Basic amplifier architectures

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

Basic Amplifiers

- Analysis, Operation, and Design
Exam 3  Friday April 13
Review Previous Lecture

Two-Port Equivalents of Interconnected Two-ports

Apply $V_1$, open $V_2$ to get $A_V$ but short $V_2$ to get $R_{IN}$

Apply $V_2$, open $V_1$ to get $A_{VR}$ but short $V_1$ to get $R_{OUT}$
Circuit analysis steps

- **Large signal Q-point analysis**
  - Open cap, short inductors
  - Assume operation regions for active devices
  - Replace each nonlinear device by its simplified piecewise linear model
  - Compute Q-point: node voltages and device currents
  - Verify assumed region

- **Small signal DC analysis**
  - Short DC V-source, open DC I-source
  - Short coupling caps
  - Replace each nonlinear device by its ss model
  - Perform standard linear analysis as in 201
Review Previous Lecture

**Basic Amplifier Structures**

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

**MOS**

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**BJT**

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**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
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
Two-Port Models of Basic Amplifiers widely used for Analysis and Design of Amplifier Circuits

Methods of Obtaining Amplifier Two-Port Network

1. \( \text{\textbf{V}}_{\text{TEST}} : \text{\textbf{i}}_{\text{TEST}} \) Method (considered in last lecture)

2. Write \( \textbf{v}_1 : \textbf{v}_2 \) equations in standard form

   \[
   \textbf{v}_1 = \textbf{i}_1 R_{\text{IN}} + A_{VR} \textbf{v}_2 \\
   \textbf{v}_2 = \textbf{i}_2 R_{O} + A_{V0} \textbf{v}_1
   \]

3. Thevenin-Norton Transformations

4. Ad Hoc Approaches

Any of these methods can be used to obtain the two-port model
Method for Obtaining Two-Port Amplifier Parameters

**SUMMARY from PREVIOUS LECTURE**

If Unilateral $A_{VR} = 0$

- $A_{V0} = \frac{V_{\text{out-test}}}{V_{\text{test}}}$
- $R_{in} = \frac{V_{\text{test}}}{i_{\text{test}}}$
- $R_{0} = \frac{V_{\text{test}}}{i_{\text{test}}}$
- $A_{VR} = \frac{V_{\text{out-test}}}{V_{\text{test}}}$
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 $g_\pi=0$
Basic CE/CS Amplifier Structures

Common Emitter Amplifier

Common Source Amplifier

Can include or exclude $R$ and $R_1$ 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

\[ \begin{align*}
V_{be} & \quad g_m V_{be} & \quad g_O \\
\end{align*} \]

\[ \begin{align*}
R_i, A_{V_0} \text{ and } R_O \\
\end{align*} \]
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
   \[
   v_1 = i_1 R_{\text{IN}} + A_{\text{VR}} v_2 \\
   v_2 = i_2 R_{\text{O}} + A_{\text{V0}} v_1
   \]

3. Thevenin-Norton Transformations

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

By Thevenin : Norton Transformations

\[ R_{in} = \frac{1}{g_\pi} \quad A_{V0} = -\frac{g_m}{g_0} \quad R_0 = \frac{1}{g_0} \quad A_{VR} = 0 \]
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

   $v_1 = i_1 R_{\text{IN}} + A_{vR} v_2$

   $v_2 = i_2 R_O + A_{v_0} v_1$

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 $R_{\text{in}}$

\[ R_{\text{in}} = \frac{V_{\text{test}}}{i_{\text{test}}} \]

\[ R_{\text{in}} = \frac{1}{g_{\pi}} \]

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

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

To obtain $A_{V0}$

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

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

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

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

Alternate, 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:

\[ R_{in} = \frac{1}{g_{\pi}} \quad A_{V0} = -\frac{g_m}{g_0} \quad R_0 = \frac{1}{g_0} \quad A_{VR} = 0 \]

In terms of operating point and model parameters:

\[ R_i = \frac{\beta V_t}{I_{CQ}} \quad A_{V0} = -\frac{V_{AF}}{V_t} \quad R_0 = \frac{V_{AF}}{I_{CQ}} \quad A_{VR} = 0 \]

