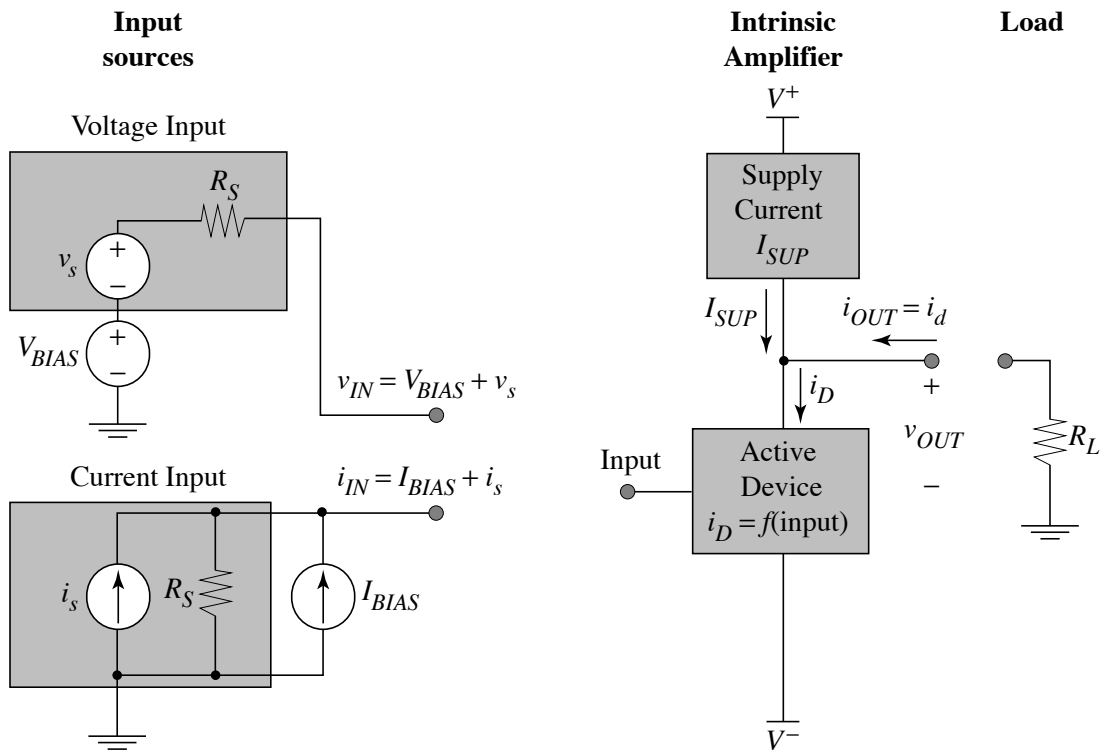


Transistor Amplifiers

- Perspective: look at the various configurations of bipolar and MOS transistors, for which a *small-signal* voltage or current is transformed (e.g., usually *amplified* -- increased in magnitude) between the input and output ports.
- Amplifier terminology:



Abstractions:

Sources include precisely adjusted bias voltages or currents

Source resistance is associated with the small-signal source (and neglected for bias calculations)

Load resistance typically models another amplifier, speaker, actuator, etc.

Amplifier Biasing

- Input bias voltage V_{IN} sets the DC device current, I_D to precisely equal the supply current I_{SUP}
(note -- $D = \text{“device”}$ here)
- Likewise, if the input is the sum of small-signal and DC current sources, then the input bias current I_{BIAS} is chosen so that it sets $I_D = I_{SUP}$
The DC output current is $I_{OUT} = I_D - I_{SUP} = 0$ A,
which implies that the DC output voltage $V_{OUT} = 0$ V also.

Note: both positive and negative DC supply voltages are used so $V_{OUT} = 0$ V does *not* mean that the DC voltage drop is zero!

