Basic amplifier architectures

- Common Emitter/Source
- Common Collector/Drain
- Common Base/Gate
Two-port representation of amplifiers

Amplifiers can be modeled as a two-port

- Amplifier often **unilateral** (signal propagates in only one direction: wlog $y_{12}=0$)
- One terminal is often common

Review from Earlier Lecture
Two-port representation of amplifiers

- Thevenin equivalent output port often more standard
- $R_{IN}$, $A_v$, and $R_{OUT}$ often used to characterize the two-port of amplifiers

\[
\begin{align*}
v_1 & \quad y_{11} & \quad v_2 \\
\quad y_{21}v_1 & \quad y_{22} & \\
\end{align*}
\]

\[
\begin{align*}
v_1 & \quad R_{IN} & \quad A_vv_1 \\
\quad R_{OUT} & \quad v_2 & \\
\end{align*}
\]
Amplifier input impedance, output impedance and gain are usually of interest.

Why?

Example 1: Assume amplifier is unilateral

\[ V_{IN} \]
\[ R_S \]
\[ V_{OUT} \]

L |
IN

L |
OUT
S

\[ V_{IN} (\pm) \]
\[ R_S \]
\[ + \]
\[ V_{OUT} \]

L |
IN

L |
OUT
S

\[ V_{IN} (\pm) \]
\[ + \]
\[ V_1 \]
\[ - \]
\[ A_v V_1 \]
\[ + \]
\[ V_2 \]
\[ - \]
\[ R_{IN} \]
\[ R_{OUT} \]
\[ R_L \]

\[ V_{OUT} = \left( \frac{R_L}{R_L + R_{OUT}} \right) A_v \left( \frac{R_{IN}}{R_S + R_{IN}} \right) V_{IN} \]

\[ A_{VAMP} = \frac{V_{OUT}}{V_{IN}} = \left( \frac{R_L}{R_L + R_{OUT}} \right) \left( \frac{R_{IN}}{R_S + R_{IN}} \right) A_v \]

Can get gain without reconsidering details about components internal to the Amplifier !!!

Analysis more involved when not unilateral
Amplifier input impedance, output impedance and gain are usually of interest

Why?

Example 2: Assume amplifiers are unilateral

Can get gain without reconsidering details about components internal to the Amplifier !!!

Analysis more involved when not unilateral
Two-port representation of amplifiers

- Amplifier usually **unilateral** (signal propagates in only one direction: wlog $y_{12}=0$)
- One terminal is often common
- "Amplifier" parameters often used

**y parameters**

- Amplifier parameters can also be used if not **unilateral**
- One terminal is often common

**Amplifier parameters**
Two Port Equivalents of Interconnected Two-ports

Example:

Review from Earlier Lecture
Determination of Amplifier Two-Port Parameters

• Input and output parameters are obtained in exactly the same way, only distinction is in the notation used for the ports.

• Methods given for obtaining amplifier parameters $R_{in}$, $R_{OUT}$ and $A_V$ for unilateral networks are a special case of the non-unilateral analysis by observing that $A_{VR}=0$.

• In some cases, other methods for obtaining the amplifier parameters are easier than what was just discussed.
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

Transistors as 3-terminal Devices

Small Signal Transistor Models as 3-terminal Devices
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

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

Identification of Input and Output Terminals is not arbitrary

It will be shown that all 3 of the basic amplifiers are useful!
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

Overall Amplifier Structure
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**
  - $v_{in}$
  - $v_{be}$
  - $v_{OUT}$
  - $v_{OUT} = -g_m R_L v_{be}$
  - $v_{IN} = v_{be}$
  - $A_v = \frac{v_{OUT}}{v_{IN}} = -g_m R_L$

- **Common Base**
  - $v_{in}$
  - $v_{be}$
  - $v_{OUT}$
  - $v_{OUT} = -g_m R_L v_{be}$
  - $v_{IN} = -v_{be}$
  - $A_v = \frac{v_{OUT}}{v_{IN}} = g_m R_L$

- **Common Collector**
  - $v_{in}$
  - $v_{be}$
  - $v_{OUT}$
  - $v_{OUT} = (g_m + g_\pi) v_{be} R_L$
  - $v_{IN} = v_{be} + (g_m + g_\pi) v_{be} R_L$
  - $A_v = \frac{v_{OUT}}{v_{IN}} = \frac{(g_m + g_\pi) R_L}{1 + (g_m + g_\pi) R_L} \approx 1$

- Significantly different gain characteristics for the three basic amplifiers
- There are other significant differences too ($R_{IN}$, $R_{OUT}$, ...) 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

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.

