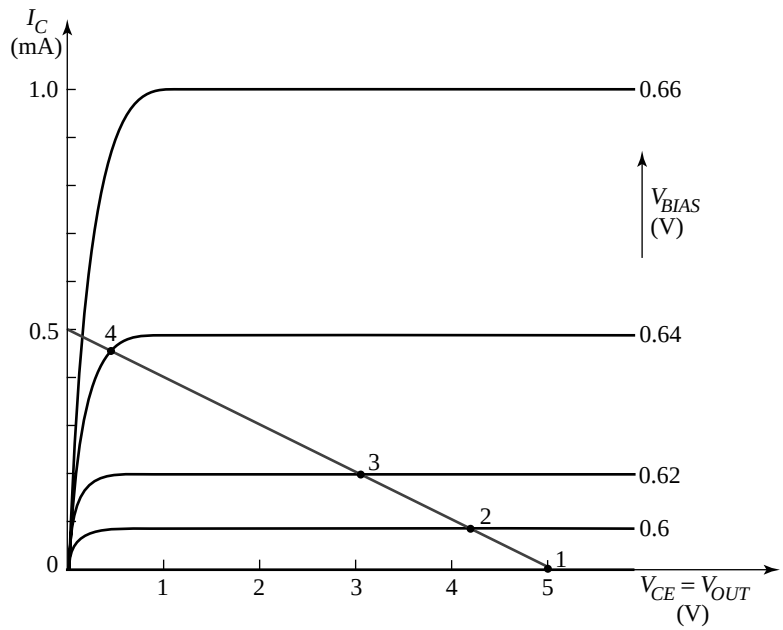
Biasing the CE Amplifier

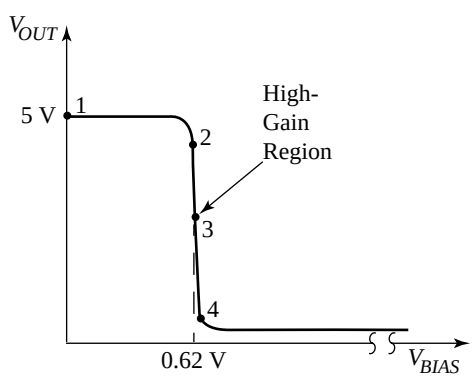
- Graphical approach: plot I_C as a function of the DC base-emitter voltage V_{BIAS} (note: normally plot vs. base current, so we must return to Ebers-Moll):

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

Load line for R_C = 10 kΩ; 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 V and that the collector resistor R_C = 10 kΩ, 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 V + 0.2 V)/2 = 2.5 V (approx.)

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

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

Small-Signal Model of CE Amplifier

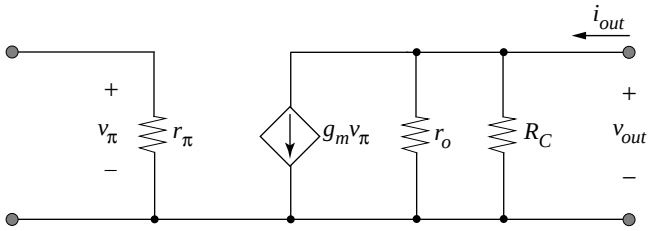
- The small-signal model is evaluated at ***Q***; we assume that the current gain is $\beta_o = 100$ and the Early voltage is $V_{An} = 25$ V:

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

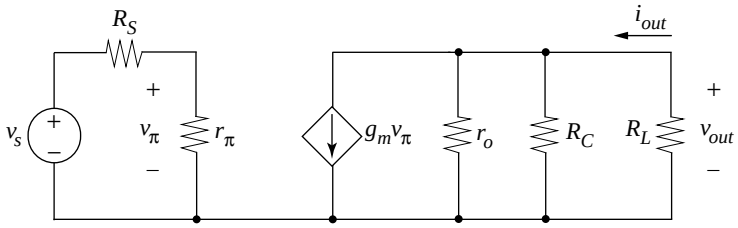
$$r_\pi = \beta_o / g_m = 10 \text{ k}\Omega$$

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

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



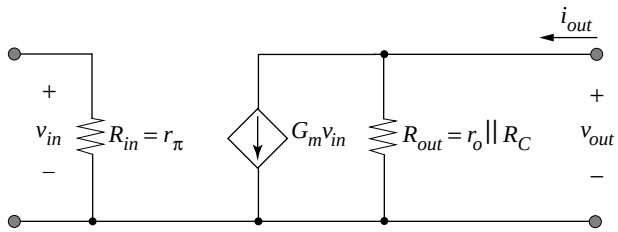
(a)



