# EE 330 Class Seating

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EE 330
Lecture 30

Basic amplifier architectures
Basic Amplifier Structures

- MOS and Bipolar Transistors Both have 3 primary terminals
- MOS transistor has a fourth terminal that is generally considered a parasitic terminal
Basic Amplifier Structures

Observation:

These circuits considered previously have a terminal (emitter or source) common to the input and output in the small-signal equivalent circuit.

For BJT, E is common, input on B, output on C

Termed “Common Emitter”

For MOSFET, S is common, input on G, output on D

Termed “Common Source”
Basic Amplifier Structures

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: termed Common Source or Common Emitter
- Gate or Base: termed Common Gate or Common Base
- Drain or Collector: termed Common Drain or Common Collector
## Basic Amplifier Structures

### Small Signal Transistor Models as 3-terminal Devices

<table>
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<th>MOS</th>
<th>BJT</th>
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<tr>
<td>Common Input</td>
<td>Output</td>
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<tr>
<td>S G D</td>
<td>E B C</td>
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<tr>
<td>G S D</td>
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<td>D G S</td>
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### Basic Amplifier Structures

- **Common Source or Common Emitter**
  - S G D
- **Common Gate or Common Base**
  - G S D
- **Common Drain or Common Collector**
  - D G S
Basic Amplifier Structures

Common Source or Common Emitter
Common Gate or Common Base
Common Drain or Common Collector

Objectives in Study of Basic Amplifier Structures

1. Obtain key properties of each basic amplifier
2. Develop method of designing amplifiers with specific characteristics using basic amplifier structures
Characterization of Basic Amplifier Structures

- 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.

- Since small signal model when expressed in terms of small-signal parameters of BJT and MOSFET differ only in the presence/absence of $g_{\pi}$ term, can analyze the BJT structures and then obtain characteristics of corresponding MOS structure by setting $g_{\pi}=0$.
The three basic amplifier types for both MOS and bipolar processes

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

Will focus on the performance of the bipolar structures and then obtain performance of the MOS structures by observation
The three basic amplifier types for both MOS and bipolar processes

- **Common Emitter**
  - \( V_{in} \)
  - \( V_{out} \)
  - \( R_L \)

- **Common Base**
  - \( V_{in} \)
  - \( V_{out} \)
  - \( R_L \)

- **Common Collector**
  - \( V_{in} \)
  - \( V_{out} \)
  - \( R_L \)

- Significantly different gain characteristics for the three basic amplifiers
- There are other significant differences too \((R_{IN}, R_{OUT}, \ldots)\) as well
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?

More general models are needed to accommodate biasing, understand performance capabilities, and include effects of loading of the basic structures.

Two-port models are useful for characterizing the basic amplifier structures.
Two-Port Models of Basic Amplifiers widely used for Analysis and Design of Amplifier Circuits

Methods of Obtaining Amplifier Two-Port Network

1. \( v_{\text{TEST}} : i_{\text{TEST}} \) Method (considered in last lecture)

2. Write \( v_1 : v_2 \) equations in standard form

\[
\begin{align*}
v_1 &= i_1 R_{\text{IN}} + A_{\text{VR}} v_2 \\
v_2 &= i_2 R_{\text{O}} + A_{\text{V0}} v_1
\end{align*}
\]

3. Thevenin-Norton Transformations

4. Ad Hoc Approaches

Any of these methods can be used to obtain the two-port model
$V_{\text{test}} \cdot i_{\text{test}}$ Method for Obtaining Two-Port Amplifier Parameters

**SUMMARY from PREVIOUS LECTURE**

If Unilateral $A_{V_R} = 0$

$$A_{V0} = \frac{v_{\text{out-test}}}{v_{\text{test}}}$$

$$R_{in} = \frac{v_{\text{test}}}{i_{\text{test}}}$$

$$R_0 = \frac{v_{\text{test}}}{i_{\text{test}}}$$

$$A_{V_R} = \frac{v_{\text{out-test}}}{v_{\text{test}}}$$
Will now develop two-port model for each of the three basic amplifiers and look at one widely used application of each.
Consider Common Emitter/Common Source Two-port Models

Will focus on Bipolar Circuit since MOS counterpart is a special case obtained by setting $g_{\pi}=0$
The CE and CS amplifiers are themselves two-ports.

