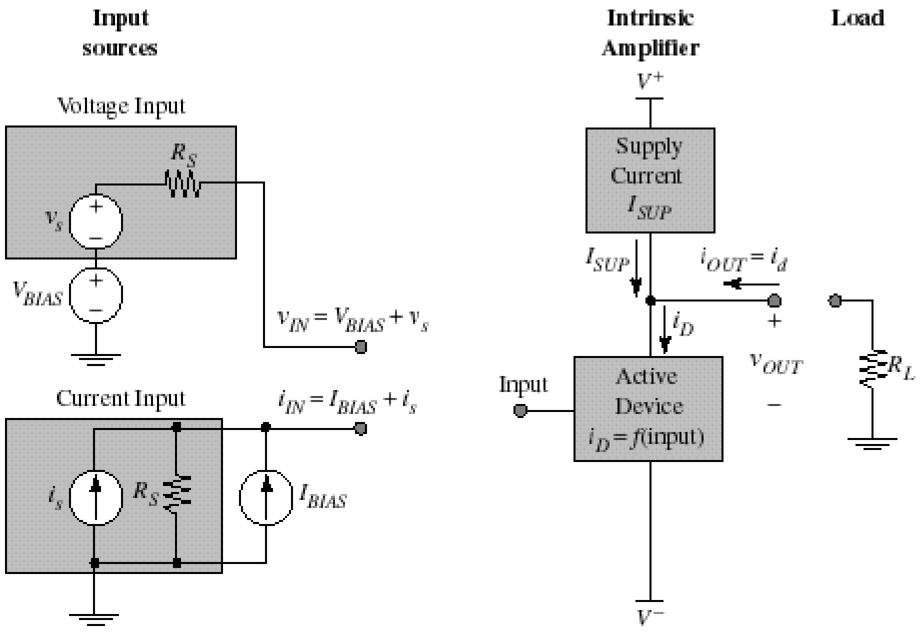
Generalized Transistor Amplifier

- 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

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 = "*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 $i_D = f$ (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 ($i_{SUP} = I_{SUP}$)

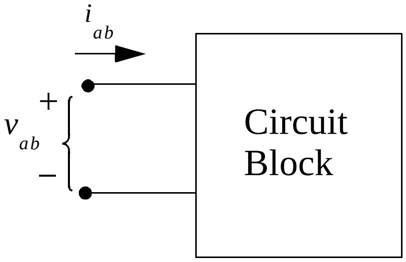
A small-signal output voltage is generated

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

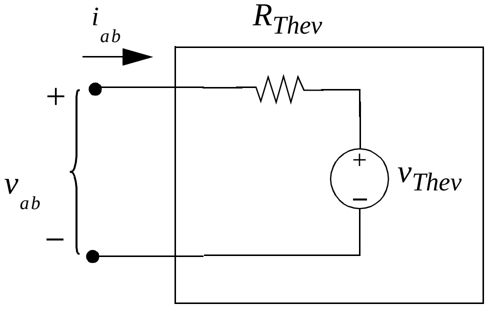
Source and Load Models are "One-Ports"

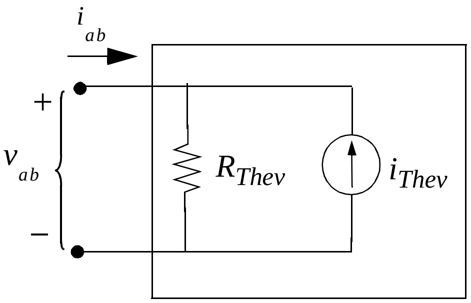
- What is a "port"?

a terminal pair
across which a
voltage and associated
current are defined



- If the circuit block contains only linear elements, then it can be represented as (according to Thevenin's and Norton's Theorems)

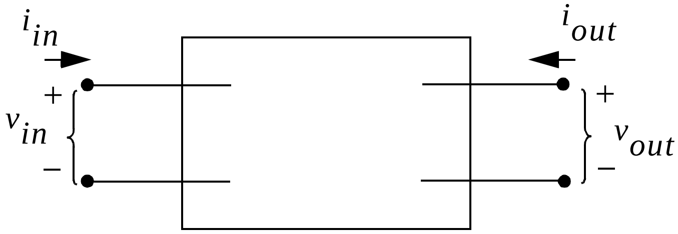




We have "one-port" models for the source and load ...

what about for the amplifier block?

