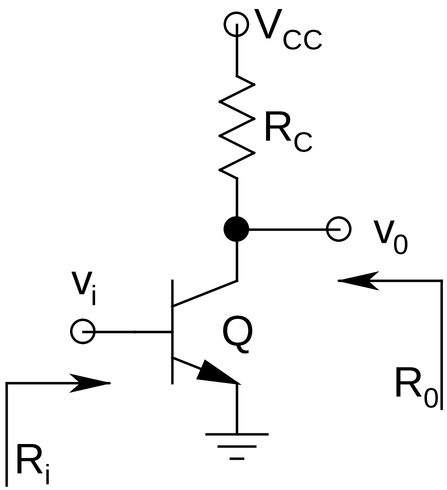
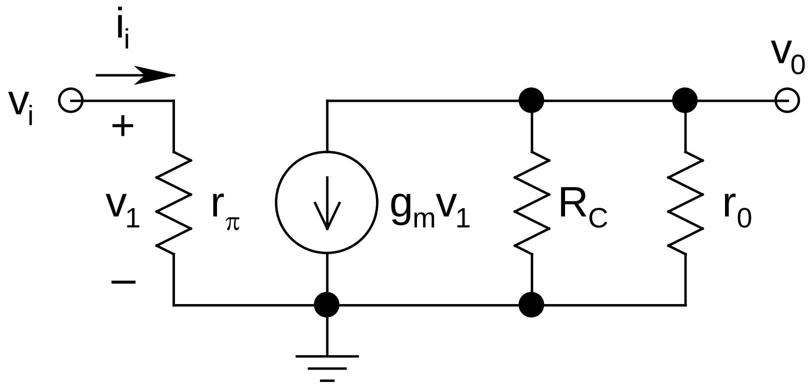
Single-Stage Amplifiers

- ***Common-Emitter*** (CE):



ac Schematic



ac Low-Frequency Equivalent

➢ ***Biasing circuit not shown***

- By inspection, ***Voltage Gain***:

$$A_v = \frac{v_0}{v_i} = \frac{-g_m v_1 \left(R_C \parallel r_0\right)}{v_i} = -g_m \left(R_C \parallel r_0\right)$$

- The ***negative sign*** in front implies ***180° phase shift*** between v_i and v_0
  - ***v_i and v_0 are exactly out of phase***
- For ***discrete circuits***, in general, $R_C << r_0$

  $\Rightarrow A_V = -\, g_m R_C \approx -\, R_C/r_E$ (***moderate to large***)
- On the other hand, if $r_0 << R_C$:

  $A_V = -\, g_m r_0 = 1/\eta = V_A/V_T$ (***can be huge***!)
  - ***Theoretical maximum voltage gain of this circuit***

- ***Current Gain***:

  $A_i = i_c/i_b = \beta$ (***large***)

- Thus, ***Power Gain***:

  $PG = A_v \times A_i$ (***very large***)

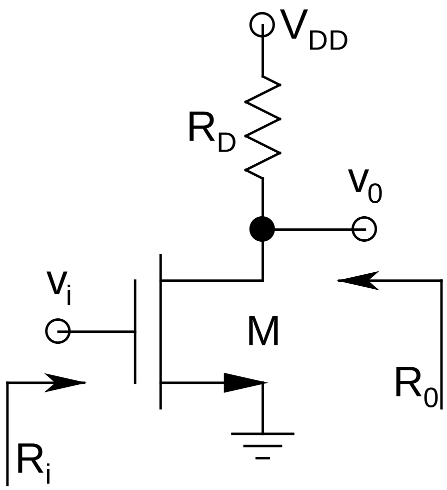
- Therefore, this circuit is ***designers' favorite***!
- Has primary use as ***audio amplifiers***
- ***Input Resistance***:

  $R_i = v_i/i_i = r_\pi$ (***decent***)