Can include or exclude R and R₁ in two-port models (of course they are different circuits)

The CE and CS amplifiers are themselves two-ports!
Two-port model for Common Emitter Configuration

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

Thus it is characterized by the parameters \{R_{in}, A_{V0} and R_0\}
Two-port model for Common Emitter Configuration

\[ \{ R_i, A_{V0} \text{ and } R_0 \} \]
Two-Port Models of Basic Amplifiers widely used for Analysis and Design of Amplifier Circuits

Methods of Obtaining Amplifier Two-Port Network

1. \( \nu_{\text{TEST}} : i_{\text{TEST}} \) Method

2. Write \( \nu_1 : \nu_2 \) equations in standard form

\[
\nu_1 = i_1 R_{\text{IN}} + A_{\nu R} \nu_2
\]

\[
\nu_2 = i_2 R_O + A_{\nu 0} \nu_1
\]

3. Thevenin-Norton Transformations

4. Ad Hoc Approaches
Two-port model for Common Emitter Configuration

By Thevenin : Norton Transformations

\[ R_{in} = \frac{1}{g_\pi} \quad \quad A_{V0} = -\frac{g_m}{g_0} \quad \quad R_0 = \frac{1}{g_0} \]
Two-Port Models of Basic Amplifiers widely used for Analysis and Design of Amplifier Circuits

Methods of Obtaining Amplifier Two-Port Network

1. $v_{\text{TEST}} : i_{\text{TEST}}$ method

2. Write $v_1 : v_2$ equations in standard form

   \[ v_1 = i_1 R_{\text{IN}} + A_{VR} v_2 \]
   \[ v_2 = i_2 R_{\text{O}} + A_{V0} v_1 \]

3. Thevenin-Norton Transformations

4. Ad Hoc Approaches
Two-port model for Common Emitter Configuration

Alternately, by $v_{\text{TEST}} : i_{\text{TEST}}$ Method

To obtain $R_{\text{in}}$

$$R_{\text{in}} = \frac{v_{\text{test}}}{i_{\text{test}}}$$

$$R_{\text{in}} = \frac{1}{g_{\pi}}$$

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

Alternately, by $v_{\text{TEST}} : i_{\text{TEST}}$ Method

To obtain $A_{V0}$

\[
A_{V0} = \frac{v_{\text{out-test}}}{v_{\text{test}}}
\]

\[
v_{\text{out-test}} = v_{\text{test}} \left( -\frac{g_m}{g_0} \right)
\]

\[
A_{V0} = -\frac{g_m}{g_0}
\]

{\text{R}_{\text{in}}, A_{V0} \text{ and } R_0}
Two-port model for Common Emitter Configuration

Alternately, by $v_{\text{TEST}} : i_{\text{TEST}}$ Method

To obtain $g_0$

$$R_0 = \frac{v_{\text{test}}}{i_{\text{test}}}$$

$$v_{\text{test}} = i_{\text{test}}(g_0)$$

$$R_0 = \frac{1}{g_0}$$

$${R_{\text{in}}, A_{V0} \text{ and } R_0}$$
Two-port model for Common Emitter Configuration

In terms of small signal model parameters:

\[ R_{\text{in}} = \frac{1}{g_\pi} \quad A_{V0} = -\frac{g_m}{g_0} \quad R_0 = \frac{1}{g_0} \]

In terms of operating point and model parameters:

\[ R_i = \frac{\beta V_t}{I_{CQ}} \quad A_{V0} = -\frac{V_{AF}}{V_t} \quad R_0 = \frac{V_{AF}}{I_{CQ}} \]

- Input impedance is mid-range
- Voltage Gain is Large and Inverting
- Output impedance is large
- Widely used to build voltage amplifiers
Common Emitter Configuration

