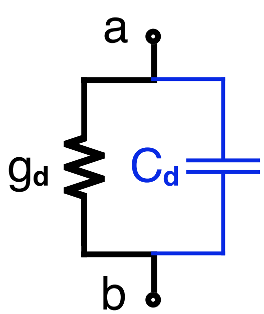
Lecture 17 - Linear Amplifier Basics - Outline

- **Announcements**
  - Handouts - Lecture Outline and Summary
  - Web posting - Expanded Lecture 16 foil set
  - Exam 2 - Wednesday night, November 5, Room 10-250
- **Review - CMOS inverters**
  - Noise Margins: when $\{dv_{OUT}/dv_{IN}| > 1$, disturbance grows
  - Gate delay: often defined as average, i.e. $(\tau_{LO\text{-}HI} + \tau_{HI\text{-}LO})/2$ (We leave the 2 out)
  - Power density: $PD = P_{ave}@f_{max}/Area$ (Maximum power density is what matters)
    - Using $P_{ave} = f\, C_L V_{DD}^2$, and noting $f_{max} \propto 1/GD$, and Area $\propto W_n L_{min}$):
    - $PD \propto \varepsilon_e \varepsilon_{ox} V_{DD}(V_{DD} - V_T)^2/t_{ox} L_{min}^2$ (Must reduce dimensions and voltage - Lec 25)
- **Biasing transistors**
  - Current source biasing
  - Transistors as current sources
  - Current mirror current sources and sinks
- **Linear amplifiers**
  - Performance metrics: gains (voltage, current, power)
    - input and output resistances
    - power dissipation
    - bandwidth (We'll save this for later - Lec. 22)
  - Possible amplifier connections of transistors

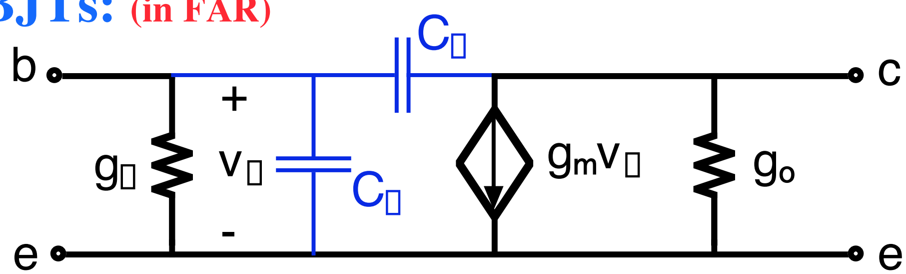
- **Linear equivalent circuits:**

pn diodes:



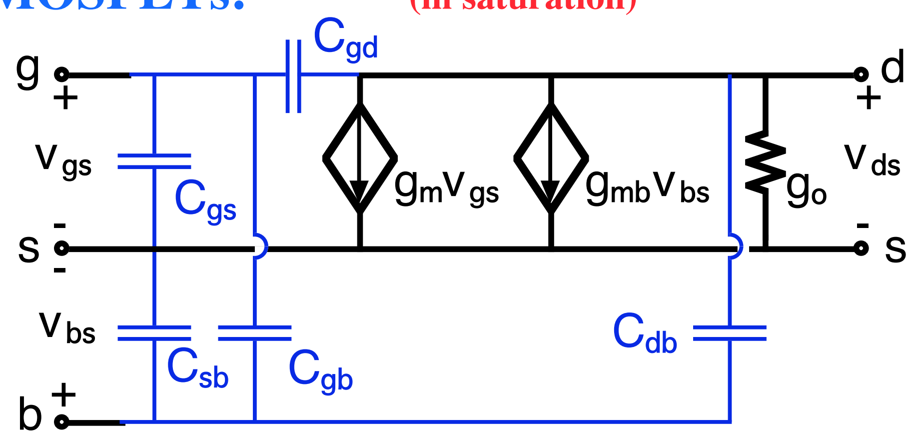
$g_d = q|I_D|/kT$
$C_d = g_d \tau_d + C_{dpl}(V_{AB})$

BJTs: **(in FAR)**



$g_m = q|I_C|/kT$
$g_\pi = g_m/\beta_F$
$g_o = |I_C/V_A|$ [or $\approx \lambda|I_C|$]
$C_\pi = g_m \tau_b + C_{dpl,be}(V_{BE})$
$[\tau_b = w_B^2/2D_e]$
$C_\mu = C_{dpl,bc}(V_{BC})$

