EE 330
Lecture 25

Amplifier Biasing (precursor)
Two-Port Amplifier Model
Amplifier Biasing (precursor)

Not convenient to have multiple dc power supplies
\( V_{\text{OUTQ}} \) very sensitive to \( V_{\text{EE}} \)
Amplifier Biasing (precursor)

Not convenient to have multiple dc power supplies
$V_{OUTQ}$ very sensitive to $V_{EE}$

Compare the small-signal equivalent circuits of these two structures
Amplifier Biasing (precursor)

Compare the small-signal equivalent circuits of these two structures

Since Thevenin equivalent circuit in red circle is $V_{IN}$, both circuits have same voltage gain
Amplifier Characterization (an example)

Determine $V_{\text{OUTQ}}$, $A_V$, $R_{\text{IN}}$

Determine $v_{\text{OUT}}$ and $v_{\text{OUT}}(t)$ if $v_{\text{IN}} = 0.002\sin(400t)$

In the following slides we will analyze this circuit.
Amplifier Characterization (an example)

(biasing components: $C$, $R_B$, $V_{CC}$ in this case, all disappear in small-signal gain circuit)

Several different biasing circuits can be used
Amplifier Characterization (an example)

Determine $V_{\text{OUTQ}}$ and the SS voltage gain, assume $\beta=100$
Amplifier Characterization (an example)

Determine $V_{OUTQ}$

\[ I_{CQ} = \beta I_{QB} = 100 \left( \frac{12V - 0.6V}{500K} \right) = 2.3mA \]

\[ V_{OUTQ} = 12V - I_{CQ}R_1 = 12V - 2.3mA \times 2K = 7.4V \]
Amplifier Characterization (an example)

Determine the SS voltage gain

\[ \beta = 100 \]

\[ R_1 = 2K \]

\[ Q_1 \]

\[ V_{IN}(t) \]

\[ V_{OUT} \]

\[ V_{CC} = 12V \]

\[ R_B = 500K \]

\[ C = 1uF \]

\[ \beta = 100 \]

\[ V_{IN} \]

\[ V_{OUT} \]

\[ R_B \]

\[ R_1 \]

\[ V_{BE} \]

\[ g_m \]

\[ R_1 \]

\[ g_m V_{BE} \]

\[ \nu_{OUT} = -g_m \nu_{BE} R_1 \]

\[ \nu_{IN} = \nu_{BE} \]

\[ A_V = -R_1 g_m \]

\[ A_V \approx -\frac{I_{CQ} R_1}{V_t} \]

\[ A_V \approx -\frac{2.3mA \cdot 2K}{26mV} \approx -177 \]

This basic amplifier structure is widely used and repeated analysis serves no useful purpose

Have seen this circuit before but will repeat for review purposes
Amplifier Characterization (an example)

Determine $R_{IN}$

$$R_{in} = \frac{V_{IN}}{i_{IN}}$$

Usually $R_B >> r_\pi$

$$R_{in} = R_B / / r_\pi \approx r_\pi$$

$$R_{in} \approx r_\pi = \frac{I_{CQ}}{\beta V_t}$$
Examples

Determine $v_{OUT}$ and $V_{OUT}(t)$ if $v_{IN} = .002\sin(400t)$

$V_{OUT} = A_v v_{IN}$

$V_{OUT} = -177 \cdot .002\sin(400t) = -0.354\sin(400t)$

$V_{OUT}(t) \approx V_{OUTQ} + A_v v_{IN}$

$V_{OUT} \approx 7.4V - 0.35 \cdot \sin(400t)$
Two-Port Representation of Amplifiers

- Two-port model representation of amplifiers useful for insight into operation and analysis
- Internal components to the two-port can be quite complicated but equivalent two-port model is quite simple
Two-port representation of amplifiers

Amplifiers can be modeled as a two-port for small-signal operation

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

![Two-port representation of amplifiers](image-url)
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
Amplifier input impedance, output impedance and gain are usually of interest

Why?