KEY IDEA: the small-signal voltage or current source perturbs the amplifier bias, through $i_D = f(\text{input})$, which results in a small-signal output current

$$i_{OUT} = i_D - i_{SUP} = (I_D + i_d) - I_{SUP} = i_d$$

since the supply current is DC ($i_{SUP} = I_{SUP}$)

A small-signal output voltage is generated

$$v_{out} = -R_L i_{out}, \text{ where } R_L \text{ is the load resistor}$$

Two-Port Amplifier Models

- How do we characterize an amplifier's response to a general input signal (Thévenin or Norton source)?

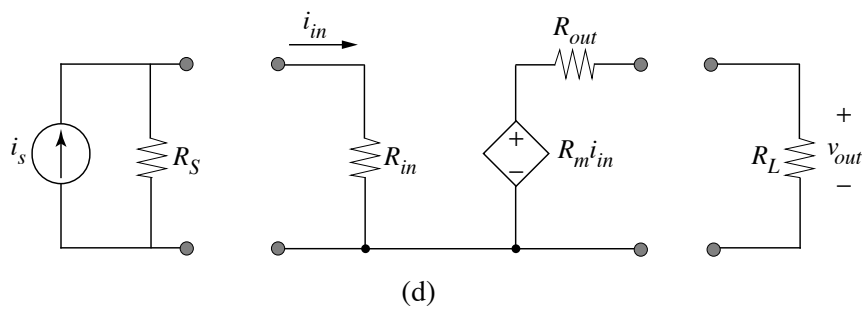
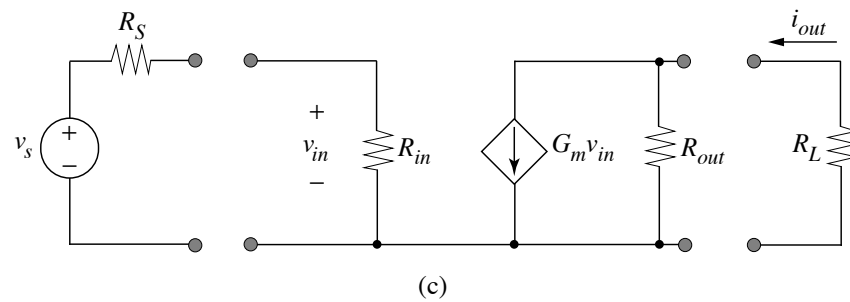
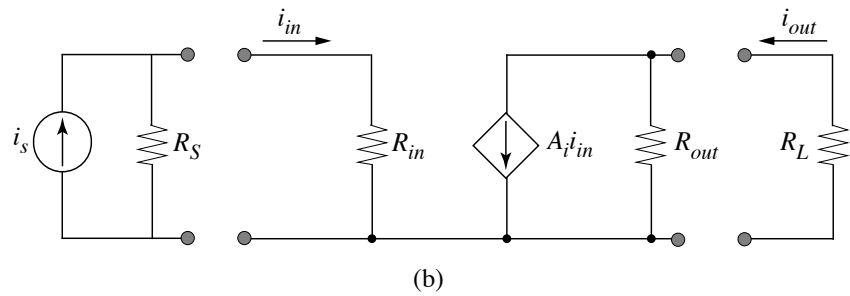
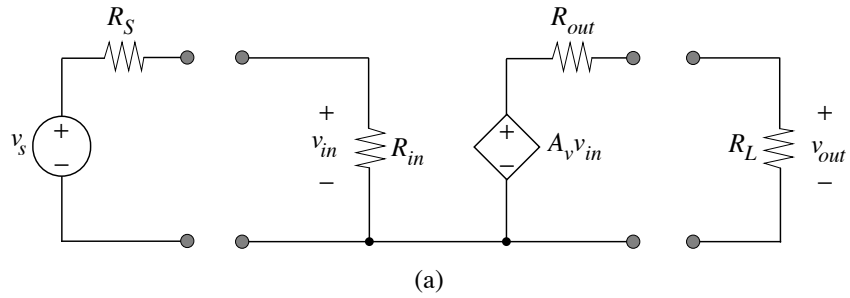
the controlled source is determined by output signal (voltage or current ... we select which is of interest) and by the input signal

Therefore, there are **FOUR** types of amplifiers:

- Voltage
 - Current
 - Transconductance (voltage in, current out)
 - Transresistance (current in, voltage out)
- From network theory, any linear two-port network can be represented by y_{ij} , z_{ij} , h_{ij} , g_{ij} ... our amplifier models are closely related to these formal two-port equivalent circuits, but they have
 - > intuitively based elements, that can depend on R_L or R_S
 - > only numerically significant elements (no reverse transmission from output to input is included in any of our models)
- We need methods to find the key parameters for all four models:

R_{in} = Input Resistance	R_{out} = Output Resistance
A_v = Voltage Gain	A_i = Current Gain
G_m = Transconductance	R_m = Transresistance

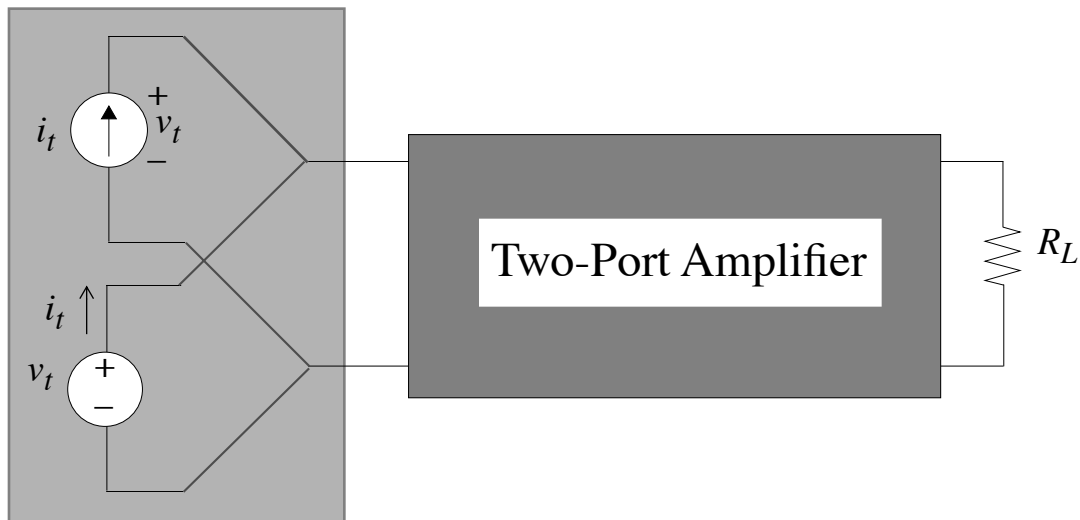
Two-Port Small-Signal Amplifiers



Input Resistance R_{in}

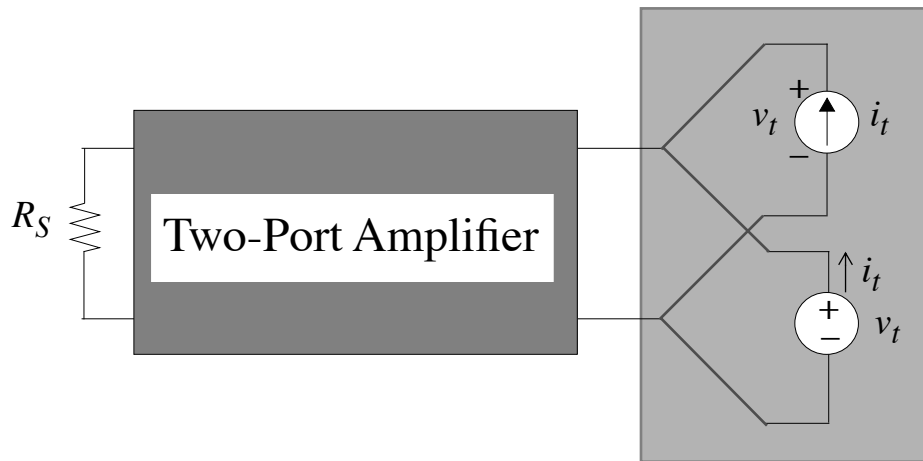
- Define systematic procedures to find the two-port parameters
- **Key idea:** leave the *load* resistance R_L attached when finding R_{in}
- Apply a small-signal *test source* (voltage source **or** current source) and compute (using KVL, KCL, or inspection) the resulting current or voltage:

$$R_{in} = \frac{v_t}{i_t}$$



Output Resistance R_{out}

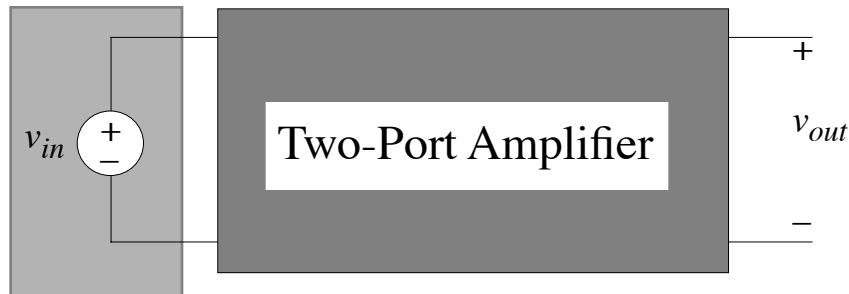
- Remove R_L ; leave the source resistance attached when finding R_{out}



$$R_{out} = \frac{v_t}{i_t}$$

Voltage Gain A_v and Current Gain A_i

- **Voltage gain:** open-circuit the output port ($R_L \rightarrow \infty$) and short the source resistance ($R_S \rightarrow 0 \Omega$) to find the unloaded voltage gain A_v :



$$A_v = \left. \frac{v_{out}}{v_{in}} \right|_{R_S = 0, R_L \rightarrow \infty}$$

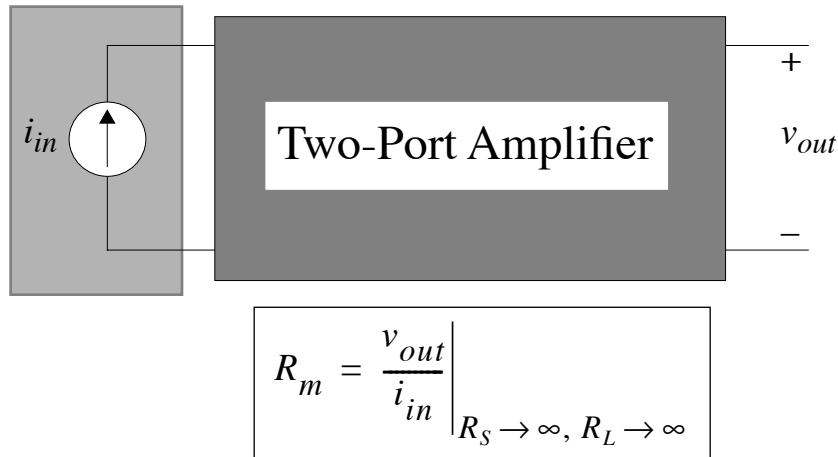
- **Current gain:** short-circuit the output port ($R_L \rightarrow 0 \Omega$) and open-circuit the source resistance ($R_S \rightarrow \infty$) to find the short-circuit current gain A_i :



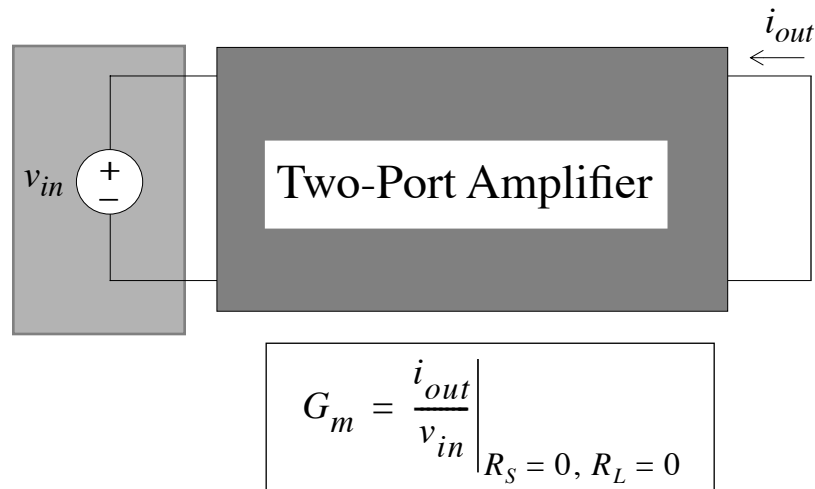
$$A_i = \left. \frac{i_{out}}{i_{in}} \right|_{R_S \rightarrow \infty, R_L = 0}$$