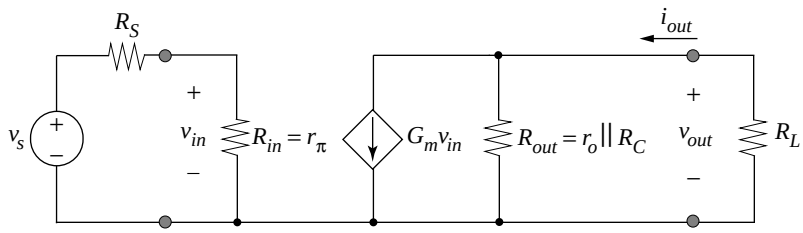
(b)

Two-Port Model: CE Amplifier

- Use transconductance amplifier form for model (*not* mandatory)
- $R_{in} = r_\pi$, $R_{out} = r_o \parallel R_C$, $G_m = g_m$ by inspection



(a)



(b)

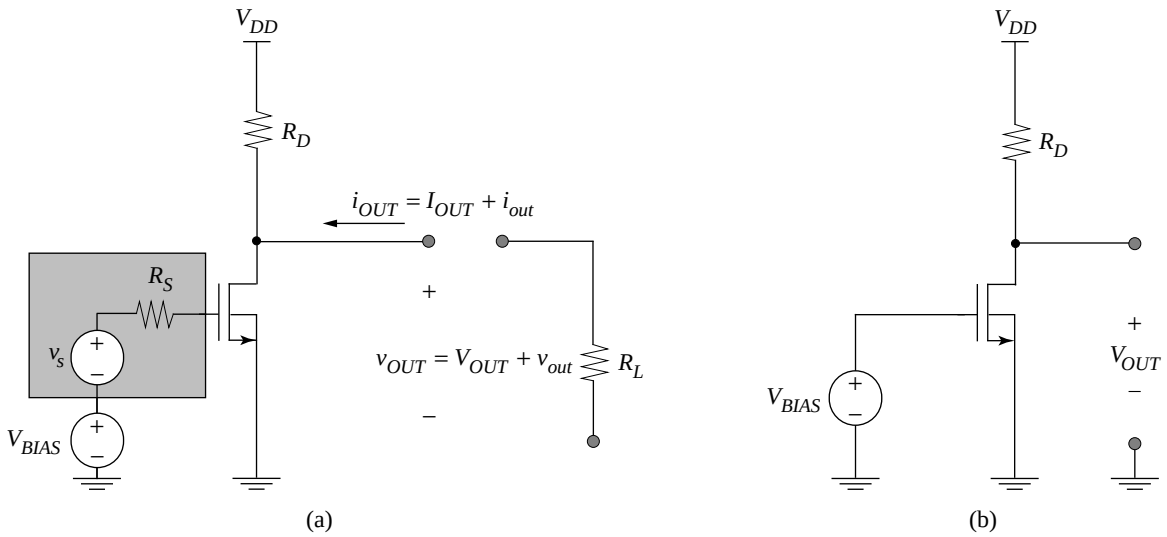
- Loaded ratio of i_{out} to v_{in}

$$G_m\left(\frac{R_{out}}{R_{out} + R_L}\right) = g_m\left(\frac{r_o \| R_C}{r_o \| R_C + R_L}\right)$$

Increasing R_C seems desirable for increasing i_{out} / v_{in} ... but note that the DC collector current decreases for a fixed V_{CC} --> g_m decreases

