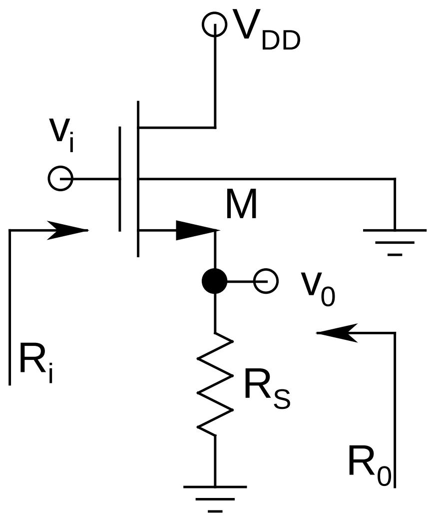
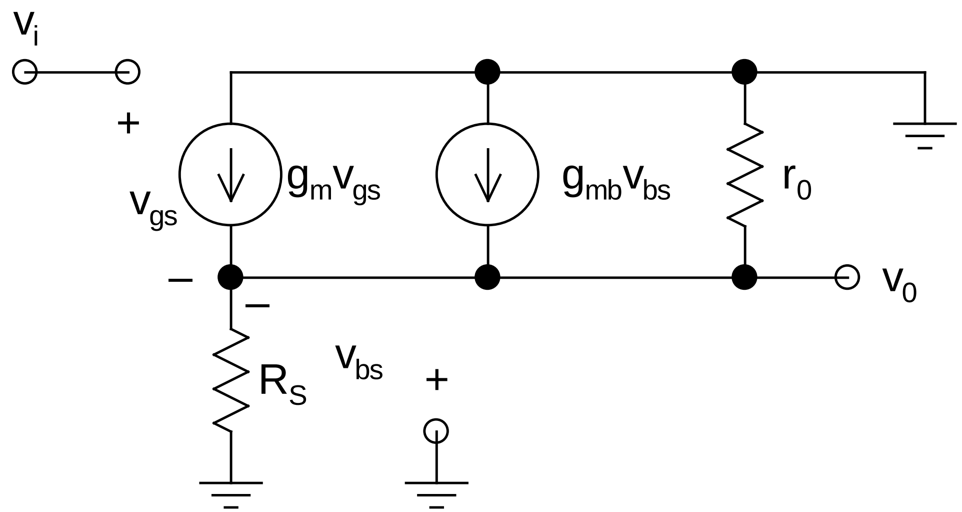
- ***Common-Drain*** (CD):
  - Also known as ***Source Follower***



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 $v_{bs} = -v_0$

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

- ***Simplification***:
  - In general, $r_0 >> R_S$:

$$\Rightarrow A_v \simeq \frac{g_m R_S}{1+\left(g_m + g_{mb}\right) R_S}$$

  - If ***body effect is neglected***:

$$\Rightarrow A_v \simeq \frac{g_m R_S}{1+g_m R_S} = \frac{R_S}{1/g_m + R_S}$$

Note the remarkable similarity with CC stage

  - If $(g_m + g_{mb})R_S >> 1$:

$$\Rightarrow A_v \simeq \frac{g_m}{g_m + g_{mb}} = \frac{1}{1+\chi}$$

- ***Note***:

$$\chi = \frac{\gamma}{2\sqrt{2\phi_F + V_{SB}}}$$

with $V_{SB} = -V_0$ (***DC level of v_0***)

- ***Typical values of χ ~ 0.1-0.5***
- Thus, ***A_v can depart significantly from its ideal value of unity***
- ***No phase shift between input and output***

➢ ***Input Resistance***: $R_i \rightarrow \infty$

➢ ***Output Resistance***: ***By inspection***:

$$R_0 = (g_m + g_{mb} + g_0 + g_S)^{-1} \ (g_0 = 1/r_0,\ g_S = 1/R_S)$$

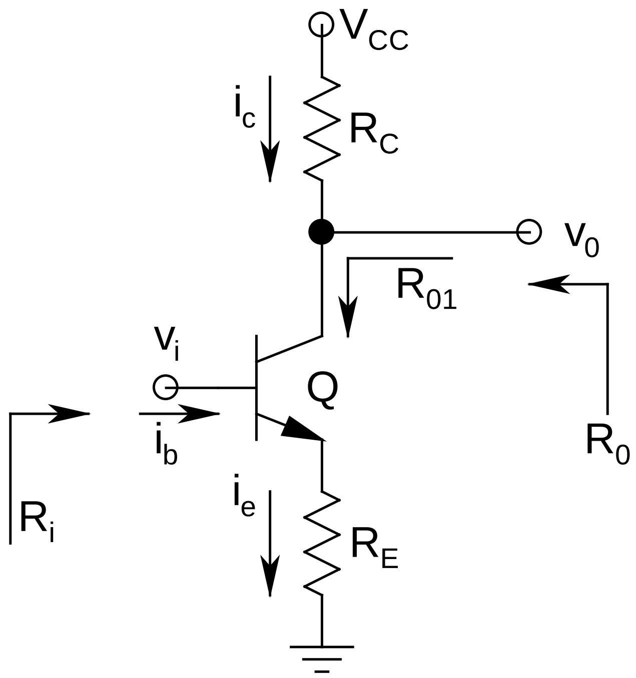
- ***Common-Emitter (Degeneration)*** [CE(D)]:
  - Let's attempt to analyze this circuit by ***inspection***
  - $v_0 = -\, i_c R_C$

    $v_i = i_e(r_E + R_E)$

    $\Rightarrow\ A_v = v_0/v_i$

    $\approx -\, R_C/(r_E + R_E)$

    Piece of cake?