Transresistance R_m and Transconductance G_m

- Open-circuit the source resistance ($R_S \rightarrow \infty$) and open-circuit the output port ($R_L \rightarrow \infty$) to find the transresistance R_m :

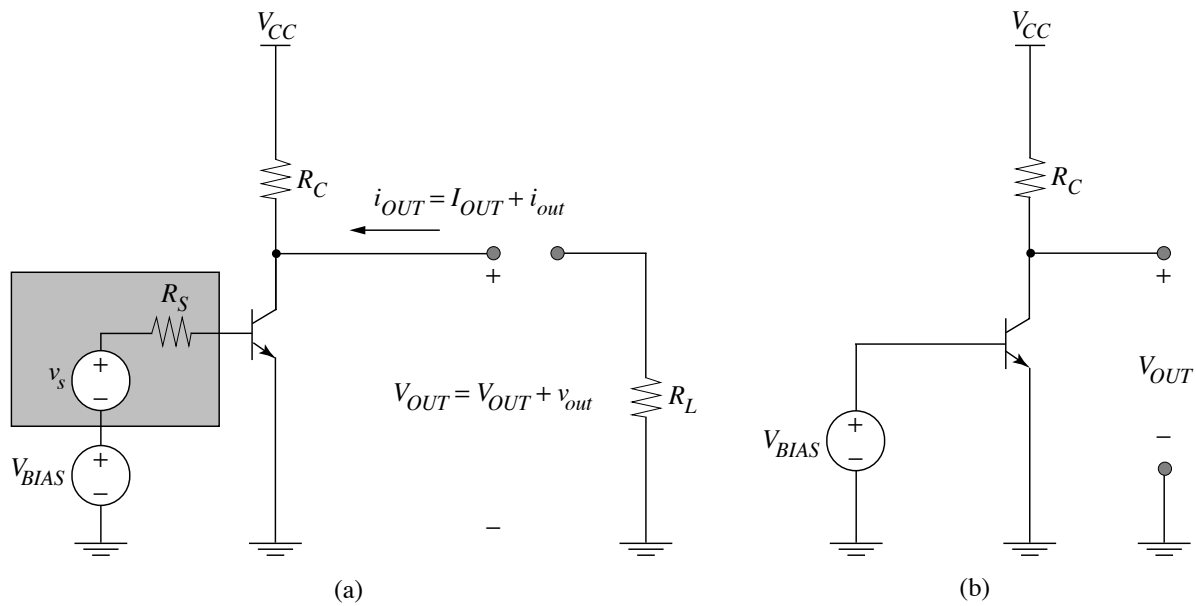


- Short-circuit the input resistance ($R_S = 0 \Omega$) and short-circuit the output port ($R_L = 0 \Omega$) to find the transconductance G_m :