Common-Source Amplifier

- Configuration is similar to common-emitter

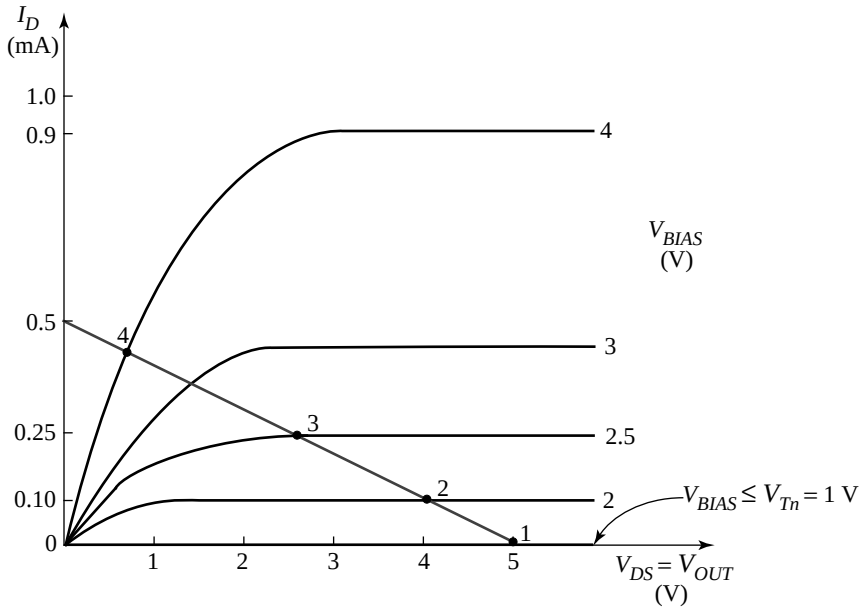


- Bias: remove source and load resistances (b)

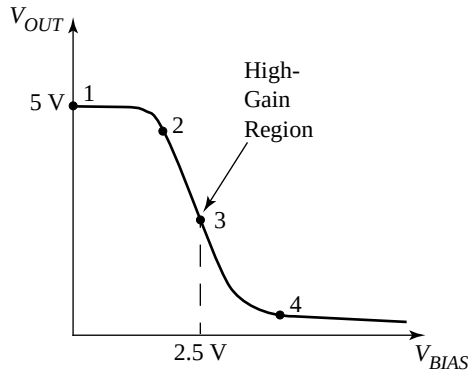
Graphical Load-Line Analysis

- Load line is given by:

$$I_D = (V_{DD} - V_{OUT})/R_D$$



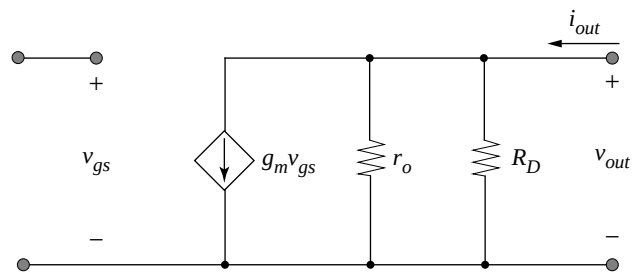
(a)



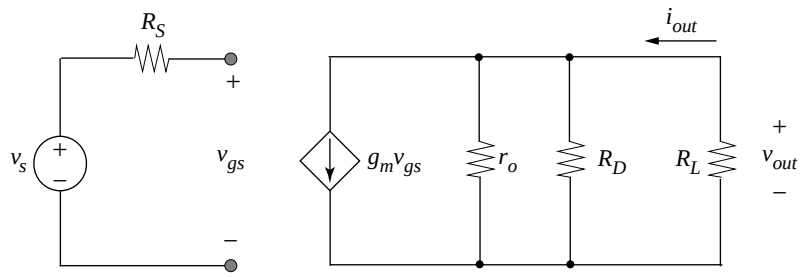
(b)

Small-Signal Model of CS Amplifier

- Substitute parameters at operating point selected so that $V_{OUT} \approx V_{DD}/2$



(a)



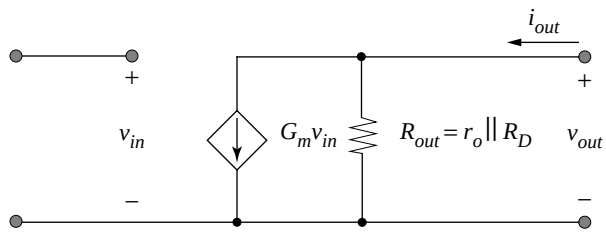
(b)

Transconductance is proportional to $I_D^{1/2}$ unlike bipolar transistor

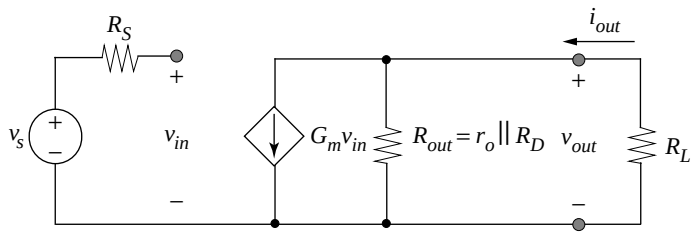
Two-Port Model of Common-Source Amplifier