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

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

3. Thevenin-Norton Transformations

4. Ad Hoc Approaches

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

SUMMARY from PREVIOUS LECTURE

If Unilateral: \( A_{\text{VR}} = 0 \)

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

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

\[ R_{0} = \frac{V_{\text{test}}}{i_{\text{test}}} \]

\[ A_{\text{VR}} = \frac{V_{\text{out-test}}}{V_{\text{test}}} \]
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 $g_{\pi}=0$
The CE and CS amplifiers are themselves two-ports! Can include or exclude $R$ and $R_1$ in two-port models (of course they are different circuits).
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 \( \{ R_{\text{in}}, A_{V0} \text{ and } R_0 \} \)
Two-port model for Common Emitter Configuration

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

\[ \begin{align*}
V_1 & \quad R_{in} \quad A_{v_0} V_1 \\
& \quad R_0 \\
V_2 & \quad R_i, A_{v_0} \text{ and } R_0 \\
\end{align*} \]
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

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

\[ A_{V0} = -\frac{g_{m}}{g_{0}} \]

\[ R_{0} = \frac{1}{g_{0}} \]
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

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

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

3. Thevenin-Norton Transformations

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

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 $A_{V0}$

\[
\begin{align*}
A_{V0} &= \frac{v_{\text{out-test}}}{v_{\text{test}}} \\
V_{\text{out-test}} &= v_{\text{test}} \left( -\frac{g_m}{g_0} \right) \\
A_{V0} &= -\frac{g_m}{g_0}
\end{align*}
\]

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

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

To obtain $g_0$

\[
\begin{align*}
R_0 &= \frac{v_{\text{test}}}{i_{\text{test}}} \\
v_{\text{test}} &= i_{\text{test}}(g_0) \\
R_0 &= \frac{1}{g_0}
\end{align*}
\]

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

In terms of small signal model parameters:

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

In terms of operating point and model parameters:

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

Characteristics:

- 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

\( \nu_{out} \left( g_C + g_0 \right) = g_0 A_{V0} \nu_{in} \)

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

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

\[ R_{outC} = R_o // R_C = \frac{1}{g_0 + g_C} \approx R_C \]
Consider the following CE application

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

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

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

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

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

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

\[ A_v \approx -\frac{I_{CQ} R_C}{V_t} \]

\[ R_{out} \approx R_C \]

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

Characteristics:

- 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**
  - $R_{in} = \frac{1}{g_\pi}$
  - $A_{V0} = -\frac{g_m}{g_0}$
  - $R_0 = \frac{1}{g_0}$

- **Common Source**
  - $R_{in} = \infty$
  - $A_{V0} = -\frac{g_m}{g_0}$
  - $R_0 = \frac{1}{g_0}$

In terms of operating point and model parameters:

- $R_{in} = \frac{\beta V_t}{I_{CQ}}$
- $A_{V0} = -\frac{V_{AF}}{V_t}$
- $R_0 = \frac{V_{AF}}{I_{CQ}}$

Characteristics:

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

In terms of operating point and model parameters:

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

\[ A_v \approx -g_m R_C \]

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

\[ A_v \approx -\frac{l_{CQ} R_C}{V_t} \]

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

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

Characteristics:
- 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

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

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

\[ \{ R_{iX}, A_v, A_{v0}, A_{v0r} and R_{0X} \} \]
Two-Port Models of Basic Amplifiers widely used for Analysis and Design of Amplifier Circuits

Methods of Obtaining Amplifier Two-Port Network

1. $\nu_{\text{TEST}} : i_{\text{TEST}}$ Method

2. Write $\nu_1 : \nu_2$ equations in standard form

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

   $\nu_2 = i_2 R_{\text{O}} + A_{\nu O} \nu_1$

3. Thevenin-Norton Transformations

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

Applying KCL at the input and output node, obtain

\[ i_1 = (V_1 - V_2) g_\pi \]
\[ i_2 = (g_m + g_\pi + g_o) V_2 - (g_m + g_\pi) V_1 \]

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

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

Two-port Common Collector Model

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

\[ A_{V0r} = 1 \]