Consider the following CE application

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

\[ v_{out} \left( g_C + g_0 \right) = g_0 A_{V0} v_{in} \]

\[ A_{VC} = \frac{v_{out}}{v_{in}} = \frac{g_0 A_{V0}}{g_0 + g_C} \approx -g_m R_C \]

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

\[ R_{outC} = R_o // R_C = \frac{1}{g_0 + g_C} \approx R_C \]
Common Emitter Configuration

Consider the following CE application

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

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

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

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

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

Consider the following CE application

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

Small signal parameter domain

\[ A_v \overset{g_o \ll g_c}{\approx} -g_m R_C \]

\[ R_{out} = \frac{1}{g_0 + g_C} \overset{g_o \ll g_c}{\approx} R_C \]

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

Operating point and model parameter domain

\[ A_v \overset{g_o \ll g_c}{\approx} -\frac{I_{CQ}R_C}{V_t} \]

\[ R_{out} \overset{g_o \ll g_c}{\approx} R_C \]

\[ R_{in} = \frac{\beta V_t}{I_{CQ}} \]

- Input impedance is mid-range
- Voltage Gain is large and Inverting
- Output impedance is mid-range
- Widely used as a voltage amplifier
Common Source/ Common Emitter Configurations

- **Common Emitter**
- **Common Source**

\[
R_{\text{in}} = \frac{1}{g_\pi} \quad A_{V0} = -\frac{g_m}{g_0} \quad R_0 = \frac{1}{g_0} \quad R_{\text{in}} = \infty \quad A_{V0} = -\frac{g_m}{g_0} \quad R_0 = \frac{1}{g_0}
\]

In terms of operating point and model parameters:

\[
R_{\text{in}} = \frac{\beta V_t}{I_{CQ}} \quad A_{V0} = -\frac{V_{AF}}{V_t} \quad R_0 = \frac{V_{AF}}{I_{CQ}} \quad R_{\text{in}} = \infty \quad R_0 = \frac{1}{\lambda I_{DQ}} = \frac{V_{AF}}{I_{DQ}}
\]

\[
A_{V0} = -2 \frac{2}{\lambda V_{EBQ}} = -2 \frac{V_{AF}}{V_{EBQ}}
\]

- Input impedance is mid-range (infinite for MOS)
- Voltage Gain is Large and Inverting
- Output impedance is large
- Widely used to build voltage amplifiers
In terms of operating point and model parameters:

- Input impedance is mid-range (infinite for MOS)
- Voltage Gain is Large and Inverting
- Output impedance is mid-range
- Widely used as a voltage amplifier
Consider Common Collector/Common Drain Two-port Models

Common Emitter

Common Base

Common Collector

Common Source

Common Gate

Common Drain

Will focus on Bipolar Circuit since MOS counterpart is a special case obtained by setting $g_{m}=0$
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

\[ \begin{align*}
\text{Common Collector} & \\
\text{Common Collector} & \\
\text{Common Collector} & \\
\end{align*} \]
Two-Port Models of Basic Amplifiers widely used for Analysis and Design of Amplifier Circuits

Methods of Obtaining Amplifier Two-Port Network

1. \( V_{\text{TEST}} : i_{\text{TEST}} \) Method

2. Write \( V_1 : V_2 \) equations in standard form
   \[
   V_1 = i_1 R_{\text{IN}} + A_{\text{VR}} V_2 \\
   V_2 = i_2 R_{O} + A_{\text{V0}} V_1
   \]

3. Thevenin-Norton Transformations

4. Ad Hoc Approaches
Two-port model for Common Collector Configuration

Applying KCL at the input and output node, obtain

\[ i_1 = \left( v_1 - v_2 \right) g_\pi \]
\[ i_2 = \left( g_m + g_\pi + g_o \right) v_2 - \left( g_m + g_\pi \right) v_1 \]

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

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

Two-port Common Collector Model

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

\[ A_{V0r} = 1 \]

\[ R_{0X} = \left( \frac{1}{g_m + g_\pi + g_o} \right) \approx \frac{1}{g_m} \]

\[ A_{V0} = \left( \frac{g_m + g_\pi}{g_m + g_\pi + g_o} \right) \approx 1 \]
Consider the following CC application