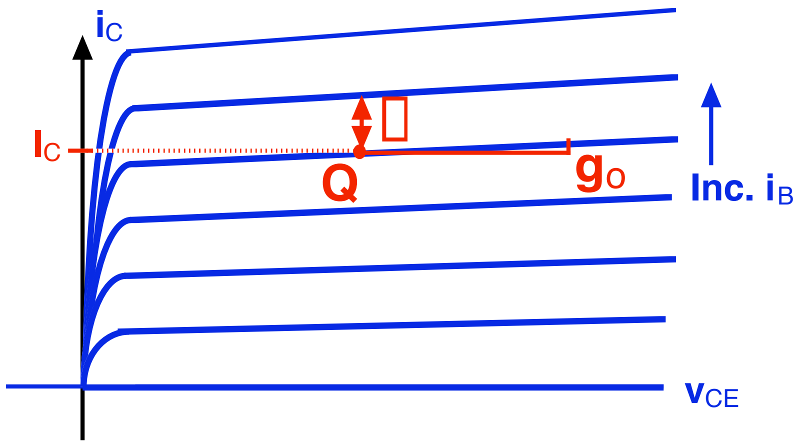
MOSFETs: **(in saturation)**

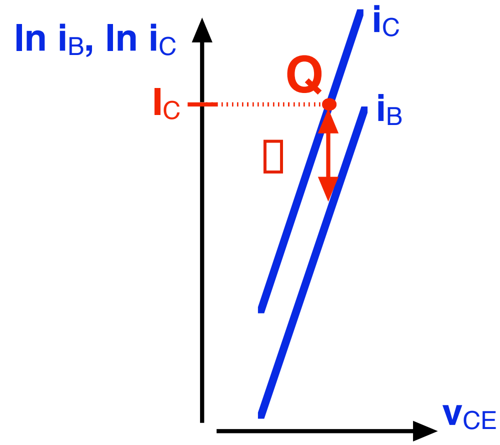


$g_m = K(V_{GS} - V_T) = (2K|I_D|)^{1/2}$
$g_{mb} = \eta g_m$
$[\eta = \{\varepsilon_{Si} q N_A/2(|2\phi_p| - V_{BS})\}^{1/2}/C_{ox}^*]$
$g_o = |I_D/V_A|$ [or $\approx \lambda|I_D|$]
$C_{gs} = (2/3)\, WL\, C_{ox}^*$
C_{gd}: G-D fringing and overlap capacitance, all parasitic
C_{sb}, C_{gb}, C_{db}: depletion capacitances

- **Identifying the incremental parameters in the characteristics**

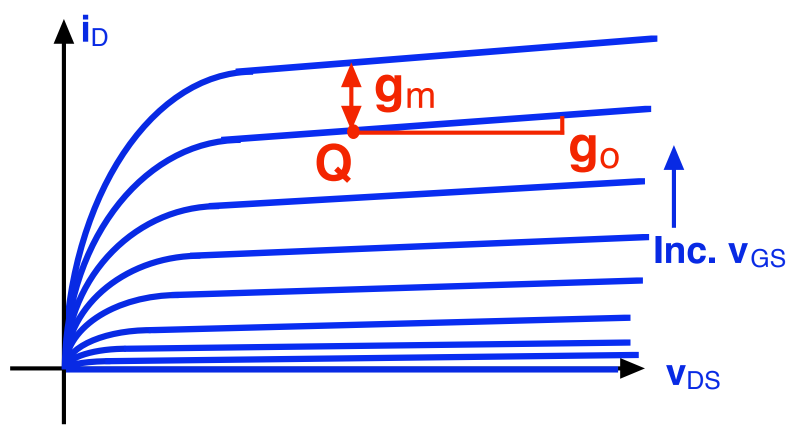
BJT:

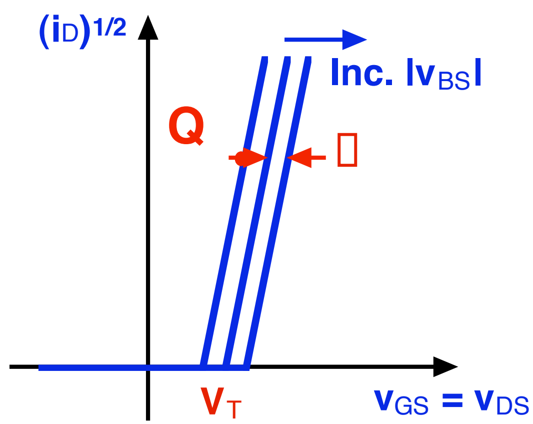




$g_m = qI_C/kT$; $g_{\square} = \square g_m$ with $\square = di_C/di_B|_Q$; $g_o = di_C/dv_{CE}|_Q$

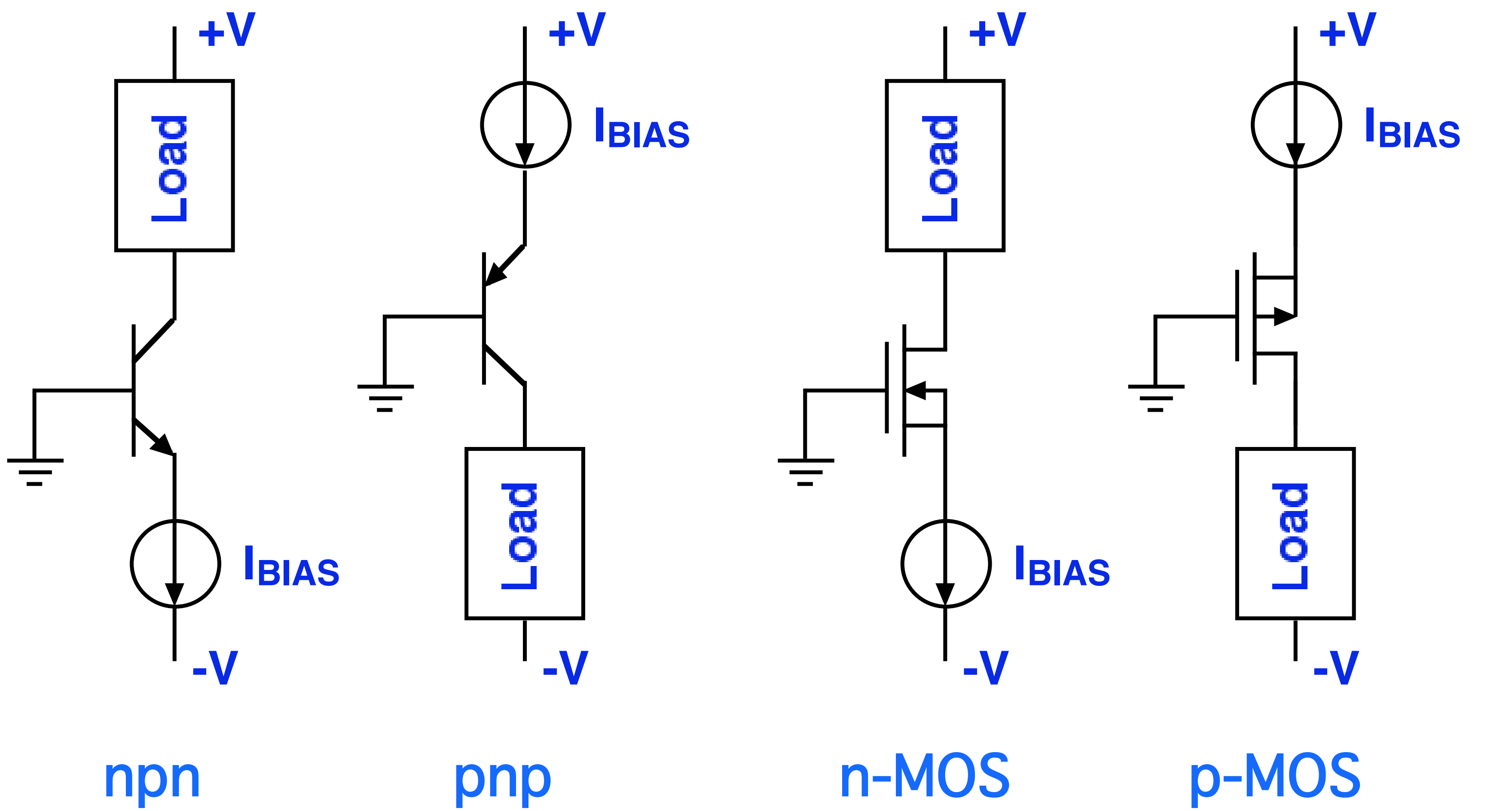
MOSFET:



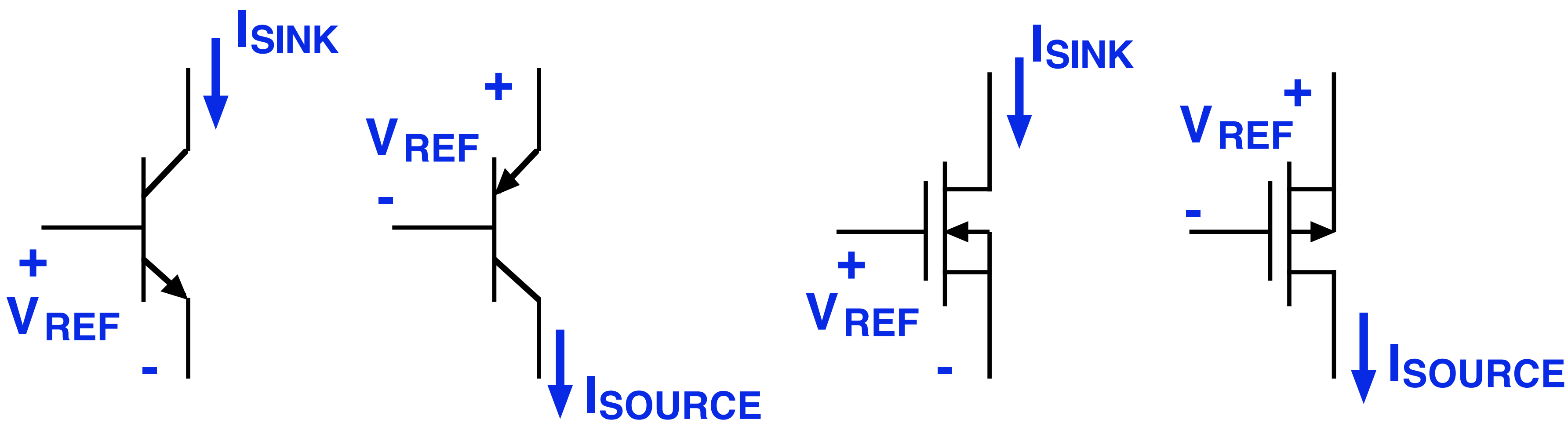


$g_m = di_D/dv_{GS}|_Q$; $g_{mb} = \square g_m$ with $\square = -dV_T/dv_{BS}|_Q$; $g_o = di_D/dv_{DS}|_Q$

