Lecture 6

OUTLINE

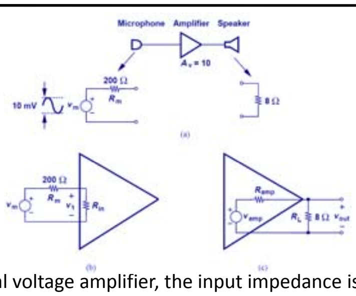
- Bipolar Amplifiers
  - General considerations
  - Bias circuit and operating point analysis

Reading: Chapter 5.1-5.2

Bipolar Amplifiers

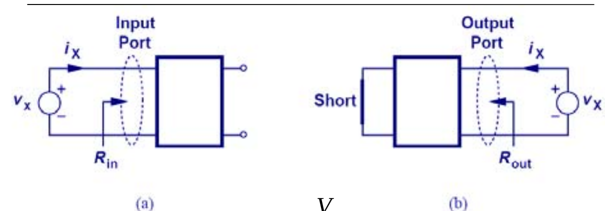
General Concepts	Operating Point Analysis	Amplifier Topologies
• Input and Output Impedances	• Simple Biasing	• Common-Emitter Stage
• Biasing	• Emitter Degeneration	• Common-Base Stage
• DC and Small-Signal Analysis	• Self-Biasing	• Emtter Follower
	• Biasing of PNP Devices	

Voltage Amplifier



- In an ideal voltage amplifier, the input impedance is infinite and the output impedance zero.
- But in reality, input or output impedances depart from their ideal values.

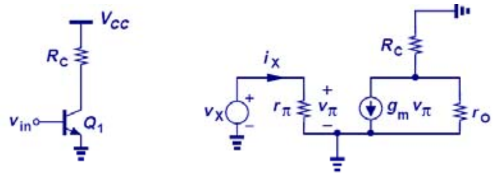
Input/Output Impedances



$$R_x = \frac{V_x}{i_x}$$

- The figure above shows the techniques of measuring input and output impedances.

Input Impedance Example I



(a) (b)

$$\frac{v_x}{i_x} = r_\pi$$

- When calculating input/output impedance, small-signal analysis is assumed.

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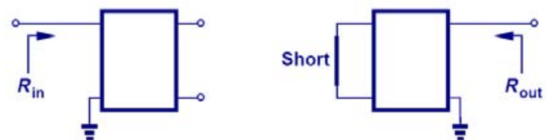
Impedance at a Node



(a) (b)

- When calculating I/O impedances at a port, we usually ground one terminal while applying the test source to the other terminal of interest.

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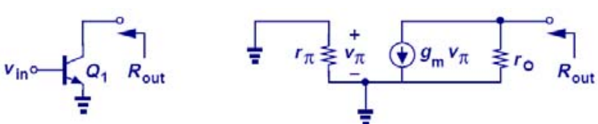
Impedance at Collector



(a) (b)

$$R_{out} = r_o$$

- With Early effect, the impedance seen at the collector is equal to the intrinsic output impedance of the transistor (if emitter is grounded).

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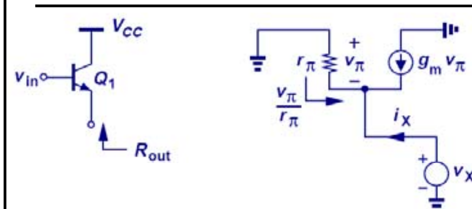
Impedance at Emitter



$$\frac{v_x}{i_x} = \frac{1}{g_m + \frac{1}{r_\pi}}$$

$$R_{out} \approx \frac{1}{g_m}$$

$$(V_A = \infty)$$

(a) (b)

- The impedance seen at the emitter of a transistor is approximately equal to one over its transconductance (if the base is grounded).

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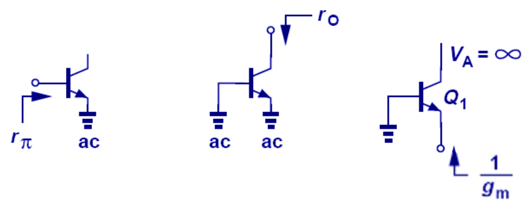
Three Master Rules of Transistor Impedances



- Rule # 1: looking into the base, the impedance is r_π if emitter is (ac) grounded.
- Rule # 2: looking into the collector, the impedance is r_o if emitter is (ac) grounded.
- Rule # 3: looking into the emitter, the impedance is $1/g_m$ if base is (ac) grounded and Early effect is neglected.

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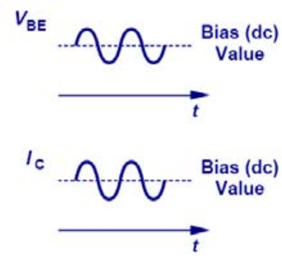
Biasing of BJT



- Transistors and circuits must be biased because (1) transistors must operate in the active region, (2) their small-signal parameters depend on the bias conditions.

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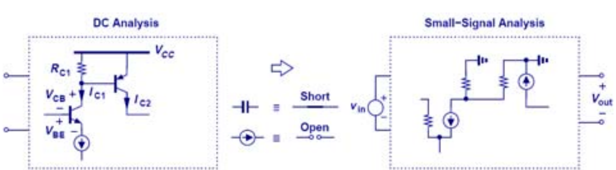
DC Analysis vs. Small-Signal Analysis



- First, DC analysis is performed to determine operating point and obtain small-signal parameters.
- Second, sources are set to zero and small-signal model is used.