Characteristics:
- Input impedance is mid-range
- Voltage Gain is Large and Inverting
- Output impedance is large
- Unilateral
- 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)

\[
\begin{align*}
\mathbf{v}_{\text{out}} \left( g_C + g_0 \right) &= g_0 A_{V_0} \mathbf{v}_{\text{in}} \\
A_{\text{VR}} &= 0 \\
A_{\text{VC}} &= \frac{\mathbf{v}_{\text{out}}}{\mathbf{v}_{\text{in}}} = \frac{g_0 A_{V_0}}{g_0 + g_C} = \frac{-g_m}{g_0 + g_C} \approx -g_m R_C \\
R_{\text{inC}} &= R_{\text{in}} = r_{\pi} \\
R_{\text{outC}} &= R_o / R_C \\
R_{\text{outC}} &= R_o / R_C = \frac{1}{g_0 + g_C} \approx R_C
\end{align*}
\]
Consider the following CE application

\( V_{be} \)

\( O \)

\( g \)

\( V_{be} \)

\( \pi \)

\( R \)

\( C \)

\( V_{in} \)

\( B \)

\( E \)

\( V_{out} \)

\( A_{VR} = 0 \)

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

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

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

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

Consider the following CE application

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

Small signal parameter domain

\[
A_v \approx -g_m R_C \\
R_{out} = \frac{1}{g_0 + g_C} \approx R_C \\
R_{in} = r_\pi
\]

Operating point and model parameter domain

\[
A_v \approx -\frac{I_{CQ} R_C}{V_t} \\
R_{out} \approx R_C \\
R_{in} = \frac{\beta V_t}{I_{CQ}} \\
A_{VR} = 0
\]

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

In terms of operating point and model parameters:

- \( R_{in} = \frac{1}{g_{\pi}} \)
- \( A_{V0} = -\frac{g_m}{g_0} \)
- \( R_0 = \frac{1}{g_0} \)
- \( R_{in} = \infty \)
- \( A_{V0} = -\frac{g_m}{g_0} \)
- \( R_0 = \frac{1}{g_0} \)

Characteristics:

- Input impedance is mid-range (infinite for MOS)
- Voltage Gain is Large and Inverting
- Output impedance is large
- Unilateral
- Widely used to build voltage amplifiers
Common Source/Common Emitter Configuration

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
- Unilateral
- 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 $g_{\pi}=0$.
Two-port model for Common Collector Configuration

\[ \{R_{iX}, A_V, A_{V0r} \text{ and } R_{0X}\} \]
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

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

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

3. Thevenin-Norton Transformations

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

Applying KCL at the input and output node, obtain

\[ i_1 = (\mathbf{v}_1 - \mathbf{v}_2) g_\pi \]
\[ i_2 = (g_m + g_\pi + g_o) \mathbf{v}_2 - (g_m + g_\pi) \mathbf{v}_1 \]

These can be rewritten as

\[ \mathbf{v}_1 = i_1 r_\pi + \mathbf{v}_2 \]
\[ \mathbf{v}_2 = \left( \frac{1}{g_m + g_\pi + g_o} \right) i_2 + \left( \frac{g_m + g_\pi}{g_m + g_\pi + g_o} \right) \mathbf{v}_1 \]

It thus follows that

\[ R_{ix} = r_\pi \quad A_{VO} = 1 \]
\[ R_{0x} = \left( \frac{1}{g_m + g_\pi + g_o} \right) \quad A_{v0} = \left( \frac{g_m + g_\pi}{g_m + g_\pi + g_o} \right) \]
Two-port model for Common Collector Configuration

Two-port Common Collector Model

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

\[ A_{V0r} = 1 \]

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

\[ A_{V0} = \left( \frac{g_m + g_{\pi}}{g_m + g_{\pi} + g_o} \right) \approx 1 \]
Common Collector Configuration

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)