- **BJTs and MOSFETs biased for linear amplifier applications**



- **Getting I_{BIAS}: Making a transistor into a current source/sink***

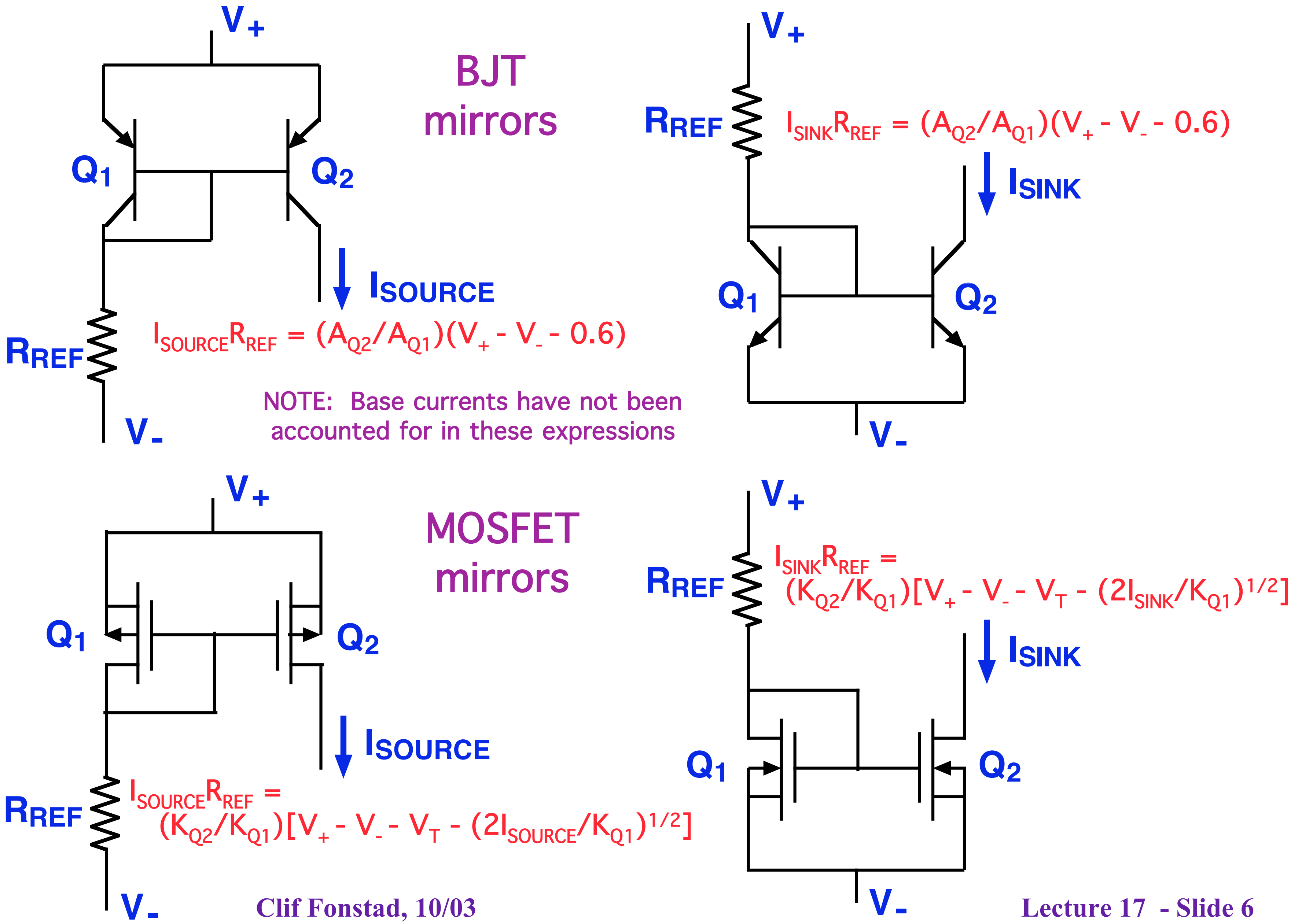


npn pnp n-MOS p-MOS

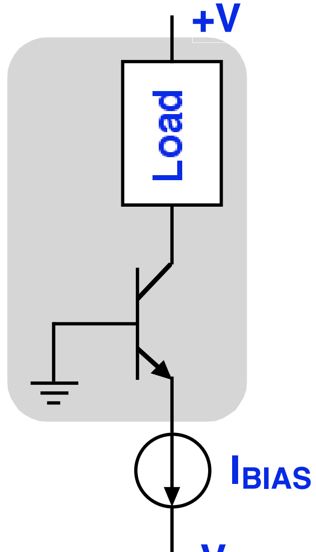
BJT current sources/sinks	MOSFET current sources/sinks
Must maintain $V_{CE} > 0.2V$ [V_{EC} in case of pnp]	Must maintain $V_{DS} > (V_{REF} - V_T)$ [$V_{SD} > (V_{REF} + V_T)$ in case of p-MOS]
$I_{SOURCE/SINK} = [\beta_F/(\beta_F+1)]\, I_{ES}(e^{qV_{REF}/kT}-1) \approx I_{ES}e^{qV_{REF}/kT}$	$I_{SOURCE/SINK} = K(V_{REF} - \lvert V_T \rvert)^2/2$

* Some people make a distinction between a "sink" and a "source"; you can call them all "sources" if you wish.