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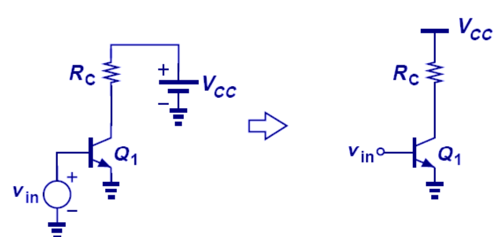
Notation Simplification



- Hereafter, the battery that supplies power to the circuit is replaced by a horizontal bar labeled V_{cc}, and input signal is simplified as one node called V_{in}.

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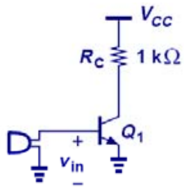
Example of Bad Biasing



- The microphone is connected to the amplifier in an attempt to amplify the small output signal of the microphone.
- Unfortunately, there's no DC bias current running through the transistor to set the transconductance.

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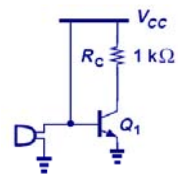
Another Example of Bad Biasing



- The base of the amplifier is connected to V_{cc}, trying to establish a DC bias.
- Unfortunately, the output signal produced by the microphone is shorted to the power supply.

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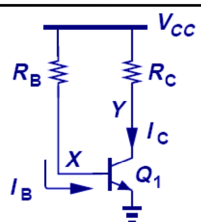
Biasing with Base Resistor



$$I_B = \frac{V_{CC} - V_{BE}}{R_B}$$

$$I_C = \beta\left(\frac{V_{CC} - V_{BE}}{R_B}\right)$$

- Assuming a constant value for V_{BE}, one can solve for both I_B and I_C and determine the terminal voltages of the transistor.
- However, bias point is sensitive to β variations.

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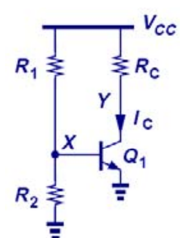
Improved Biasing: Resistive Divider



$$V_X = \frac{R_2}{R_1 + R_2} V_{CC}$$

$$I_C = I_S \exp\left(\frac{R_2}{R_1 + R_2} \frac{V_{CC}}{V_T}\right)$$

- Using resistor divider to set V_{BE}, it is possible to produce an I_C that is relatively independent of β if base current is small.

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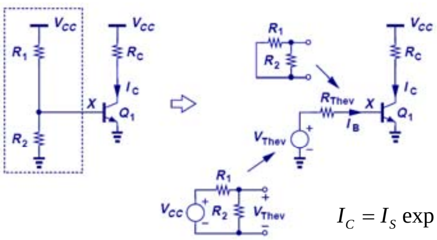
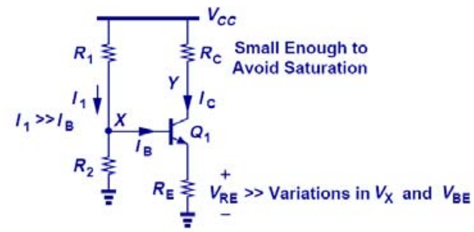
Accounting for Base Current



$$I_C = I_S \exp\left(\frac{V_{Thev} - I_B R_{Thev}}{V_T}\right)$$

- With proper ratio of R_1 and R_2, I_C can be insensitive to β; however, its exponential dependence on resistor deviations makes it less useful.

Emitter Degeneration Biasing

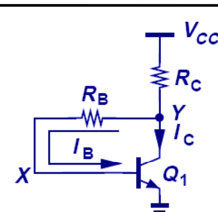


- The presence of R_E helps to absorb the error in V_X so V_{BE} stays relatively constant.
- This bias technique is less sensitive to β ($I_1 >> I_B$) and V_{BE} variations.

Design Procedure

- Choose an I_C to provide the necessary small signal parameters, g_m, r_π, etc.
- Considering the variations of R_1, R_2, and V_{BE}, choose a value for V_{RE}.
- With V_{RE} chosen, and V_{BE} calculated, V_x can be determined.
- Select R_1 and R_2 to provide V_x

Self-Biasing Technique



- This bias technique utilizes the collector voltage to provide the necessary V_x and I_B.
- One important characteristic of this technique is that collector has a higher potential than the base, thus guaranteeing active operation of the transistor.

Self-Biasing Design Guidelines

$$(1)\ R_C >> \frac{R_B}{\beta}$$

$$(2)\ \Delta V_{BE} << V_{CC} - V_{BE}$$

(1) provides insensitivity to β .

(2) provides insensitivity to variation in VBE .

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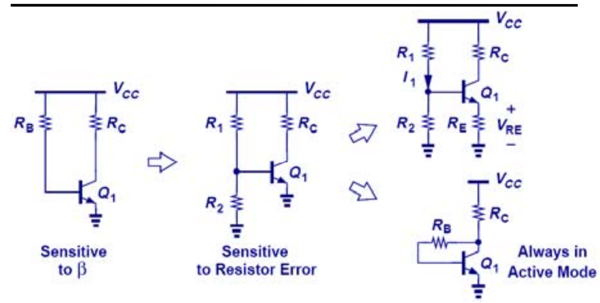
Summary of Biasing Techniques



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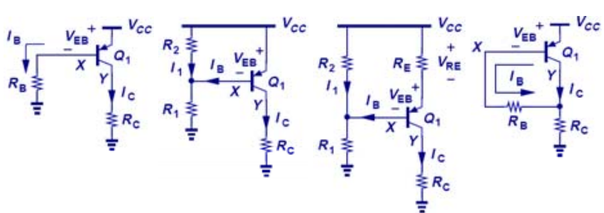
PNP Biasing Techniques



- Same principles that apply to NPN biasing also apply to PNP biasing with only polarity modifications.

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