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

$$v_{in} = i_1 R_{ix} + A_{V0} A_{V0} \frac{g_{ox}}{g_{ox} + g_E} v_{in} \Rightarrow R_{in} = \frac{r_\pi}{1 - \frac{g_{ox} + g_E}{g_{ox} + g_E}} = r_\pi \frac{g_m + g_\pi + g_o + g_E}{g_o + g_E} \approx r_\pi + \beta R_E$$

$$R_0 \approx \frac{1}{g_{ox} + g_o + g_\pi} = \frac{1}{g_{ox} + g_E} = \frac{R_E}{1 + g_m R_E} \approx \frac{1}{g_m}$$
Common Collector Configuration

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)

Alternately, this circuit can also be analyzed directly

\[
\begin{align*}
V_{out} (g_E + g_0 + g_\pi) &= V_{in} g_\pi + g_m V_1 \\
V_{in} &= V_1 + V_{out} \\
\end{align*}
\]

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

\[
\begin{align*}
i_{in} &= g_\pi \left( V_{in} - V_{out} \right) \\
V_{out} \left( g_m + g_E + g_0 + g_\pi \right) &= V_{in} \left( g_\pi + g_m \right) \\
i_{in} \left( g_m + g_E + g_0 + g_\pi \right) &= g_\pi V_{in} \left( g_E + g_0 \right) \\
R_{in} &= r_\pi \frac{g_m + g_\pi + g_o + g_E}{g_o + g_E} \quad \approx \quad r_\pi + \beta R_E
\end{align*}
\]
Consider the following CC application

\[ i_{in} = 0 \]

To obtain \( R_0 \), set \( v_{in} = 0 \)

\[ i_{out} = \frac{v_{out}}{g_E + g_0 + g_m} - g_m v_{out} \]

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

Common Collector Configuration

(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 -)
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 -)

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

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

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

**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

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

Small signal parameter domain

\[
A_V = \frac{g_\pi + g_m}{g_m + g_E + g_0 + g_\pi} \quad \text{if } g_\pi \gg g_x
\]

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

\[
R_0 \approx \frac{R_E}{1 + g_m R_E} \quad g_x R_\pi \gg 1 \quad \approx \frac{1}{g_m}
\]

Operating point and model parameter domain

\[
A_V \approx \frac{I_{CQ} R_E}{I_{CQ} R_E + V_t} \quad \approx \frac{I_{CQ} R_E}{I_{CQ} R_E \gg V_t} \quad \approx 1
\]

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

\[
R_0 \approx \frac{V_t}{I_{CQ}}
\]

Characteristics:

- 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 (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

\[ V_{CC} \rightarrow v_{in} \rightarrow v_{out} \]

\[ R_E \]

\[ V_{EE} \]

\[ v_{in} \rightarrow v_{in} \rightarrow v_{out} \]

\[ B \rightarrow E \rightarrow C \]

Common Collector

\[ V_{DD} \rightarrow v_{in} \rightarrow v_{out} \]

\[ R_D \]

\[ V_{SS} \]

Common Drain

\[ \begin{align*}
    A_V &= \frac{g_{\pi} + g_m}{g_m + g_E + g_0 + g_{\pi}} \quad \text{if } g_s \gg g_e \\
    &\approx 1 \\
    R_{in} &= r_{\pi} + \beta R_E \\
    R_0 &= \frac{R_E}{1 + g_m R_E} \approx \frac{1}{g_m}
\end{align*} \]

In terms of operating point and model parameters:

\[ \begin{align*}
    A_V \approx \frac{I_C Q R_E}{I_{CQ} R_E + V_t} \quad \text{if } I_{CQ} R_E \gg V_t \\
    R_0 \approx \frac{V_t}{I_{CQ}} \\
    R_{in} \approx \beta R_E
\end{align*} \]

- 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
Consider Common Base/Common Gate Two-port Models

Will focus on Bipolar Circuit since MOS counterpart is a special case obtained by setting $g_{\pi}=0$. 
Two-port model for Common Base Configuration

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

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

\[ \{ R_{ix}, A_{V0}, A_{V0r} and R_{ox} \} \]
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
   \[
   v_1 = i_1 R_{\text{IN}} + A_{V_R} v_2 \\
   v_2 = i_2 R_{O} + A_{V_0} v_1
   \]