Common-Emitter (CE) Amplifier

- 1. Bias amplifier in high-gain region
- 2. Determine two-port model parameters



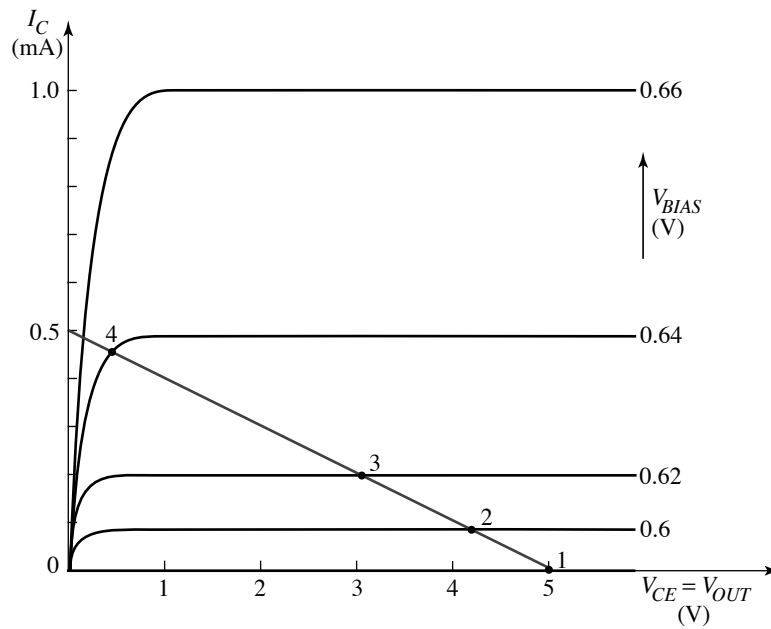
- Note that the source resistor R_S and the load resistor R_L are *disconnected* for determining the bias point

Biasing the CE Amplifier

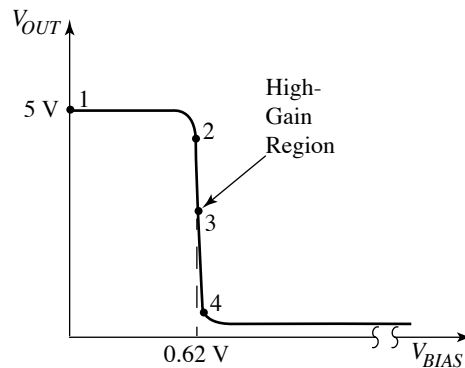
- Graphical approach: plot I_C as a function of the DC base-emitter voltage V_{BIAS} (note: normally plot vs. base current, so we must return to Ebers-Moll):

$$I_C = I_S e^{V_{BE}/V_{th}} = I_S e^{V_{BIAS}/V_{th}} \quad (\text{forward active})$$

Load line for $R_C = 10 \text{ k}\Omega$; range of variation for V_{BIAS} is only 600 mV - 660 mV



(a)



(b)

Transfer Curve

- The load line was plotted, assuming that $V_{CC} = 5 \text{ V}$ and that the collector resistor $R_C = 10 \text{ k}\Omega$, with the equation:

$$I_C = \left(\frac{1}{R_C}\right)(V_{CC} - V_{OUT})$$

The transfer curve is defined by intersections between the load line $I_C(V_{OUT})$ and the family of collector current characteristics $I_C(V_{BIAS}, V_{OUT})$

- Where to operate? Maximize potential “swing” in v_{OUT} by placing V_{OUT} halfway between cutoff and saturation ... $(5 \text{ V} + 0.2 \text{ V})/2 = 2.5 \text{ V}$ (approx.)

Solve for the input bias voltage: $I_S = 10^{-15} \text{ A}$

$$I_C = \frac{V_{CC} - V_{OUT}}{R_C} \approx \frac{V_{CC}}{2R_C} = 0.25 \text{ mA}$$

$$V_{BIAS} = V_{th} \ln\left(\frac{I_C}{I_S}\right) = (26 \text{ mV}) \ln\left(\frac{250 \mu\text{A}}{10^{-15} \text{ A}}\right) = 682 \text{ mV}$$

The operating point is defined by:

$$Q(V_{BE} = 0.682 \text{ V}, V_{CE} = 2.5 \text{ V}, I_C = 250 \mu\text{A})$$

Small-Signal Model of CE Amplifier

- The small-signal model is evaluated at Q ; we assume that the current gain is $\beta_o = 100$ and the Early voltage is $V_{An} = 25$ V:

$$g_m = I_C / V_{th} = 10 \text{ mS (at room temperature)}$$

$$r_\pi = \beta_o / g_m = 10 \text{ k}\Omega$$

$$r_o = V_{An} / I_C = 100 \text{ k}\Omega$$

- Substitute small-signal model for BJT; V_{CC} and V_{BIAS} are short-circuited for small-signals