- Use transconductance amplifier form for model (most natural choice)

  R_{in} = infinty, $R_{out} = r_o \parallel R_D$, $G_m = g_m$ by inspection



(a)



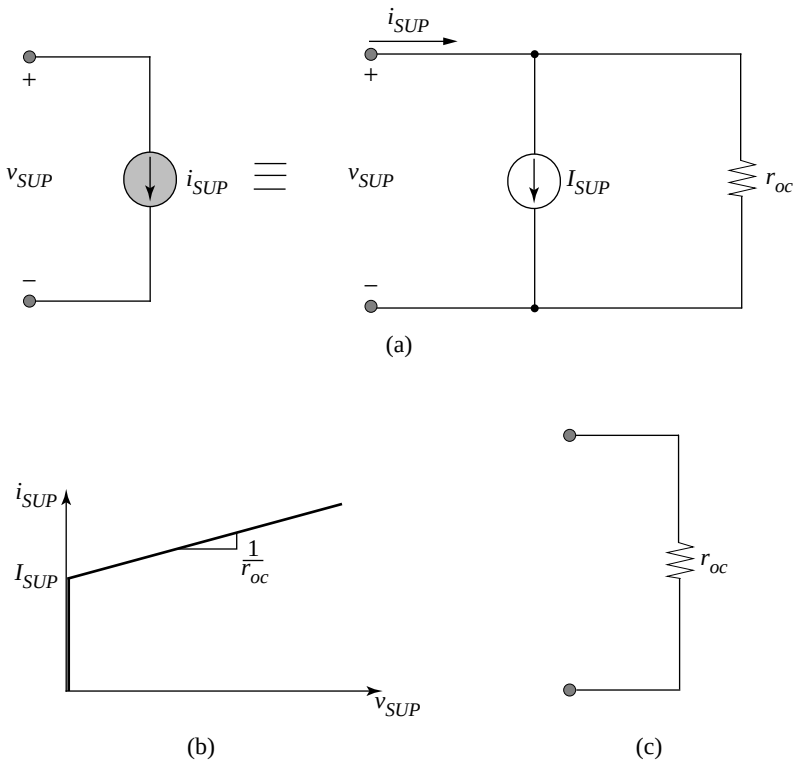
(b)

Infinite input resistance is ideal for a voltage input

Output resistance increases with R_D increasing, but DC drain current I_D will decrease and g_m will decrease with $I_D^{1/2}$

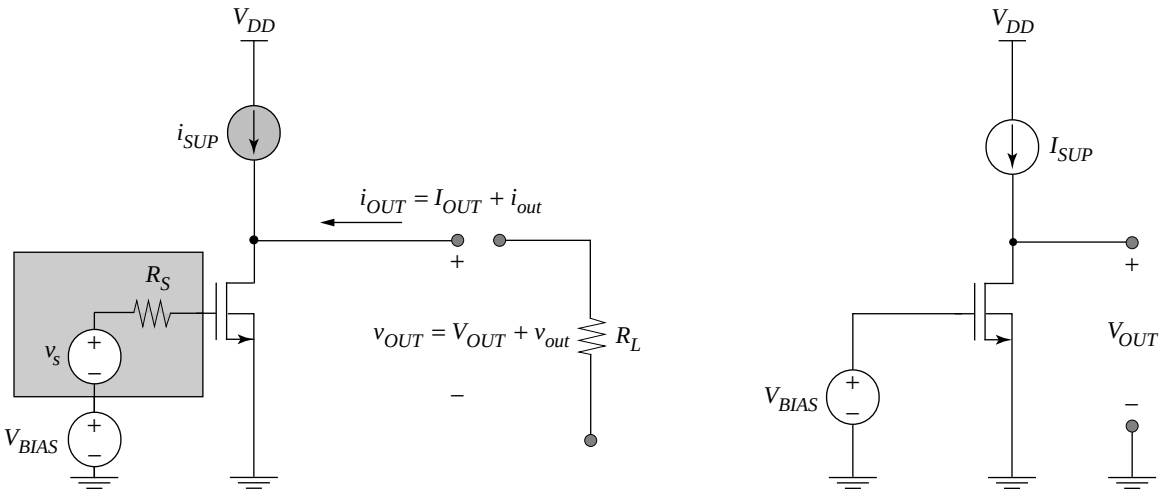
Current-Source Supplies

- A current source to supply current, rather than a resistor, allows a high DC current for the device with a large incremental (small-signal) resistance