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

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

$$A_V = A_{V_0}\frac{g_{ox}}{g_{ox} + g_E} = \frac{g_m + g_{\pi}}{g_{ox} + g_E}\left(\frac{g_m + g_{\pi} + g_o}{g_m + g_{\pi} + g_o + g_E}\right) = \frac{g_m + g_{\pi}}{g_m + g_{\pi} + g_o + g_E} \approx \frac{g_m}{g_{m} + g_E}$$

if $g_o \gg g_E$

$$v_{in} = i_1 R_{ix} + A_{V_0} A_{V_0} \frac{g_{ox}}{g_{ox} + g_E} v_{in} \quad \Rightarrow \quad R_{in} = r_{\pi} \frac{g_m + g_{\pi} + g_o + g_E}{g_o + g_E} \approx r_{\pi} + \beta R_E$$

$$R_0 \approx \frac{1}{g_m + g_E + g_o + g_{\pi}} = \frac{1}{g_m + g_E} = \frac{R_E}{1 + g_m R_E} \approx \frac{1}{g_m}$$
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 additional load on output, \( R_o \) defined for short-circuit input)

Alternately, this circuit can also be analyzed directly:

\[
\begin{align*}
\text{Common Collector} & \quad \begin{array}{c}
V_{in} \\
R_E \\
V_{OUT}
\end{array} \\
\frac{V_{out}}{V_{in}} & = \frac{g_m + g_E + g_0 + g_{\pi}}{g_m + g_E + g_0 + g_{\pi}} = \frac{g_m}{g_m + g_E} \\
A_V & = \frac{g_m}{g_m + g_E + g_0 + g_{\pi}} \quad \approx \frac{g_m}{g_m + g_E} \\
\theta & = \frac{g_m + g_E}{g_m + g_E + g_0 + g_{\pi}} = \frac{g_m}{g_m + g_E} \\
R_{in} & = r_{\pi} \frac{g_m + g_E}{g_0 + g_E} \quad \approx \quad r_{\pi} + \beta R_E
\end{align*}
\]
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, \( R_0\) defined for short-circuit input -)

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

\[
i_{out} = v_{out} \left( g_E + g_0 + g_\pi \right) - g_m \left( -v_{out} \right)
\]

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

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

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

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

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)
- \( A_{V0} \neq 0 \)
Common Collector Configuration

For this CC application

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

Small signal parameter domain

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

\[ R_{in} = \alpha + \beta R_E \]

\[ R_0 \approx \frac{R_E}{1 + g_m R_E} \quad \text{if} \quad g_x R_e \gg 1 \]

Operating point and model parameter domain

\[ A_V \approx \frac{i_{CQ} R_E}{i_{CQ} R_E + V_t} \quad \text{if} \quad i_{CQ} R_E \gg V_t \]

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

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

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

(Not two-port models for these applications)

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

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

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

In terms of operating point and model parameters:

\[ A_V \approx \frac{I_{CQ} R_E}{I_{CQ} R_E + V_t} \quad I_{col} R_e >> V_t \]

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

\[ R_0 \approx \frac{V_t}{I_{CQ}} \quad I_{col} R_e >> V_t \]

• 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
Consider Common Base/Common Gate Two-port Models

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

Common Base

\[ V_{be} \] 

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

\[ g_{o} \] 

\[ R_{oX} \] 

\[ A_{v0r} v_{2} \] 

\[ A_{v0} v_{1} \] 

\[ \{ R_{iX}, A_{v0}, A_{v0r} \text{ and } R_{0X} \} \]
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
   \[
   v_1 = i_1 R_{\text{IN}} + A_{VR} v_2 \\
   v_2 = i_2 R_O + A_{V0} v_1
   \]

3. Thevenin-Norton Transformations

4. Ad Hoc Approaches
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:

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

Common Base

Two-port Common Base Model

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

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

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

\[ R_{ox} = \frac{1}{g_0} \]
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 )
Common Base Configuration

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

$$ (g_C + g_0) v_0 = (g_m + g_0) v_{in} \quad \Rightarrow \quad A_V = \frac{g_m + g_0}{g_C + g_0} \approx g_m R_C $$

By KCL at the emitter node, obtain

$$ i_1 = (g_m + g_\pi + g_0) v_{in} - g_0 v_{out} \quad \Rightarrow \quad R_{in} = \frac{g_0 + g_C}{g_C (g_m + g_\pi + g_0) + g_\pi g_0} \approx \frac{1}{g_m} $$

$$ R_{out} = R_C // r_0 \quad \Rightarrow \quad R_{out} = \frac{R_C}{1 + g_0 R_C} \approx R_C $$
Common Base Application

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

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:

\[ A_V \approx \frac{I_{CQ} R_C}{V_t} \quad R_{in} \approx \frac{V_t}{I_{CQ}} \quad R_{out} \approx \frac{I_{o} R_C}{V_{BEQ}} \]

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
End of Lecture 31