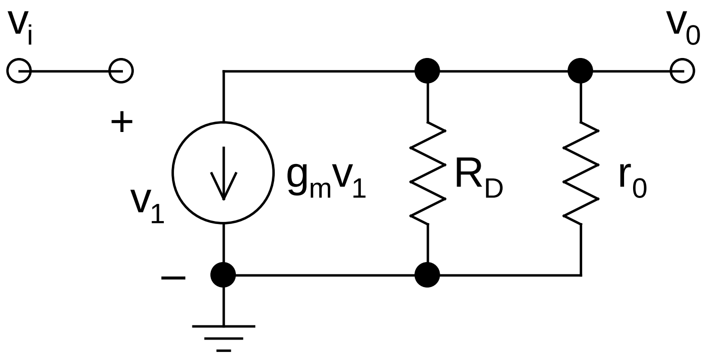
- ***Output Resistance***:

  $R_0 = R_C \| r_0$

- ***Common-Source*** (CS):



ac Schematic



ac Low-Frequency Equivalent

- ***Biasing circuit not shown***
- ***Body at ground*** $\Rightarrow$ ***No body effect***

- By inspection, ***Voltage Gain***:

$$A_v = \frac{v_0}{v_i} = \frac{-g_m v_1 \left(R_D \,||\, r_0\right)}{v_i} = -g_m \left(R_D \,||\, r_0\right)$$

- The ***negative sign*** in front implies ***180° phase shift*** between v_i and v_0
  - ***v_i and v_0 are exactly out of phase***
- For ***discrete circuits***, in general, $R_D << r_0$

  $\Rightarrow A_v = -\, g_m R_D$ (***moderate***)
- ***Input Resistance***: $R_i \rightarrow \infty$
- ***Output Resistance***: $R_0 = R_D || r_0$
- ***Note the remarkable similarity with CE stage***

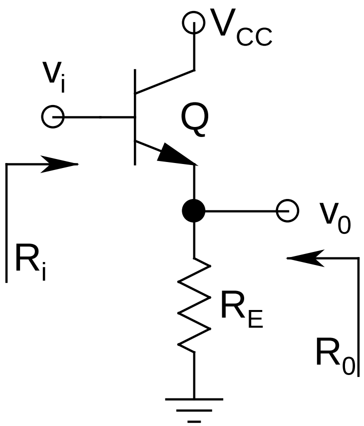
- If $R_D >> r_0$:

  $A_v = -\, g_m r_0 = -\, k_N V_{GT}/(\lambda I_D) = -\, 2/[\lambda(\Delta V)]$

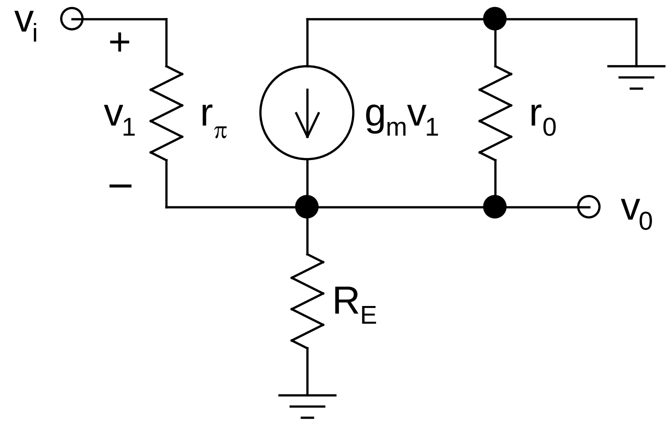
  (***assuming*** $\boldsymbol{\lambda V_{DS} < 0.1}$)
- Thus, ***for small*** $\boldsymbol{\lambda}$ ***and small*** $\boldsymbol{\Delta V}$, $\boldsymbol{A_v}$ ***can be large***
  - Keep in mind that $\boldsymbol{\Delta V(min) = 3V_T}$
- Also, $A_v \propto 1/\sqrt{I_D}$

  $\Rightarrow$ ***Lower*** $\boldsymbol{I_D}$, ***higher*** $\boldsymbol{A_v}$
- ***Recall***: For ***CE stage***, A_v(max) was ***independent of*** $\boldsymbol{I_C}$, and ***dependent only on T***