  - $A_i = i_c/i_b = \beta$
  - $R_i = r_\pi + (\beta + 1)R_E = (\beta + 1)(r_E + R_E)$

- $R_0 = R_{01} || R_C$

  Can you identify R_{01} by ***inspection***?

  $R_{01} = r_0[1 + g_m(r_\pi || R_E)]$

  Generally, $R_{01} >> R_C$

  $\Rightarrow R_0 \approx R_C$

- ***Probe A_v further***:

  $A_v = - R_C/(r_E + R_E) \approx -g_m R_C/(1 + g_m R_E)$

  For ***CE stage***, $A_v = -g_m R_C$

  For this stage, A_v is ***lower*** by a ***factor*** $(1 + g_m R_E) \Rightarrow$ ***Gain Degeneration***

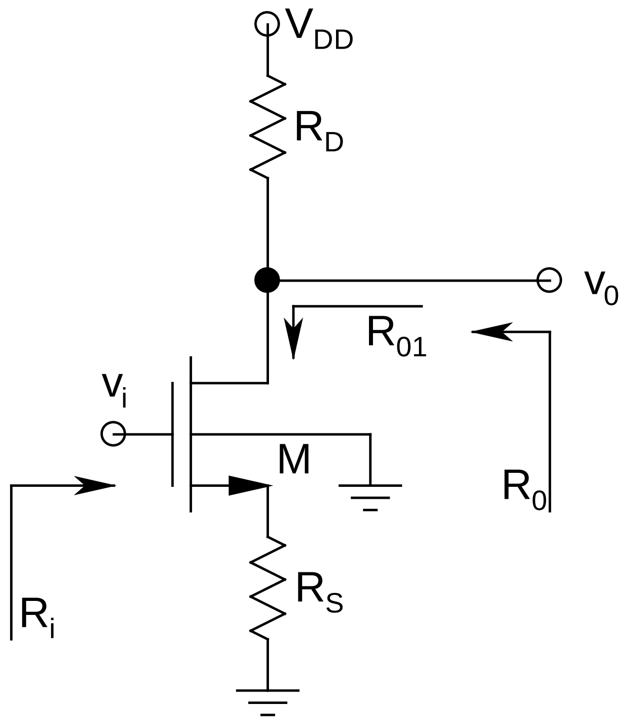
- $(1 + g_m R_E)$ is known as the ***Degeneration Factor***
- R_i can also be written as:

  $$R_i \approx r_\pi + \beta R_E = r_\pi(1 + g_m R_E)$$

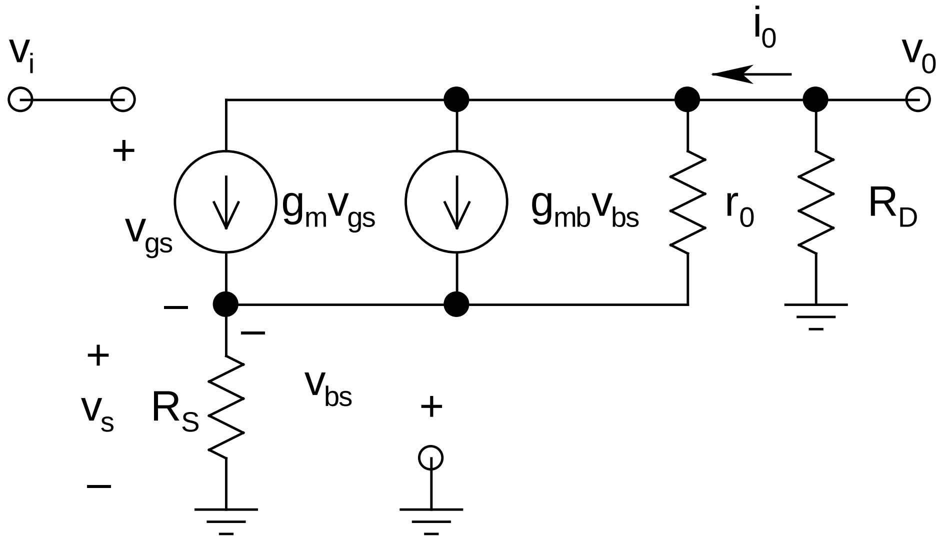
  Thus, $R_i \uparrow$ by the ***Degeneration Factor*** as compared to the ***CE stage***
- ***Interesting to note that the loss in gain is returned by this circuit to its R_i by the same factor***!