3. Thevenin-Norton Transformations

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

From KCL

\[
i_1 = v_{1g} + \left(v_1 - v_2\right) g_0 + g_m v_1
\]

\[
i_2 = \left(v_2 - v_1\right) g_0 - g_m v_1
\]

These can be rewritten as

\[
v_1 = \left(\frac{1}{g_m + g_\pi + g_0}\right) i_1 + \left(\frac{g_0}{g_m + g_\pi + g_0}\right) v_2
\]

\[
v_2 = \left(\frac{1}{g_0}\right) i_2 + \left(1 + \frac{g_m}{g_0}\right) v_1
\]

It thus follows that:

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

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

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

\[
R_{Ox} = \frac{1}{g_0}
\]

Standard Form for Amplifier Two-Port

\[
v_1 = i_1 R_{IN} + A_{VR} v_2
\]

\[
v_2 = i_2 R_O + A_{V0} v_1
\]

\[
v_1 : v_2 \text{ equations in standard form}\]
Two-port model for Common Base Configuration

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

\[ A_{V0r} = \frac{g_0}{g_m + g_\pi + g_0} \approx \frac{g_0}{g_m} \]

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

\[ R_{oX} = \frac{1}{g_0} \]
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)

$$A_v = A_{v0} \frac{R_C}{R_C + R_{0X}} = \left( \frac{g_m + g_0}{g_0} \right) \left( \frac{g_0}{g_c + g_0} \right) = \frac{g_m + g_0}{g_c + g_0} \approx g_m R_C$$

$$R_{in} = \frac{v_{in}}{i_1} = i_1 R_{iX} + A_{v0} v_{out}$$

$$R_{out} = R_C // R_{0X}$$

$$R_{in} = \frac{R_{iX}}{1 - A_{v0} A_v} = \frac{g_0 + g_c}{g_c \left( g_m + g_\pi + g_0 \right) + g_\pi g_0} \approx \frac{1}{g_m}$$

$$R_{out} = \frac{R_C}{1 + g_0 R_C}$$
Consider the following CB application

(Alternately, this circuit can also be analyzed directly)

By KCL at the output node, obtain

\[
(A_V) = \frac{g_m + g_0}{g_C + g_0} \approx g_m R_C
\]

By KCL at the emitter node, obtain

\[
R_{in} = \frac{g_0 + g_C}{g_C (g_m + g_\pi + g_0) + g_\pi g_0} \approx \frac{1}{g_m}
\]

\[
R_{out} = R_C / r_0 \approx R_C
\]
Common Base Application

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

\[ A_V \approx g_m R_C \]
\[ R_{in} \approx \frac{1}{g_m} \]
\[ R_{c} << r_0 \]
\[ R_{out} \approx R_C \]

\[ A_V \approx \frac{I_{CQ} R_C}{V_t} \]
\[ R_{in} \approx \frac{V_t}{I_{CQ}} \]
\[ R_{c} << r_0 \]
\[ R_{out} \approx R_C \]

Characteristics:

- 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
Common Base/Common Gate Application

(These are not a two-port models)

\[ A_V \approx g_m R_C \quad R_{in} \approx \frac{1}{g_m} \quad R_{out} \approx R_C \]

In terms of operating point and model parameters:

\[ A_V \approx \frac{I_{CQ} R_C}{V_t} \quad R_{in} \approx \frac{V_t}{I_{CQ}} \quad R_{out} \approx \frac{I_{oR} < V_A}{R_C} \]

\[ A_V \approx \frac{2I_{DQ} R_D}{V_{EBQ}} \quad R_{in} \approx \frac{V_{EBQ}}{2I_{DQ}} \quad R_{out} \approx \frac{I_{oR} < 1}{R_D} \]

Characteristics:

- 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
Common Emitter with Emitter Resistor Configuration

