurations are not unilateral.

Thus a 4-parameter two-port model is needed to characterize these structures.

Or, equivalently
Two-port model for Common Collector Configuration

\( \{R_{iX}, A_{V0}, A_{V0r} \text{ and } R_{0X}\} \)
Two-port model for Common Collector Configuration

Applying KCL at the input and output node, obtain

\[ i_1 = (V_1 - V_2) g_\pi \]

\[ i_2 = (g_m + g_\pi + g_o) V_2 - (g_m + g_\pi) V_1 \]

These can be rewritten as

\[ V_1 = i_1 r_\pi + V_2 \]

\[ V_2 = \left( \frac{1}{g_m + g_\pi + g_o} \right) i_2 + \left( \frac{g_m + g_\pi}{g_m + g_\pi + g_o} \right) V_1 \]

It thus follows that

\[ R_{iX} = r_\pi \quad A_{VOR} = 1 \quad R_{0X} = \left( \frac{1}{g_m + g_\pi + g_o} \right) \quad A_{V0} = \left( \frac{g_m + g_\pi}{g_m + g_\pi + g_o} \right) \]
Two-port model for Common Collector Configuration

Two-port Common Collector Model

- $i_1$  +  $V_1$  -  $i_2$
- $+  V_2  -$  $i_2$
- $R_{ix}$
- $A_{v0r} = 1$
- $R_{ox} = \left( \frac{1}{g_m + g_\pi + g_o} \right)$

Common Collector

$V_{be}$

$g_\pi$

$g_m V_{be}$

$g_o$

$R_{ix} = r_\pi$

$A_{v0r} = 1$

$A_{v0} = \left( \frac{g_m + g_\pi}{g_m + g_\pi + g_o} \right)$
Consider the following CC application

Determine \( R_{\text{in}} \), \( R_0 \), and \( A_V \)

(this is not asking for a two-port model for the CC application – \( R_{\text{in}} \) and \( A_V \) defined for no load on output, \( R_0 \) defined for short-circuit input)

\[
A_V = \frac{g_m + g_\pi}{g_m + g_\pi + g_o} \left( \frac{g_m + g_\pi + g_o + g_E}{g_m + g_\pi + g_o + g_E} \right) = \frac{g_m + g_\pi}{g_m + g_\pi + g_o + g_E} \approx \frac{g_m}{g_m + g_E} \approx 1
\]

\[
R_{\text{in}} = \frac{r_\pi}{1 - \frac{g_m + g_\pi}{g_m + g_\pi + g_o + g_E}} = r_\pi \frac{g_m + g_\pi + g_o + g_E}{g_o + g_E} \approx r_\pi + \beta R_E
\]

\[
R_0 \approx \frac{1}{g_m + g_E + g_0 + g_\pi} = \frac{1}{g_m + g_E} = \frac{R_E}{1 + g_m R_E} \approx \frac{1}{g_m}
\]
Consider the following CC application

(this is not asking for a two-port model for the CC application, – \( R_{in} \) and \( A_V \) defined for no load on output, \( R_o \) defined for short-circuit input -)

Alternately, this circuit can also be analyzed directly

(analysis shown for \( A_V \) and \( R_{in} \) only)

\[
\begin{align*}
\mathbf{v}_{\text{out}} (g_E + g_0 + g_\pi) &= \mathbf{v}_{\text{in}} g_\pi + g_m \mathbf{v}_1 \\
\mathbf{v}_{\text{in}} &= \mathbf{v}_1 + \mathbf{v}_{\text{out}}
\end{align*}
\]

\[
\begin{align*}
i_{\text{in}} &= g_\pi (\mathbf{v}_{\text{in}} - \mathbf{v}_{\text{out}}) \\
\mathbf{v}_{\text{out}} (g_m + g_E + g_0 + g_\pi) &= \mathbf{v}_{\text{in}} (g_\pi + g_m)
\end{align*}
\]

\[
A_V = \frac{g_\pi + g_m}{g_m + g_E + g_0 + g_\pi} \approx \frac{g_m}{g_m + g_E} = \frac{I_{CQ} R_E}{I_{CQ} R_E + V_t}
\]

\[
i_{\text{in}} (g_m + g_\pi + g_E + g_0) = g_\pi \mathbf{v}_{\text{in}} (g_E + g_0)
\]

\[
R_{in} = r_\pi \frac{g_m + g_\pi + g_o + g_E}{g_o + g_E} \gg g_o \approx r_\pi + \beta R_E
\]
Common Collector Configuration