- # Current mirror sources and sinks

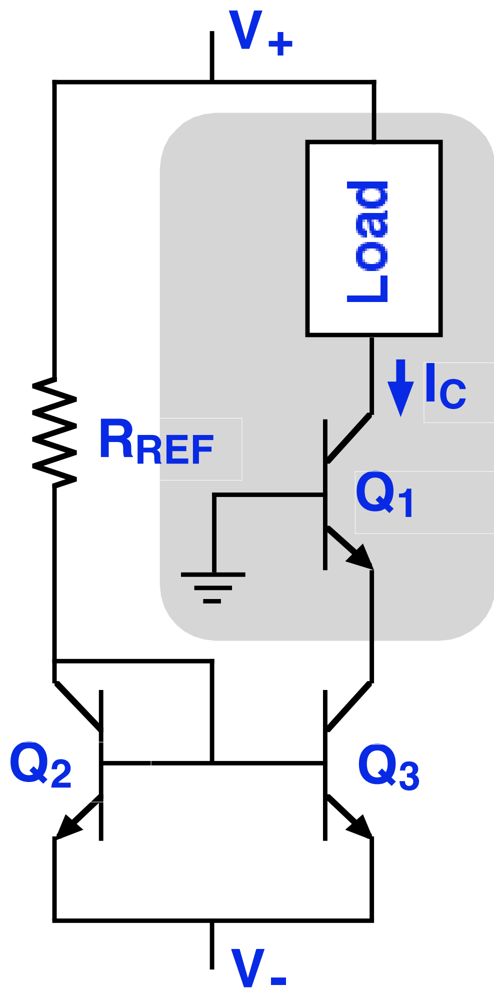


- **Examples of current mirror biased BJT circuits:**



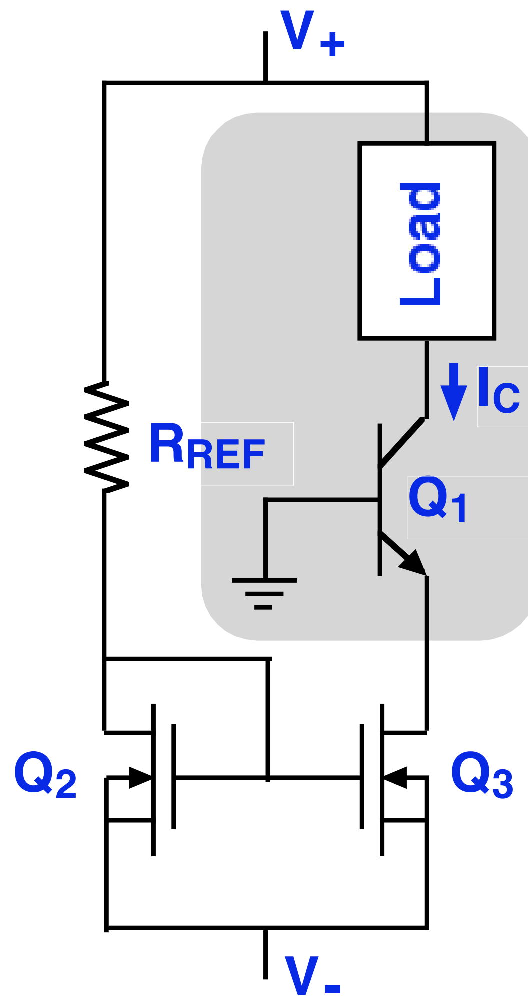
Above: Concept

Right: Implementations



BJT Mirror

$I_C \approx (A_{Q3}/A_{Q2})\ I_{REF}$



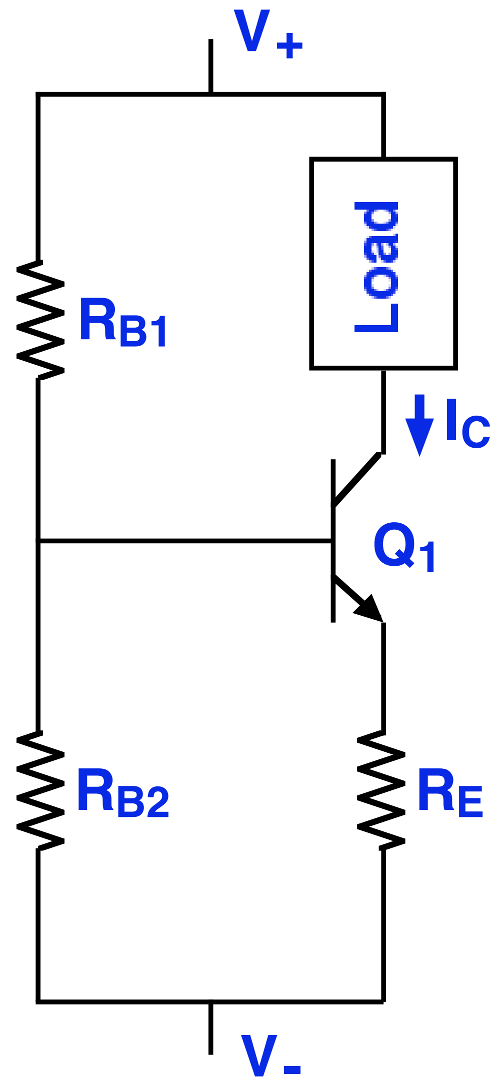
MOSFET Mirror

$I_C \approx (K_{Q3}/K_{Q2})\ I_{REF}$

- **Resistor biasing:** **An older biasing techniques used in discrete circuits where transistors are expensive.**

Resistor biasing

$I_C \approx [(V_+ - V_-)R_{B2}/(R_{B1}+R_{B2}) - 0.6]/R_E$



You might call this "poor man's current source biasing" because it uses three resistors and only one transistor. The resistor, R_E, with a constant voltage,

$$(V_+ - V_-)R_{B2}/(R_{B1}+R_{B2}) - 0.6V,$$

across it looks like a current source of magnitude:

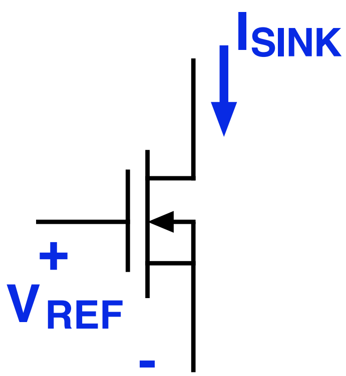
$$[(V_+ - V_-)R_{B2}/(R_{B1}+R_{B2}) - 0.6V]/R_E.$$

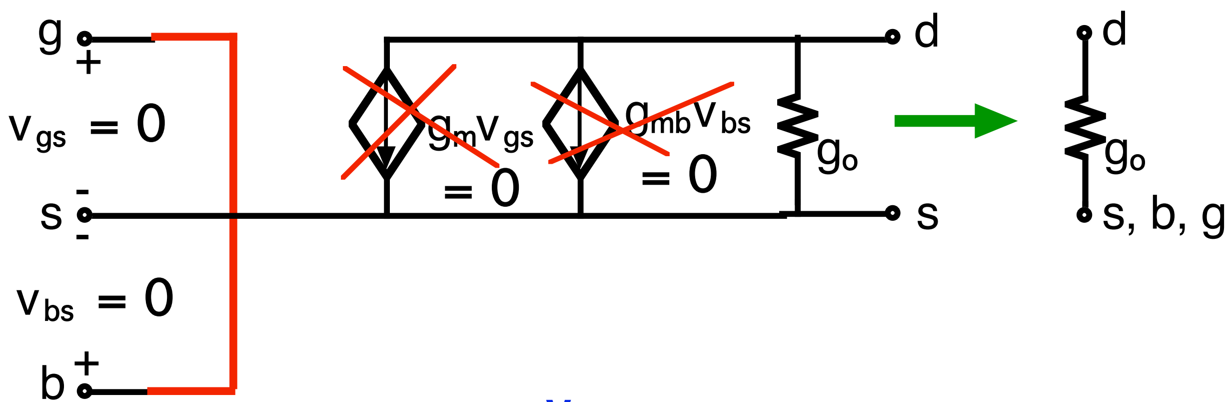
- **Final comments on current sources:**

What do they look like incrementally?