By KCL at two non-grounded nodes

\[
\begin{align*}
\nu_{out} (g_C + g_0) + (\nu_{in} - \nu_E) g_m &= g_0 \nu_E \\
\nu_E (g_E + g_0 + g_\pi) - (\nu_{in} - \nu_E) g_m &= g_0 \nu_{out} + g_\pi \nu_{in}
\end{align*}
\]

\[
A_V = \frac{\nu_{out}}{\nu_{in}} = \frac{-g_m g_E + g_0 g_\pi}{g_C g_m + g_C (g_0 + g_\pi + g_E) + g_0 (g_\pi + g_E)} \approx -\frac{R_C}{R_E}
\]
Common Emitter with Emitter Resistor Configuration

\[ A_V \approx -\frac{R_C}{R_E} \]

It can also be shown that

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

Nearly unilateral (is unilateral if \( g_o = 0 \))
Common Emitter with Emitter Resistor Configuration

\[ A_V \approx -\frac{R_C}{R_E} \]

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

\[ R_{\text{out}} \approx R_C \]

(this is not a two-port model)

Characteristics:

- Analysis would simplify if \( g_0 \) were set to 0 in model
- Gain can be accurately controlled with resistor ratios
- Useful for reasonably accurate low gains
- Input impedance is high
### Basic Amplifier Gain Table

<table>
<thead>
<tr>
<th></th>
<th>CE/CS</th>
<th>CC/CD</th>
<th>CB/CG</th>
<th>CEwRE/CSwRS</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>AV</strong></td>
<td>- $g_m R_C$</td>
<td>$\frac{g_m}{g_m + g_E}$</td>
<td>$g_m R_C$</td>
<td>$-\frac{R_C}{R_E}$</td>
</tr>
<tr>
<td><strong>R_{in}</strong></td>
<td>$\frac{\beta V_t}{I_CQ}$</td>
<td>$\frac{V_t}{I_CQ} + R_E$</td>
<td>$\frac{V_t}{I_CQ}$</td>
<td>$\beta \left( \frac{V_t}{I_CQ} + R_E \right)$</td>
</tr>
<tr>
<td><strong>R_{out}</strong></td>
<td>$R_C$</td>
<td>$g_m$</td>
<td>$R_C$</td>
<td>$R_C$</td>
</tr>
</tbody>
</table>

(not two-port models for the four basic structures)
### Basic Amplifier Gain Table

<table>
<thead>
<tr>
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</tr>
</thead>
<tbody>
<tr>
<td>BJT</td>
<td>MOS</td>
<td>BJT</td>
<td>MOS</td>
<td>BJT</td>
</tr>
</tbody>
</table>

#### AV
- **BJT**: \(- \frac{g_m R_c}{V_t}\)
- **MOS**: \(- \frac{2I_{DQ}R_D}{V_{EB}}\)
- **BJT**: \(\frac{g_m}{g_m + g_E}\)
- **MOS**: \(\frac{2I_{DQ}R_E}{2I_{DQ}R_E + V_{EB}}\)
- **BJT**: \(\frac{I_{CQ}R_c}{V_t}\)
- **MOS**: \(\frac{2I_{DQ}R_c}{V_{EB}}\)
- **BJT**: \(R_\text{C}\)
- **MOS**: \(R_\text{C}\)

#### R_in
- **BJT**: \(\frac{\beta V_t}{I_{CQ}}\)
- **MOS**: \(\infty\)
- **BJT**: \(r_t + \beta R_E\)
- **MOS**: \(\beta \left( \frac{V_t}{I_{CQ}} + R_E \right) \infty\)

#### R_out
- **BJT**: \(\frac{V_t}{I_{CQ}}\)
- **MOS**: \(\frac{V_{EB}}{2I_{DQ}}\)
- **BJT**: \(R_\text{C}\)
- **MOS**: \(R_\text{C}\)

---

Can use these equations only when small signal circuit is EXACTLY like that shown!!
Basic Amplifier Structures

1. Common Emitter/Common Source
2. Common Collector/Common Drain
3. Common Base/Common Gate
4. Common Emitter with $R_E$ / Common Source with $R_S$

5. Cascode (actually CE:CB or CS:CG cascade)
6. Darlington (special CC:CE or CD:CS cascade)

The first 4 are most popular

Will be discussed later
Why are we focusing on these basic circuits?

1. So that we can develop analytical skills
2. So that we can design a circuit
3. So that we can get the insight needed to design a circuit

Which is the most important?
End of Lecture 33