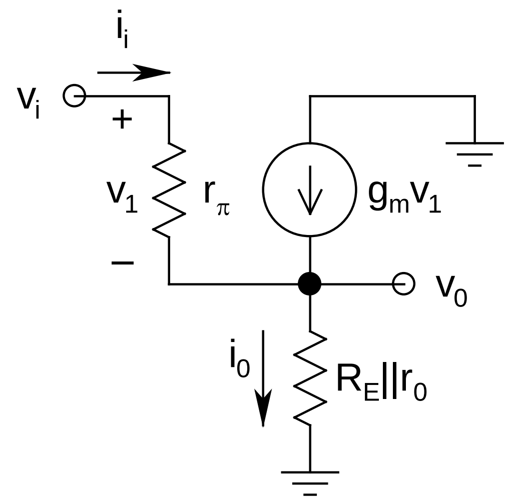
- ***Common-Collector*** (CC):
  - Also known as ***Emitter-Follower***



ac Schematic



ac Low-Frequency Equivalent



Simplified ac Low-Frequency Equivalent

- ***Biasing circuit not shown***

- ***Voltage Gain***:

$$A_v = \frac{v_0}{v_i} = \frac{i_0\left(R_E \,||\, r_0\right)}{v_1 + v_0} = \frac{\left(\beta+1\right)i_i\left(R_E \,||\, r_0\right)}{i_i r_\pi + \left(\beta+1\right)i_i\left(R_E \,||\, r_0\right)}$$

$$= \frac{\left(R_E \,||\, r_0\right)}{r_\pi/\left(\beta+1\right)+\left(R_E \,||\, r_0\right)} = \frac{\left(R_E \,||\, r_0\right)}{r_E + \left(R_E \,||\, r_0\right)}$$

- Now, in general, $r_0 >> R_E$

  $\Rightarrow A_v = R_E/(r_E + R_E)$

- ***Two important observations***:
  - ***$A_v \le 1$***
  - ***No phase shift between v_i and v_0***

- ***Current Gain***:

  $A_i = i_e/i_b = \beta + 1$ (***large***)

- ***Input Resistance***:

$$R_i = \frac{v_i}{i_i} = \frac{i_i r_\pi + i_0 \left(R_E \parallel r_0\right)}{i_i}$$

$$= \frac{i_i r_\pi + \left(\beta + 1\right) i_i \left(R_E \parallel r_0\right)}{i_i}$$

$$= r_\pi + \left(\beta + 1\right)\left(R_E \parallel r_0\right)$$

  - If $r_0 >> R_E$, $R_i = r_\pi + (\beta + 1)R_E$

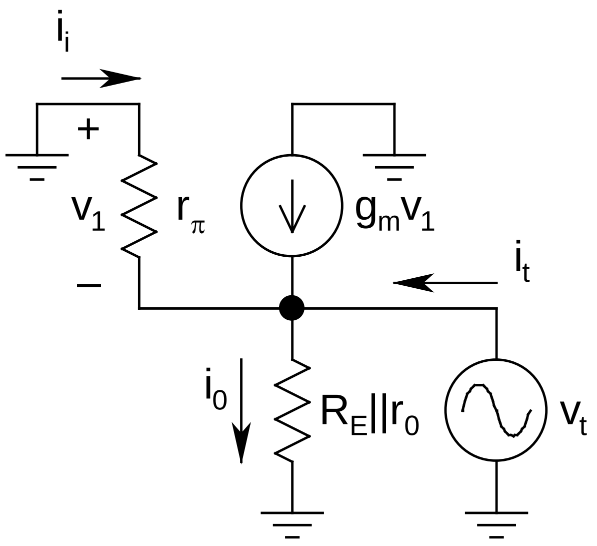
- Note that this result could have been written from ***inspection*** from the ***ac schematic*** using the technique of ***Resistance Transformation***

➢ ***Output Resistance***:

$$i_t = i_0 - g_m v_1 - i_i$$

$$= \frac{v_t}{R_E \parallel r_0} + g_m v_t + \frac{v_t}{r_\pi}$$

$$\Rightarrow \quad R_0 = R_E \| r_0 \| r_E \| r_\pi \approx r_E$$

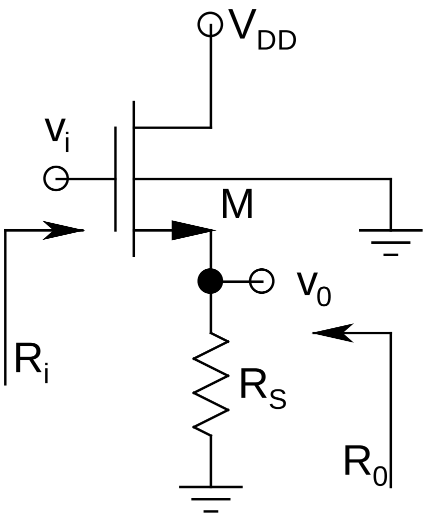


- Note that this expression also could have been written by ***inspection***

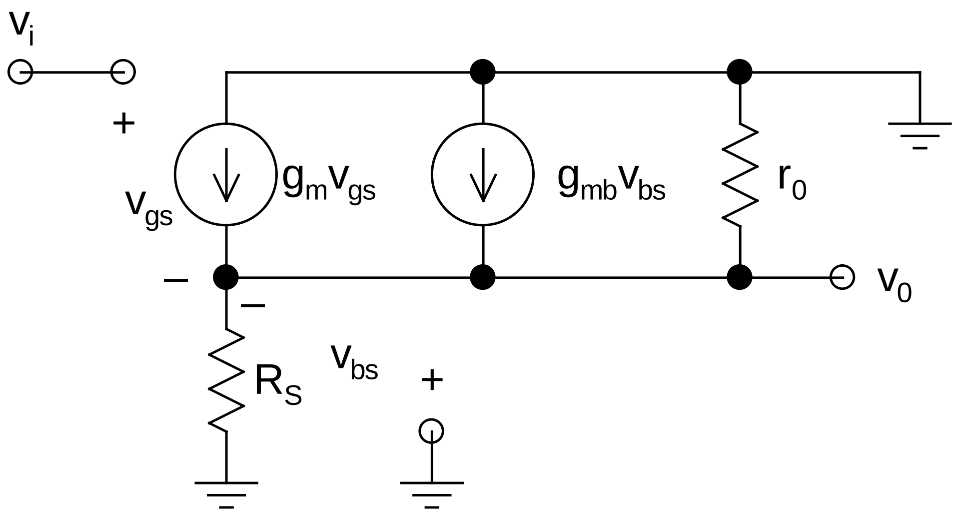
- ***Output excited by a test voltage source v_t:***
  - ***The current has two parallel paths***: ***one going through the parallel combination of r_0 and R_E***, and ***the other into the emitter of Q***
  - The ***resistance in the base lead of Q is r_π***, which ***needs to be transformed to emitter by dividing it by (β+1)*** $\Rightarrow$ ***yields r_E***
  - Thus, ***R_0 becomes a parallel combination of r_0, R_E, and r_E***, which will be ***typically equal to r_E***, since, in general, ***it's the least among the three***
- ***Understand the inspection technique, it will become immensely useful to analyze circuits***

- ***Some special properties of this circuit***:
  - $A_v \leq 1$ (***by proper design, it can be made to approach unity very closely***)
  - ***Input and output in phase***
  - ***Quite large input resistance***
  - ***Very small output resistance***
- These properties are ***highly desirable*** to prevent ***loading effect*** of ***cascaded stages*** (to be discussed later)
- Thus, this stage is also known as ***Buffer*** or ***Isolator*** or ***Impedance Matcher***

- ***Common-Drain*** (CD):
  - Also known as ***Source Follower***



ac Schematic



ac Low-Frequency Equivalent

- ***Biasing circuit not shown***

- ***Note***: ***Body terminal at ground***, but ***source is at a floating potential*** (***it's the output terminal***)

  $\Rightarrow$ ***Body effect will be very much present for M***

  $\Rightarrow$ ***Can be avoided by putting M in its separate island*** (to be discussed later)

- ***Voltage Gain***:
  - ***KCL at output node***:

$$g_m v_{gs} + g_{mb} v_{bs} = v_0/(R_S || r_0)$$

with $v_{gs} = v_i - v_0$, and $v_{bs} = -v_0$

$$\Rightarrow A_v = \frac{v_0}{v_i} = \frac{g_m\left(R_S \,||\, r_0\right)}{1+\left(g_m + g_{mb}\right)\left(R_S \,||\, r_0\right)}$$