For this CC application
(this is not a two-port model for this CC application)

\[ A_V = \frac{g_\pi + g_m}{g_m + g_E + g_0 + g_\pi} \]

\[ R_{in} \approx r_\pi + \beta R_E \]

\[ R_0 \approx \frac{R_E}{1 + g_m R_E} \approx \frac{1}{g_m} \]

\[ A_V \approx \frac{I_{CQ} R_E}{I_{CQ} R_E + V_t} \]

\[ R_{in} \approx \beta R_E \]

\[ R_0 \approx \frac{g_m R_E}{1} \approx \frac{V_t}{I_{CQ}} \]

- Output impedance is low
- \( A_{V0} \) is positive and near 1
- Input impedance is very large
- Widely used as a buffer
- Not completely unilateral but output-input transconductance is small
Two-port model for Common Base Configuration

Common Base

\[ V_{be} \]

\[ g_{m} V_{be} \]

\[ g_{O} \]

\[ R_{o}X \]

\[ i_{1} \]

\[ v_{1} \]

\[ \{R_{ix}, A_{v0}, A_{v0r} \text{ and } R_{ox}\} \]
Two-port model for Common Base Configuration

From KCL

\[
\begin{align*}
    i_1 &= v_1 g_\pi + (v_1 - v_2) g_0 + g_m v_1 \\
    i_2 &= (v_2 - v_1) g_0 - g_m v_1
\end{align*}
\]

These can be rewritten as

\[
\begin{align*}
    v_1 &= \left( \frac{1}{g_m + g_\pi + g_0} \right) i_1 + \left( \frac{g_0}{g_m + g_\pi + g_0} \right) v_2 \\
    v_2 &= \left( \frac{1}{g_0} \right) i_2 + \left( 1 + \frac{g_m}{g_0} \right) v_1
\end{align*}
\]

It thus follows that:

\[
\begin{align*}
    R_{iX} &= \frac{1}{g_m + g_\pi + g_0} \approx \frac{1}{g_m} \\
    A_{\text{VOR}} &= \frac{g_0}{g_m + g_\pi + g_0} \\
    A_{V0} &= 1 + \frac{g_m}{g_0} \approx \frac{g_m}{g_0} \\
    R_{oX} &= \frac{1}{g_0}
\end{align*}
\]
Two-port model for Common Base Configuration

\[ R_{iX} = \frac{1}{g_m + g_g + g_0} \approx \frac{1}{g_m} \]

\[ A_{V0} = 1 + \frac{g_m}{g_0} \approx \frac{g_m}{g_0} \]

\[ A_{VOR} = \frac{g_0}{g_m + g_g + g_0} \]

\[ R_{oX} = \frac{1}{g_0} \]
Consider the following CB application

(this is not asking for a two-port model for this CB application - $R_{in}$ and $A_v$ defined for no load on output, $R_o$ defined for short-circuit input)
Consider the following CB application

(this is not asking for a two-port model for this CB application – \( R_{in} \) and \( A_V \) defined for no load on output, \( R_o \) defined for short-circuit input )

Alternately, this circuit can also be analyzed directly

By KCL at the output node, obtain

\[
(\ \text{g}_C + \text{g}_0) \, V_0 = (\ \text{g}_m + \text{g}_0) \, V_{\text{in}}
\]

\[
A_V = \frac{\text{g}_m + \text{g}_0}{\text{g}_C + \text{g}_0} \approx \text{g}_m R_C
\]

By KCL at the emitter node, obtain

\[
\text{i}_1 = (\ \text{g}_m + \text{g}_\pi + \text{g}_0) \, V_{\text{in}} - \text{g}_0 \, V_{\text{out}}
\]

\[
R_{in} = \frac{\text{g}_0 + \text{g}_C}{\text{g}_C (\ \text{g}_m + \text{g}_\pi + \text{g}_0) + \text{g}_\pi \text{g}_0} \approx \frac{1}{\text{g}_m}
\]

\[
\text{R}_{out} = R_C / / r_0
\]

\[
\text{R}_{out} = \frac{R_C}{1 + \text{g}_0 R_C}
\]
Two-port model for Common Base Configuration

Output impedance is mid-range
\( A_{V0} \) is large and positive (equal in mag to that to CE)
Input impedance is very low
Not completely unilateral but output-input transconductance is small