They look like a resistor with conductance g_o

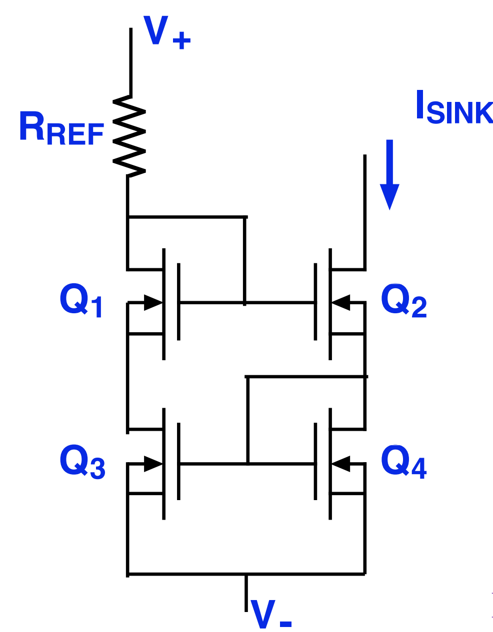
For example, consider an n-MOS sink:





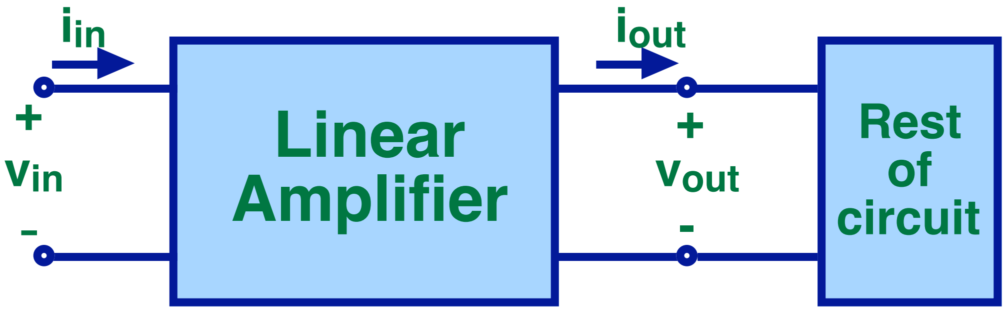
How do you do better?
The Wilson connection:

check it out for yourself

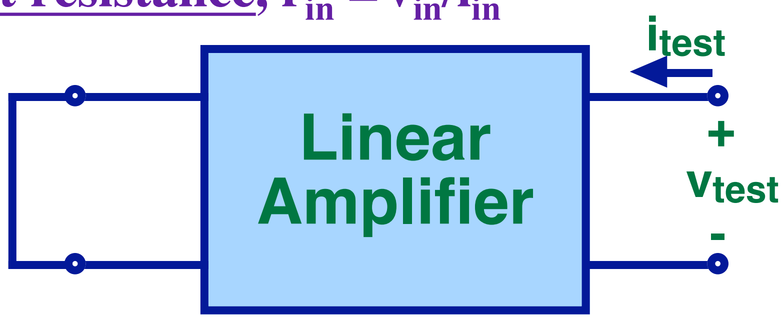


- Linear amplifier performance metrics:

The characteristics of linear amplifiers that we use to compare different amplifier designs, and to judge their performance and suitability for a given application are given below:



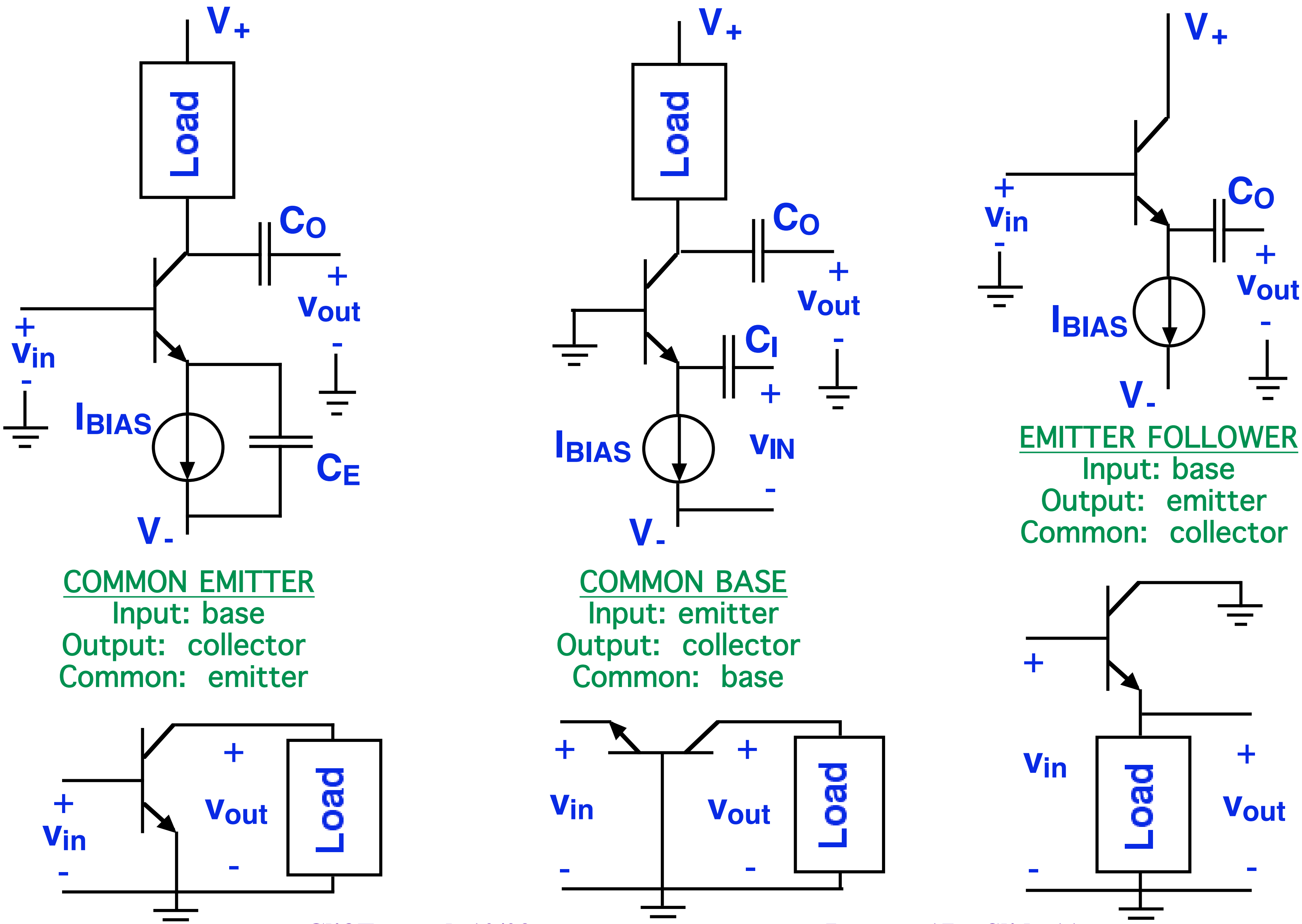
<u>Voltage gain</u>, $A_v = v_{out}/v_{in}$
<u>Current gain</u>, $A_i = i_{out}/i_{in}$
<u>Power gain</u>, $A_{power} = P_{out}/P_{in} = v_{out}i_{out}/v_{in}i_{in} = A_vA_i$
<u>Input resistance</u>, $r_{in} = v_{in}/i_{in}$