Example 1: Assume amplifier is unilateral

\[
V_{\text{IN}} \quad R_S \quad \text{Amplifier} \quad V_{\text{OUT}}
\]

\[
V_{\text{IN}} \quad R_S \quad \text{V}_{1} \quad R_{IN} \quad A_V \cdot V_1 \quad R_{OUT} \quad \text{V}_{2} \quad R_L \quad V_{\text{OUT}}
\]

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

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

Can get gain without reconsdidering 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 recondsidering 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**

- Amplifier parameters can also be used if not unilateral
- One terminal is often common
Determination of small-signal model parameters:

In the past, we have determined small-signal model parameters from the nonlinear port characteristics

\[ \begin{align*}
I_1 &= f_1(V_1, V_2) \\
I_2 &= f_2(V_1, V_2)
\end{align*} \]

\[ y_{ij} = \left. \frac{\partial f_i(V_1, V_2)}{\partial V_j} \right|_{\bar{V}=\bar{V}_Q} \]

- Will now determine small-signal model parameters for two-port comprised of linear networks
- Results are identical but latter approach is often much easier
Two-Port Equivalents of Interconnected Two-ports

Example:

- could obtain two-port in any form
- often obtain equivalent circuit w/o identifying independent variables
- Unilateral iff $A_{VR}=0$
- Thevenin-Norton transformations can be made on either or both ports
Two-Port Equivalents of Interconnected Two-ports

Example:
Determination of two-port model parameters
(One method will be discussed here)

A method of obtaining $R_{in}$

\[ i_1 = v_1 \left( \frac{1}{R_{in}} \right) + v_2 \left( -A_{VR} \right) \]
\[ i_2 = v_1 \left( -A_{V0} \right) + v_2 \left( \frac{1}{R_0} \right) \]

\[ v_2 = 0 \]
\[ v_1 = v_{test} \]
\[ i_1 = i_{test} \]

\[ R_{in} = \frac{v_{test}}{i_{test}} \]
Determination of two-port model parameters

A method of obtaining $A_{v0}$

Terminating the output in an open-circuit

$$i_1 = v_1 \left( \frac{1}{R_{in}} \right) + v_2 \left( -\frac{A_{VR}}{R_{in}} \right)$$

$$i_2 = v_1 \left( -\frac{A_{v0}}{R_0} \right) + v_2 \left( \frac{1}{R_0} \right)$$

$$i_2 = 0$$

$V_1 = V_{\text{test}}$

$V_2 = V_{\text{out-test}}$

$$A_{v0} = \frac{V_{\text{out-test}}}{V_{\text{test}}}$$
Determination of two-port model parameters

A method of obtaining $R_0$

Terminate the input in a short-circuit

\[
\begin{align*}
  i_1 &= v_1 \left( \frac{1}{R_{in}} \right) + v_2 \left( -\frac{A_{VR}}{R_{in}} \right) \\
  i_2 &= v_1 \left( -\frac{A_{V0}}{R_0} \right) + v_2 \left( \frac{1}{R_0} \right)
\end{align*}
\]

$v_1 = 0$

\[
R_0 = \frac{V_{test}}{i_{test}}
\]
Determination of two-port model parameters

A method of obtaining $A_{VR}$

Terminate the input in an open-circuit

\[
\begin{align*}
i_1 &= v_1 \left( \frac{1}{R_{in}} \right) - v_2 \left( \frac{A_{VR}}{R_{in}} \right) \\
i_2 &= v_1 \left( -\frac{A_{V0}}{R_0} \right) + v_2 \left( \frac{1}{R_0} \right)
\end{align*}
\]

\[A_{VR} = \frac{v_{out-test}}{v_{test}}\]
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.
Examples

Determine $V_{OUTQ}$ and the SS voltage gain ($A_V$), assume $\beta=100$

($A_V$ is one of the small-signal model parameters for this circuit)
Examples

\[ R_2 = 2K \]
\[ Q_1 \]
\[ V_{OUT} \]
\[ V_{CC} = 12V \]
\[ R_{B1} = 50K \]
\[ C = 1uF \]
\[ R_{B2} = 10K \]
\[ R_1 = 0.5K \]

Determine \( V_{OUTQ} \) and the SS voltage gain \( (A_V) \), assume \( \beta = 100 \)

\( (A_V \) is one of the small-signal model parameters for this circuit)
Examples

This circuit is most practical when $I_B << I_{BB}$

With this assumption,

$$V_B = \left( \frac{R_{B2}}{R_{B1} + R_{B2}} \right) V_{CC} = \left( \frac{2K}{50K + 10K} \right) 12V = 2.8V$$

$$I_C = I_Q = \left( \frac{V_B - 0.6V}{R_1} \right) = \left( \frac{2.8V - 0.6V}{0.5K} \right) = 4mA$$

$$V_{OUT} = 12V - I_C R_1 = 6.4V$$

Note: This Q-point is nearly independent of the characteristics of the nonlinear BJT!
Examples

This voltage gain is nearly independent of the characteristics of the nonlinear BJT!