Small-Signal *Two-Port* Models for Amplifier Blocks



$$\left.\begin{array}{c}\text{Linear}\\ \text{and}\\ \text{Unilateral}\end{array}\right\}\begin{array}{c}\text{If } v_{in} = 0,\ i_{in} = 0\\ \text{and}\\ i_{in} \propto v_{in}\end{array}$$

$$\frac{v_{in}}{i_{in}} \equiv R_{in}$$

But, output depends linearly on what's connected both at input and output: (α s are constants)

$$\left.\begin{array}{lll}\text{e.g.,} & i_{out} = \alpha_1 v_{in} + \alpha_2 v_{out} & (1)\\ \text{or} & i_{out} = \alpha_3 i_{in} + \alpha_4 v_{out} & (2)\\ \text{or} & v_{out} = \alpha_5 v_{in} + \alpha_6 i_{out} & (3)\\ \text{or} & v_{out} = \alpha_7 i_{in} + \alpha_8 i_{out} & (4)\end{array}\right\}\begin{array}{c}\text{ALL EQUIVALENT}\\ \text{(only need one)}\end{array}$$

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)

- We need *methods* to find the parameters for these four models for a particular transistor amplifier configuration:

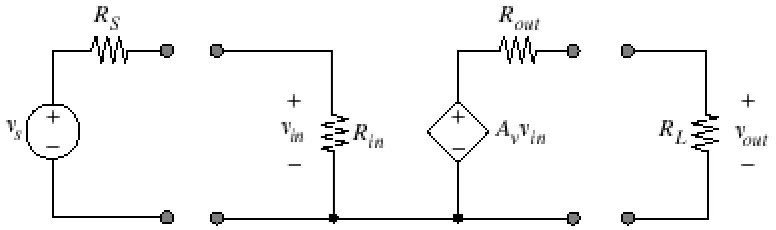
R_{in} = Input Resistance R_{out} = Output Resistance

A_v = Voltage Gain A_i = Current Gain

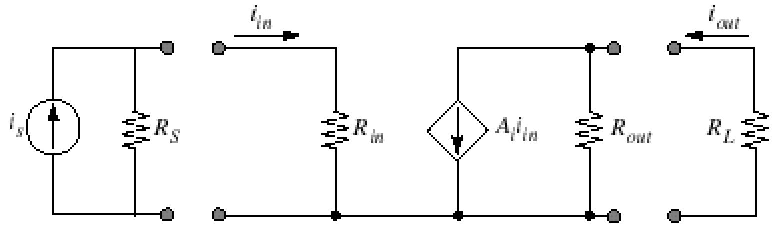
G_m = Tranconductance R_m = Transresistance