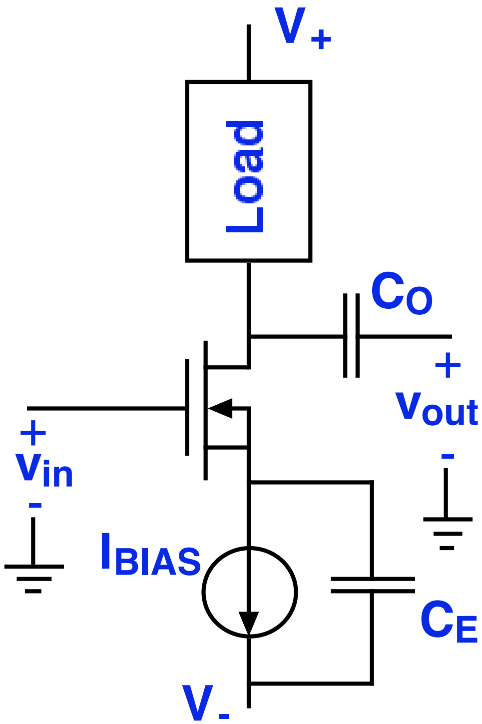
<u>Output resistance</u>, $r_{out} = v_{test}/i_{test}$ with $v_{in} = 0$

<u>DC Power dissipation</u>, $P_{DC} = (V_+ - V_-)(\Sigma I_{BIAS}$'s)

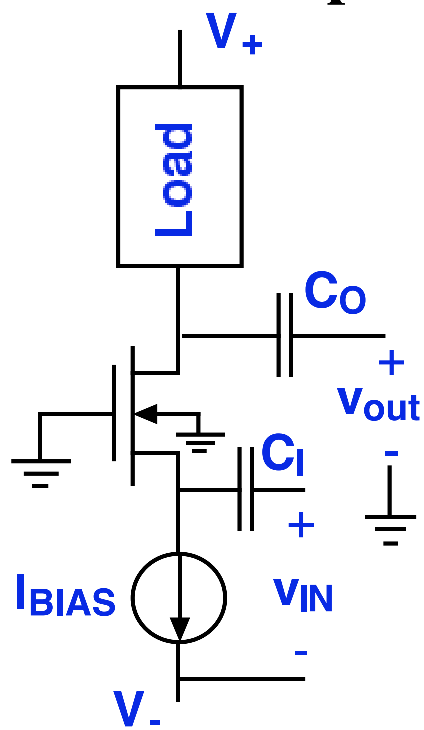
- **Three BJT single-transistor amplifiers**



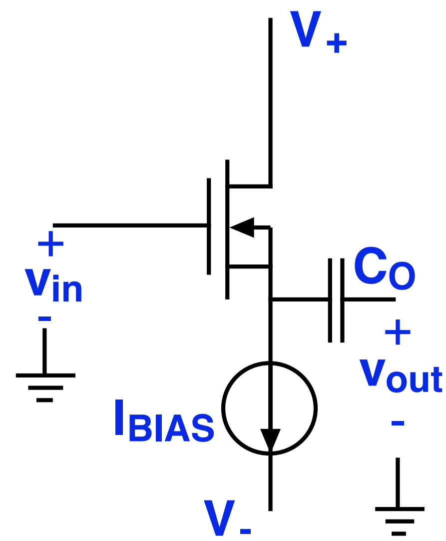
- **Three MOSFET single-transistor amplifiers**



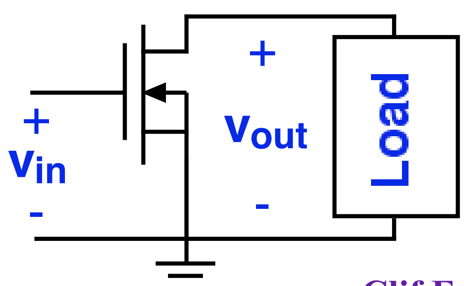
COMMON SOURCE
Input: gate
Output: drain
Common: source
Substrate: to source