Common-Source with Current Source Supply

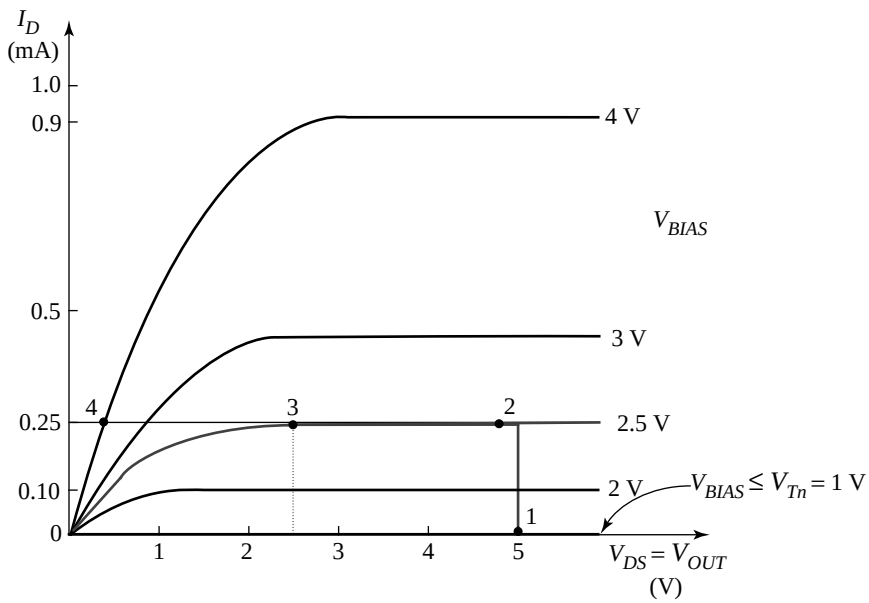
- R_D is replaced with idealized current source with internal resistance



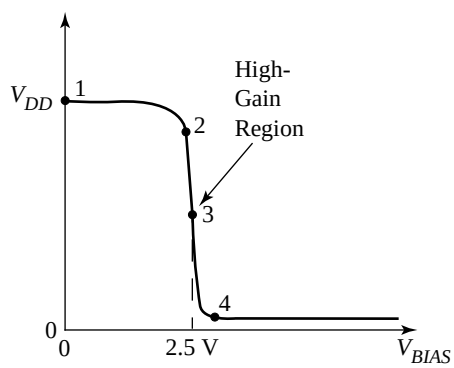
(a) (b)

- For DC bias analysis, the small-signal source (with R_S) and the load resistor R_L are eliminated, along with the internal resistance r_{oc} of the current source

Graphical Analysis of CS Amplifier with Current-Source Supply



(a)

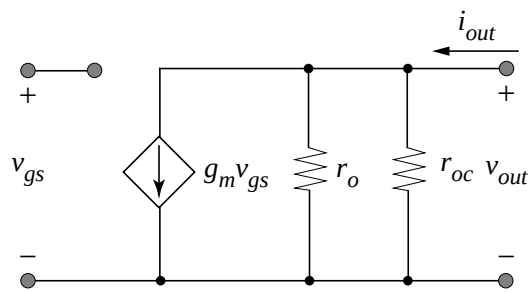


(b)

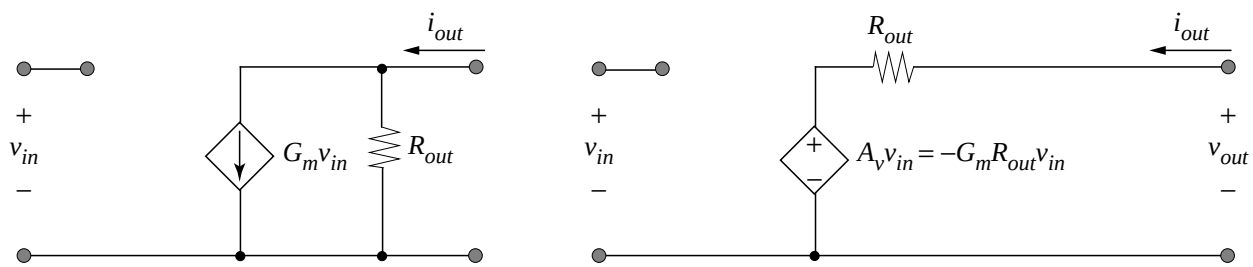
- The region of input bias voltage V_{BIAS} for which the current source and the MOSFET are in their constant-current regions is *extremely* small ....