Two-Port Small-Signal Amplifiers

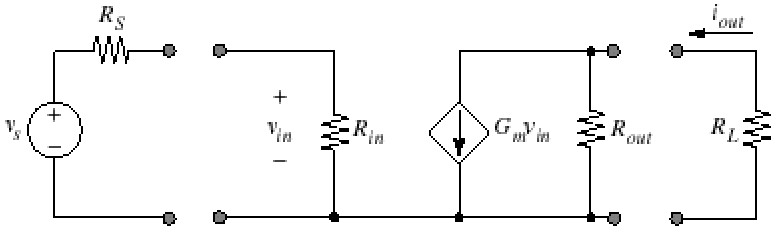
Voltage Amplifier



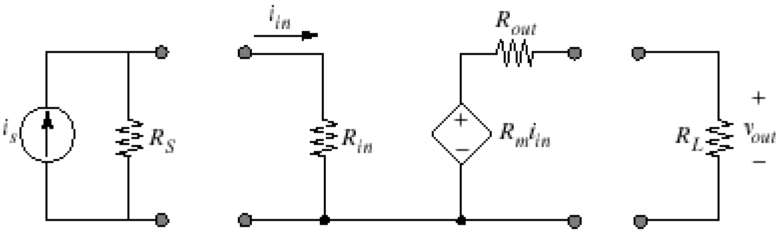
Current Amplifier



Transconductance Amplifier



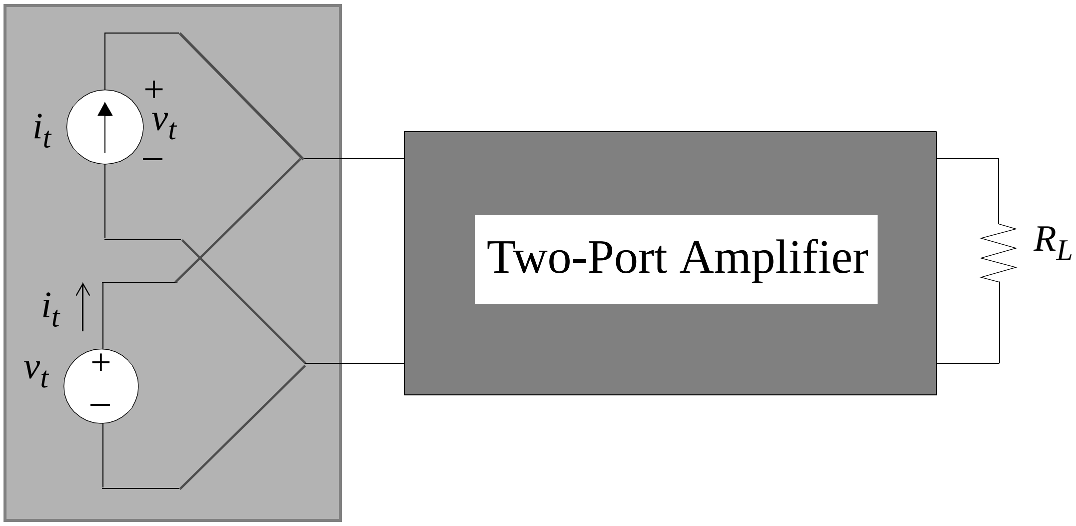
Transresistance Amplifier



Input Resistance R_{in}

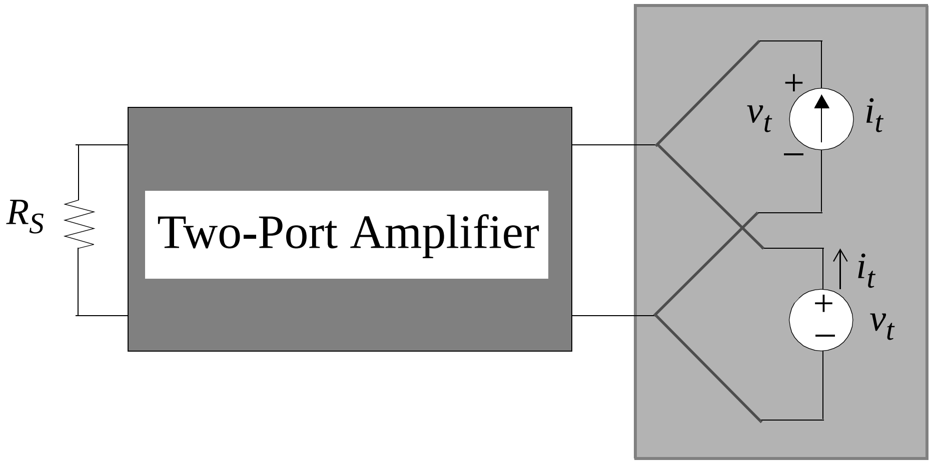
- Define systematic procedures to find the two-port parameters
- **Key idea**: leave the *load* resistance R_L attached when finding R_{in}
- Apply a small-signal *test source* (voltage source **or** current source) and compute (using KVL, KCL, or inspection) the resulting current or voltage:

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



Output Resistance R_{out}

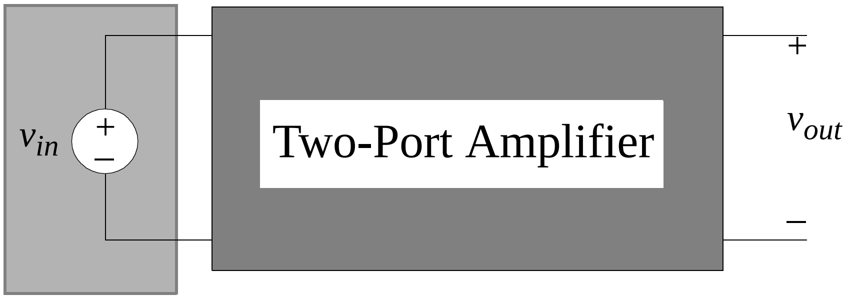
- Remove R_L; leave the source resistance attached when finding R_{out}



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

Voltage Gain A_v and Current Gain A_i

- **Voltage gain**: open-circuit the output port (R_L --> infinity) and short the source resistance (R_S --> 0 Ω) to find the unloaded voltage gain A_v:



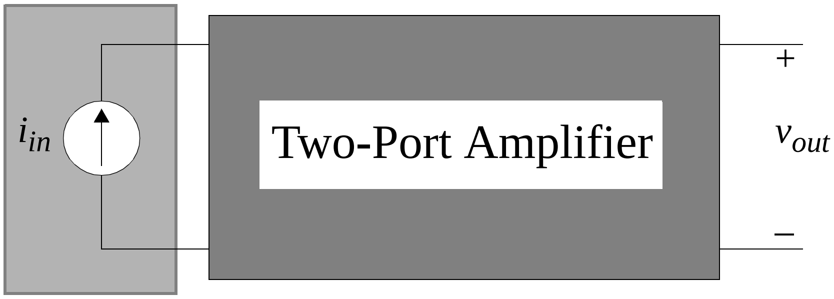
$$A_v = \left.\frac{v_{out}}{v_{in}}\right|_{R_S = 0,\, R_L \to \infty}$$

- Current gain: short-circuit the output port (R_L --> 0 Ω) and open-circuit the source resistance (R_S --> infinity) to find the short-circuit current gain A_i:

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

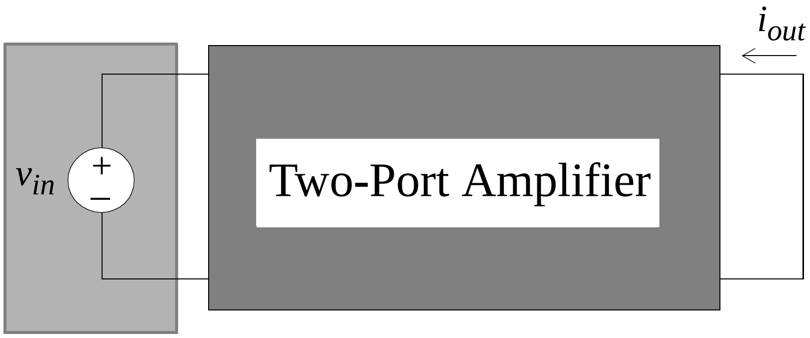
Transresistance R_m and Transconductance G_m

- Open-circuit the source resistance (R_S --> infinity)and open-circuit the output port (R_L --> infinity) to find the transresistance R_m:



$$\boxed{R_m = \left.\frac{v_{out}}{i_{in}}\right|_{R_S \to \infty,\ R_L \to \infty}}$$

- 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:



$$\boxed{G_m = \left.\frac{i_{out}}{v_{in}}\right|_{R_S = 0,\ R_L = 0}}$$

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