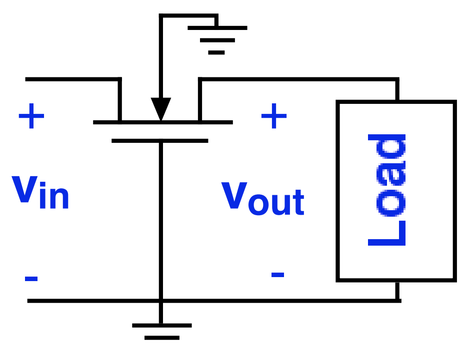


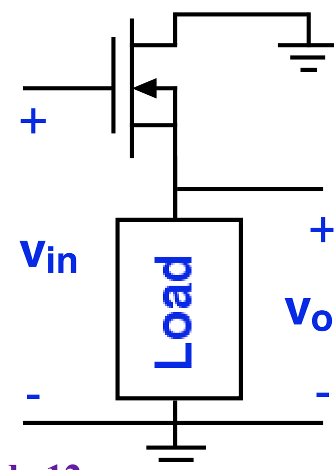
COMMON GATE
Input: source; Output: drain
Common: gate; Substrate: to ground



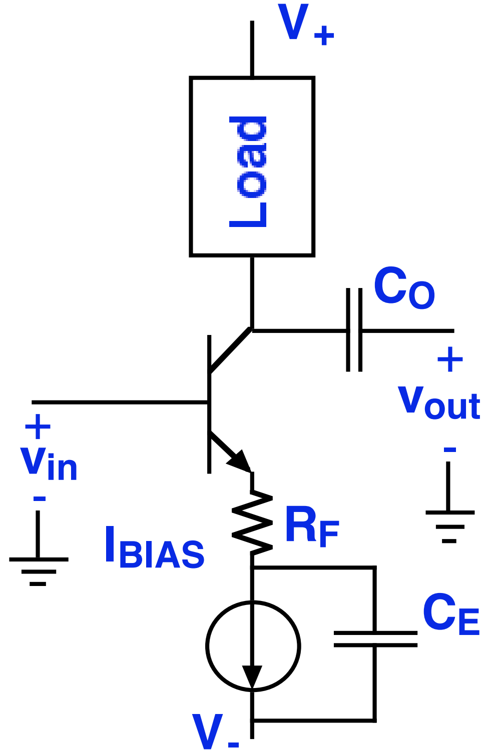
SOURCE FOLLOWER
Input: gate
Output: source
Common: drain
Substrate: to source

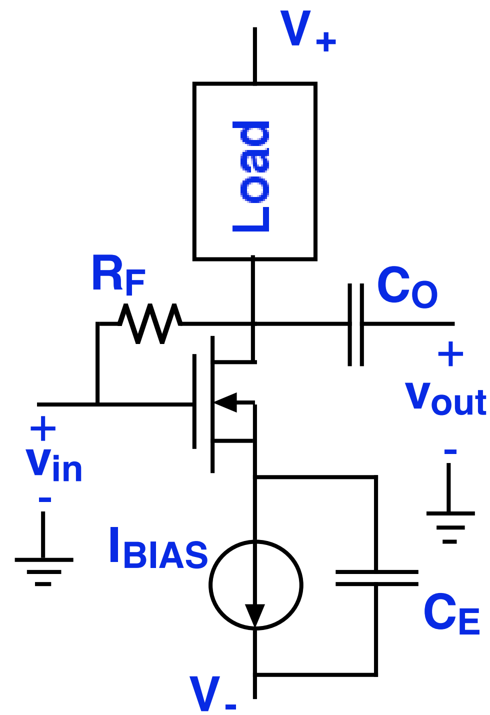






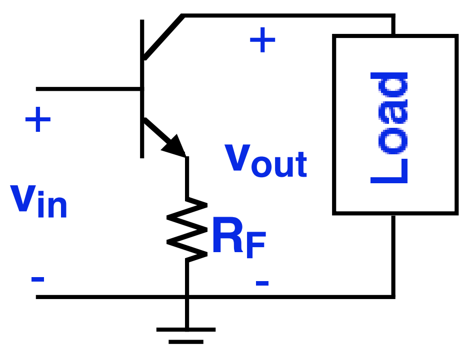
- **Single-transistor amplifiers with feedback**

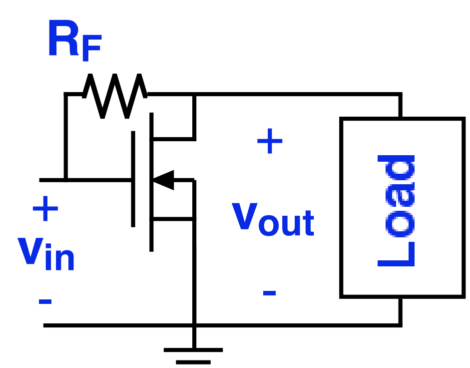




Parallel feedback
also termed "emitter degeneration"

Series feedback





Lecture 17 - Linear Amplifier Basics - Summary

- **Biasing transistors**

  Current source biasing: a current source is used to establish a stable bias pt.
  large signals models are used in this analysis

  Transistors as current sources: great as long as in saturation or FAR

  Current mirror current sources and sinks: it takes one to know one

- **Linear amplifiers**

  Performance metrics: gains (voltage, current, power)

  $A_v = v_{out}/v_{in}$, $A_i = i_{out}/i_{in}$, $A_{power} = v_{out}i_{out}/v_{in}i_{in}$

  input and output resistances

  $r_{in} = v_{in}/i_{in}$, $r_{out} = v_{test}/i_{test}$ with $v_{in} = 0$

  dc power dissipation: $(V_+ - V_-)(\Sigma I_{BIAS}\text{'s})$

  bandwidth (We'll save this for later - Lec. 22)

  Possible amplifier connections of transistors:

  Simple stages: Common emitter, common source
  Common base, common gate
  Emitter follower, Source follower

  Stages with feedback: Parallel (Degeneracy in emitter/source)
  Series