This is a fundamentally different amplifier structure

It can be shown that this is slightly non-unilateral

\[ V_{\text{OUT}} = -g_m V_{\text{BE}} R_2 \]

\[ V_{\text{IN}} = V_{\text{BE}} + R_1 \left( V_{\text{BE}} \left[ g_\pi + g_m \right] \right) \]

\[ A_V = \frac{-R_2 g_m V_{\text{BE}}}{V_{\text{BE}} + R_1 \left( V_{\text{BE}} \left[ g_\pi + g_m \right] \right)} = \frac{-R_2 g_m}{1 + R_1 \left( \left[ g_\pi + g_m \right] \right)} \]

\[ A_V \approx \frac{-R_2 g_m}{R_1 g_m} = \frac{-R_2}{R_1} \]
Examples

Biasing Circuit

- $V_{CC} = 12V$
- $R_{B1} = 50K$
- $C_1 = 1\mu F$
- $R_{B2} = 10K$
- $R_2 = 2K$
- $Q_1$
- $V_{OUT}$
- $V_{IN}(t)$
- $R_1 = 0.5K$
- $C_2 = 100\mu F$

Determine $V_{OUTQ}$, $R_{IN}$, $R_{OUT}$, and the SS voltage gain, and $A_{VR}$ assume $\beta = 100$
Examples

\[ R_2 = 2K \]
\[ Q_1 \]
\[ V_{OUT} \]
\[ V_{CC} = 12V \]
\[ V_{IN}(t) \]
\[ R_{B1} = 50K \]
\[ C_1 = 1uF \]
\[ R_1 = 0.5K \]
\[ R_{B2} = 10K \]
\[ C_2 = 100uF \]

Determine \( V_{OUT} \), \( R_{IN} \), \( R_{OUT} \), and the SS voltage gain, and \( AVR \); assume \( \beta = 100 \)

(\( AV \), \( R_{IN} \), \( R_{OUT} \), and \( AVR \) are the small-signal model parameters for this circuit)
Examples

Determine $V_{\text{OUTQ}}$

This is the same as the previous circuit!

$$V_{\text{OUTQ}} = 6.4\,\text{V}$$

$$I_{\text{CQ}} = \frac{5.6\,\text{V}}{2\,\text{K}} = 2.8\,\text{mA}$$

Note: This Q-point is nearly independent of the characteristics of the nonlinear BJT!
Examples

Determine the SS voltage gain

This is the same as another previous-previous circuit!

\[ A_v \approx -g_m R_2 \]

\[ A_v \approx -\frac{I_{CQ} R_2}{V_t} \]

\[ A_v \approx -\frac{5.6V}{26mV} = -215 \]

Note: This Gain is nearly independent of the characteristics of the nonlinear BJT!
Examples

Determination of $R_{IN}$

The SS equivalent circuit

$\beta = 100$

$R_{IN} = R_{B1} // R_{B2} // r_\pi \approx r_\pi$

$r_\pi = \left( \frac{I_{CQ}}{\beta V_t} \right)^{-1} = \left( \frac{2.8mA}{100 \cdot 26mV} \right)^{-1} = 928\Omega$

$R_{IN} = R_{B1} // R_{B2} // r_\pi \approx r_\pi = 930\Omega$
Examples

Determination of $R_{OUT}$

The SS equivalent circuit

$\beta=100$

$$R_{OUT} = \frac{V_{TEST}}{i_{TEST}} = R_2/r_o$$

$$r_o = \left(\frac{I_{CQ}}{V_{AF}}\right)^{-1} = \left(\frac{2.8\text{mA}}{200\text{V}}\right)^{-1} = (1.4E-5)^{-1} = 71\Omega$$

$$R_{OUT} = R_2/r_o \approx R_2 = 2K$$
Examples

Determine $A_{VR}$

The SS equivalent circuit

$$V_{IN}$$

$$V_{OUT}$$

$$V_{be}$$

$$g_m$$

$$g_o$$

$$V_{ce}$$

$$R_{B1//R_B2}$$

$$R_2$$

$$V_{OUT}$$

$$V_{TEST}$$

$$V_{OUT TEST} = 0$$

$$A_{VR} = 0$$
Determination of small-signal two-port representation

\[ V_{OUT} = V_{CC} - A_V V_1 \]

\[ V_1 \]

\[ R_{IN} \approx R \]

\[ A_V \approx -215 \]

\[ R_{IN} \approx r_T = 930 \Omega \]

\[ R_{OUT} \approx R_2 = 2K \]

This is the same basic amplifier that was considered many times.
End of Lecture 25