Determine $R_{in}$, $R_0$, and $A_V$

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

$A_V = A_{V0} \frac{g_{ox}}{g_{ox} + g_E} = \frac{g_m + g_{\pi}}{g_m + g_{\pi} + g_o} \frac{g_m + g_{\pi} + g_o + g_E}{g_m + g_{\pi} + g_o + g_E} = \frac{g_m + g_{\pi}}{g_m + g_{\pi} + g_o + g_E} \approx \frac{g_m}{g_m + g_E} \approx 1$

$v_{in} = i_1 R_{ix} + A_{V0} A_{V0} \frac{g_{ox}}{g_{ox} + g_E} v_{in}$

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

$R_0 \approx \frac{1}{g_m + g_E + g_0 + g_{\pi}} = \frac{1}{g_m + g_E} = \frac{R_E}{1 + g_m R_E}$

$g_m \gg g_E$
Consider the following CC application:

\[ V_{out} (g_E + g_0 + g_\pi) = V_{in} g_\pi + g_m V_1 \]
\[ V_{in} = V_1 + V_{out} \]

\[ i_{in} = g_\pi (V_{in} - V_{out}) \]
\[ V_{out} (g_m + g_E + g_0 + g_\pi) = V_{in} (g_\pi + g_m) \]

Alternately, this circuit can also be analyzed directly:

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

\[ R_{in} = r_\pi \frac{g_m + g_\pi + g_0 + g_E}{g_0 + g_E} \approx r_\pi + \beta R_E \]
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 additional load on output, $R_o$ defined for short-circuit input -)

To obtain $R_0$, set $v_{in} = 0$

$$i_{out} = v_{out} (g_E + g_0 + g_\pi) - g_m (-v_{out})$$

$$R_{out} = \frac{1}{g_m + g_\pi + g_o + g_E} \approx \frac{1}{g_m}$$
Consider the following CC application

\[ A_V = \frac{g_m + g_{\pi}}{g_m + g_E + g_0 + g_{\pi}} \approx \frac{g_m}{g_m + g_E} = \frac{I_{CQ}R_E}{I_{CQ}R_E + V_t} \approx 1 \]

\[ R_{in} = r_{\pi} \frac{g_m + g_{\pi} + g_0 + g_E}{g_0 + g_E} \approx r_{\pi} + \beta R_E \]

\[ R_{out} = \frac{1}{g_m + g_{\pi} + g_0 + g_E} \approx \frac{1}{g_m} \]

**Question:** Why are these not the two-port parameters of this circuit?

- \( R_{in} \) defined for open-circuit on output instead of short-circuit (see previous slide: -2 slides)
- \( A_{V0r} \neq 0 \)
Common Collector Configuration

For this CC application

\[
A_V = \frac{g_{\pi} + g_m}{g_m + g_E + g_0 + g_{\pi}} \approx 1
\]

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

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

Output impedance is low

\[A_{V0} \text{ is positive and near 1}\]

Input impedance is very large

Widely used as a buffer

Not completely unilateral but output-input transconductance (or \(A_{Vr}\)) is small and effects are generally negligible though magnitude same as \(A_V\)
Common Collector/Common Drain Configurations

For these CC/CD applications

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

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

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

In terms of operating point and model parameters:

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

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

\[ R_0 \approx \frac{l_{CQ} R_s}{l_{CQ} R_s + V_t} \]

- 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

\[ A_V = \frac{g_m}{g_m + g_S + g_0} \approx 1 \]

\[ R_{in} = \infty \]

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

\[ A_V \approx \frac{2l_{DQ} R_S}{2l_{DQ} R_S + V_{EBQ}} \]

\[ R_0 \approx \frac{V_{EBQ} R_S}{V_{EBQ} + 2l_{DQ} R_S} \approx \frac{V_{EBQ}}{2l_{DQ}} \]

\[ R_{in} = \infty \]
End of Lecture 30