Common-Source/Current-Source Supply Models

- The small-signal model is identical to the resistor supply, except that the current source's internal resistance r_{oc} replaces R_D



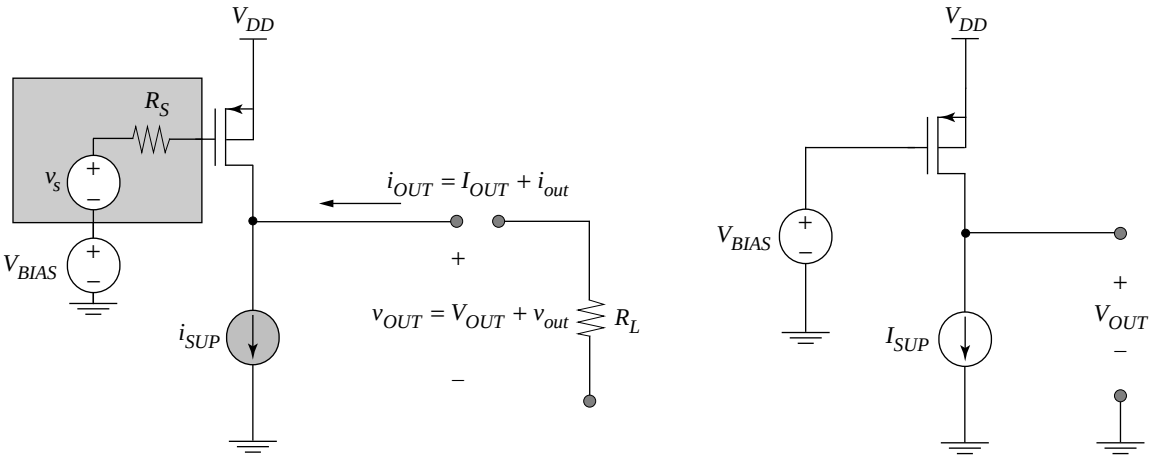
- Two-port model in both transconductance and voltage amplifier forms (the latter by direct conversion from the former ... by applying procedure for finding A_v)



(a) (b)

p-Channel Common-Source Amplifier

- Source of p-channel is tied to positive supply; current supply sinks I_{SUP} to ground or to lower supply

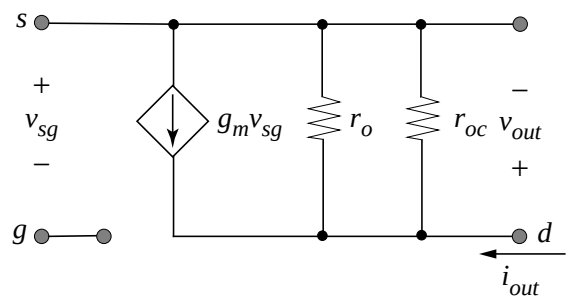


(a) (b)

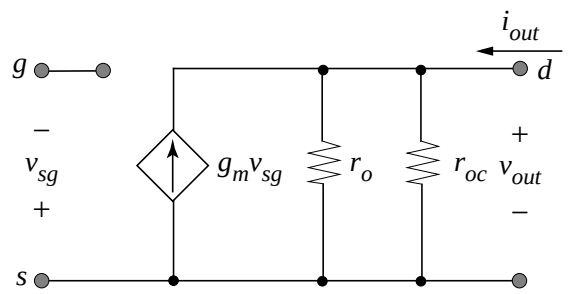
- Small-signal model: substitute p-channel model directly

p-Channel CS Small-Signal Model

- Source is at top, but circuit can be inverted to show correspondence with n-channel common-source amplifier



(a)