- ***Why do we sacrifice gain***?
  - Later on, we will see that this ***sacrifice in gain*** leads to a ***commensurate increase in the bandwidth*** of the circuit
- ***For a given bias point***, the ***gain-bandwidth product (GBP) of a circuit remains constant*** (will be explored later)
- This is one of the ***famous paradoxes*** of analog circuits:
  - ***To increase gain, sacrifice bandwidth, and vice versa***

- ***Common-Source (Degeneration)*** [CS(D)]:



ac Schematic



ac Low-Frequency Equivalent

- ***Defining Relations***:

$$v_0 = -\, i_0 R_D$$

$$i_0 = g_m v_{gs} + g_{mb} v_{bs} + (v_0 - v_s)/r_0$$

$$v_s = i_0 R_S$$

$$v_{gs} = v_i - v_s$$

$$v_{bs} = -\, v_s$$

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

- Pretty ***complicated*** expression, however, ***simplifications*** can be made

- Generally, $(R_S + R_D)/r_0$ can be ***neglected***:

$$\Rightarrow A_v = \frac{v_0}{v_i} \simeq -\frac{g_m R_D}{1+\left(g_m + g_{mb}\right) R_S}$$

- ***Neglect body effect***:

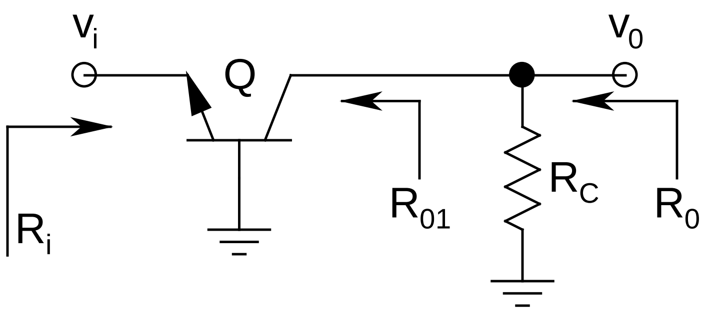
$$\Rightarrow A_v \simeq -\frac{g_m R_D}{1+g_m R_S} = -\frac{R_D}{1/g_m + R_S}$$

- Again, ***remarkable similarity with CE(D) stage***
- ***Golden Observation***:
  - ***MOS stages, in absence of body effect, is absolutely similar to BJT stages, with r_E replaced by $1/g_m$***

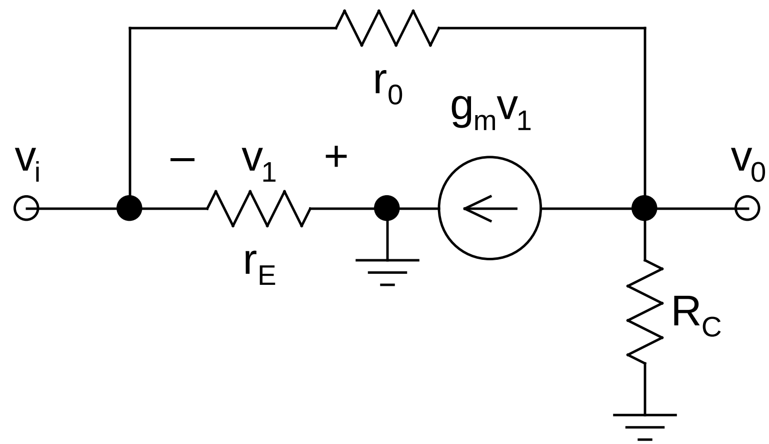
- Note that here the ***Degeneracy Factor*** is $(1 + g_m R_S)$
- $R_i \rightarrow \infty$
- $R_0 = R_{01} || R_D$

  $R_{01} = r_0[1 + (g_m + g_{mb})R_S]$ (***Show***!)
- Again ***gain is sacrificed*** in order to ***improve the bandwidth*** by the ***same amount***
- The complexity of analysis of this circuit is slightly more than the others encountered so far

- ***Common-Base*** (CB):



ac Schematic



ac Low-Frequency Equivalent

- Note that the ***alternate hybrid-π model appropriate for CB circuit*** has been used
- ***r_0 appears between input and output***

- For now, ***neglect r_0***
- Noting that $v_1 = -v_i$:

$$A_v = \frac{v_0}{v_i} = \frac{-g_m v_1 R_C}{v_i} = +g_m R_C \simeq \frac{R_C}{r_E}$$

- Note that the ***expression*** for A_v is ***identical*** to that for the ***CE stage***, ***without the negative sign in front***
- For this circuit, ***input and output are in phase***
- $A_i = i_c/i_e = \alpha$
- $R_i = r_E$

- $R_0 = R_{01} || R_C$

  $R_{01} \to \infty$ (Why?)

  $\Rightarrow R_0 = R_C$
- ***Ex.: Find A_v and R_i with r_0 included***
- ***With r_0 included***, the circuit shows ***two different values*** of R_{01}:
  - ***When excited by a voltage source***, $R_{01} = r_0$
  - ***When excited by a current source***, $R_{01} = \beta r_0$ (***Show***)

    [***Hint***: ***For this derivation, need to use $g_m r_E = \alpha$***]
  - ***Thus, possibility of huge R_0 under the second case, but R_C ruins it***!