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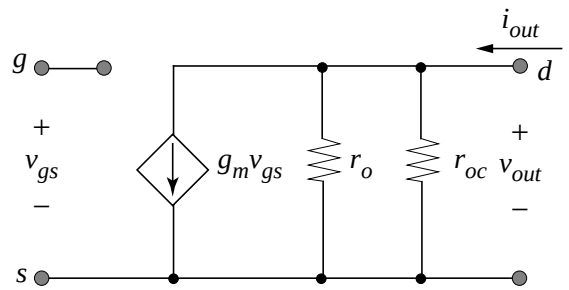


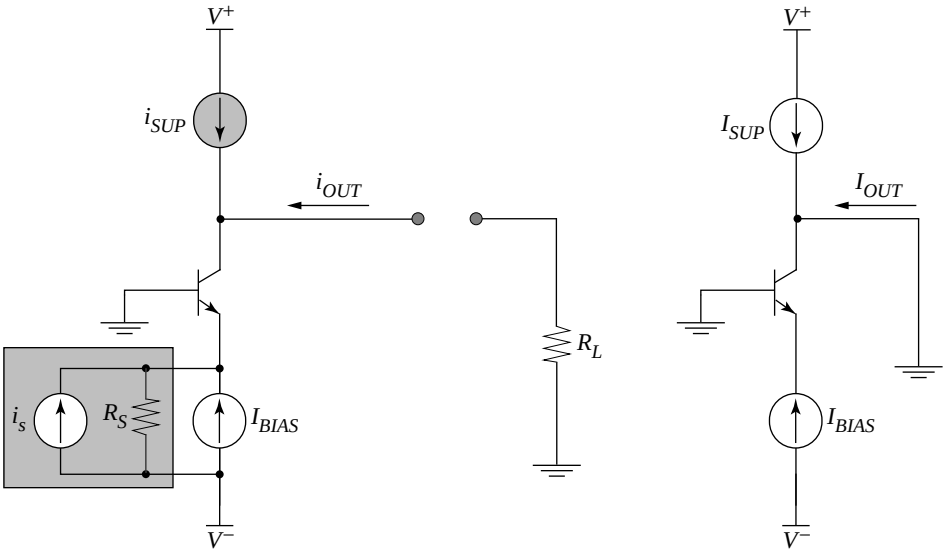
(c)

Common Base / Common Gate Amplifiers

- Input signal is applied to the emitter, output is taken from the collector
- Summary:

  current gain is about unity, input resistance is low, output resistance is high

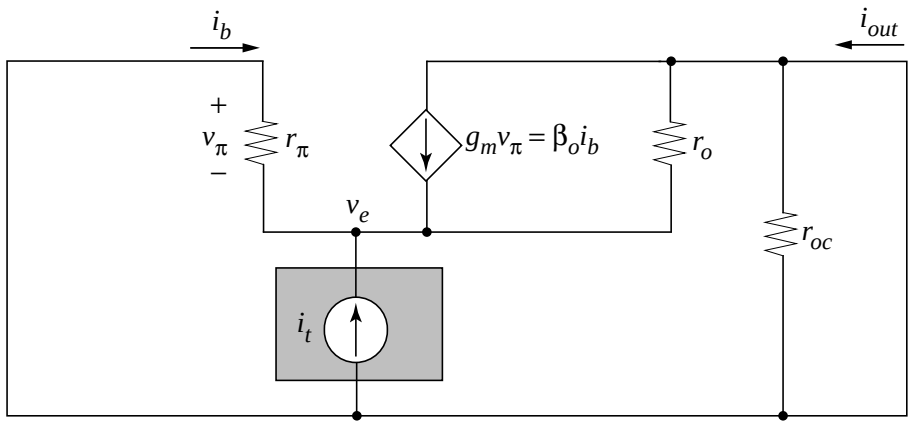
  a CB stage is a good current “buffer” ... it takes a current at the input that may have a relatively small Norton resistance and replicates it at the output port, which is a good current source due to the high output resistance.



Biasing is very easy ... $I_{BIAS} = - I_{SUP}$, with a small correction factor due to the fact that β_F isn’t infinity

Common-Base Current Gain A_i

- Small-signal circuit, with output shorted (according to the procedure)



Analysis: $i_{out} = i_c \approx \beta_o i_b$ and $i_c = -i_e - i_b = -i_t - i_b = -i_t - \dfrac{i_{out}}{\beta_o}$

Solving for the short-circuit current gain:

$$\boxed{A_i = \frac{i_{out}}{i_t} = \frac{-\beta_o}{1+\beta_o} \cong -1}$$