ELC2020

Electronics II

CS/CD/CG Amplifiers

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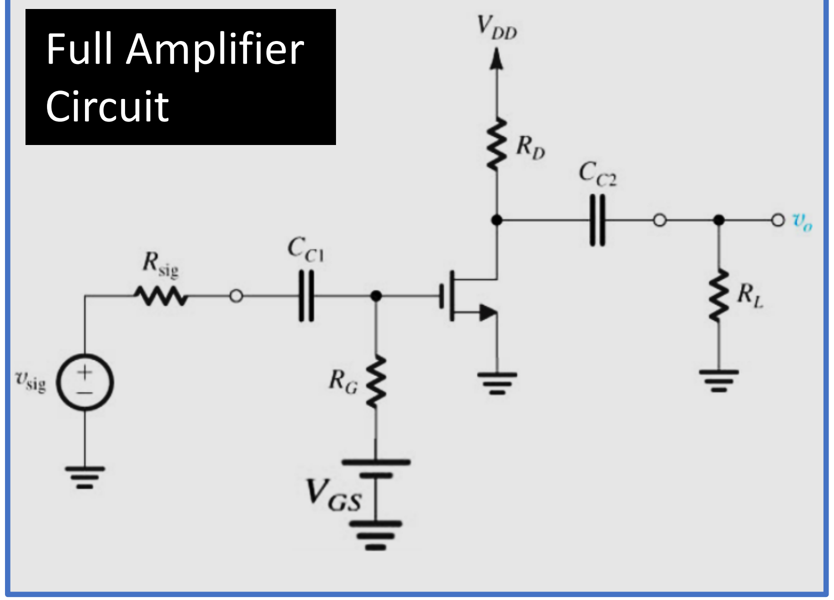
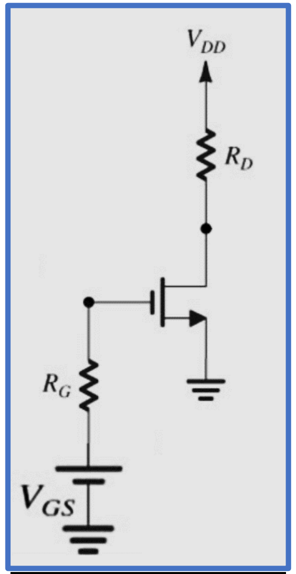
Amplifiers Review

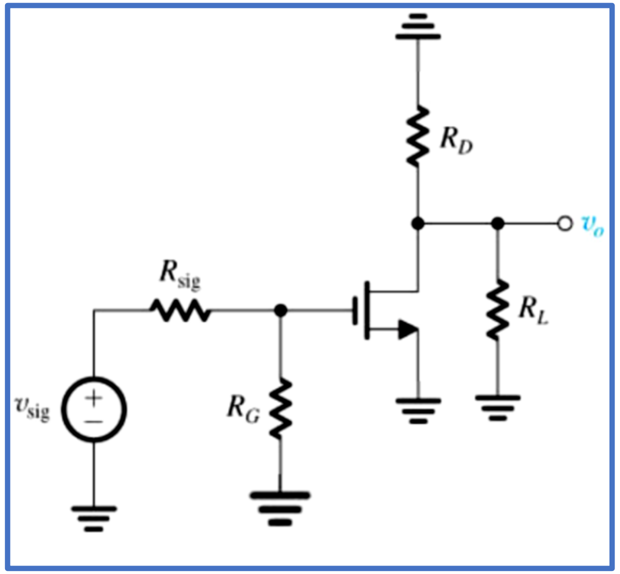
- Large capacitor help to separate AC signal from DC bias
  - Since capacitors are large, they are considered short circuit during AC analysis ($Z_C = \frac{1}{j\omega C}$)
- DC Analysis:
  - At DC, caps are open circuit
  - Since gate current = 0, R_G will not impact V_G, DC analysis is very similar to basic common source amplifier (for this example)
  - After solving the DC analysis, calculate the small singal parameters (g_m, r_o)
- AC Analysis:
  - At AC, caps are short circuit
  - DC voltage sources are short circuit
  - DC current sources are open circuit
  - Draw small signal model and calculate $G_m, Z_{out}, and\ A_v$.

Full Amplifier Circuit





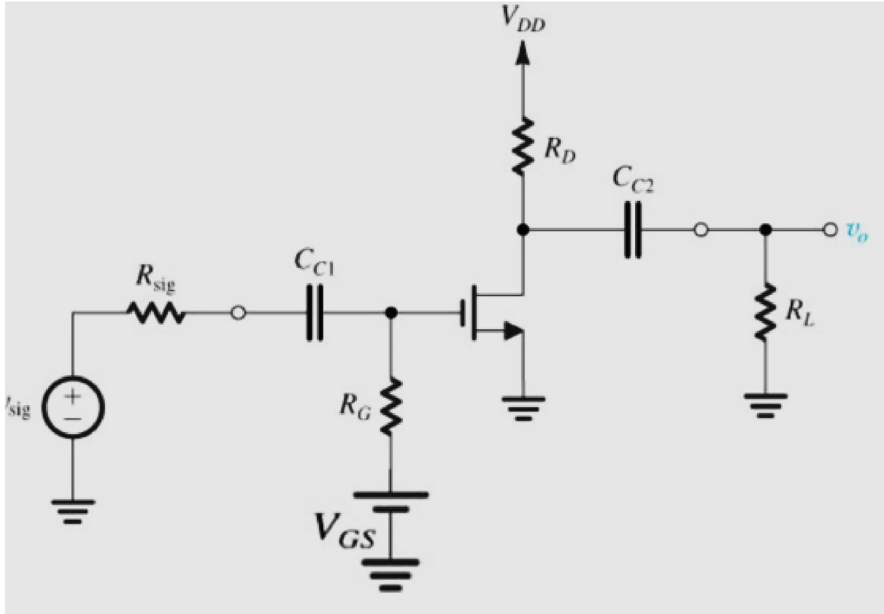
DC Analysis



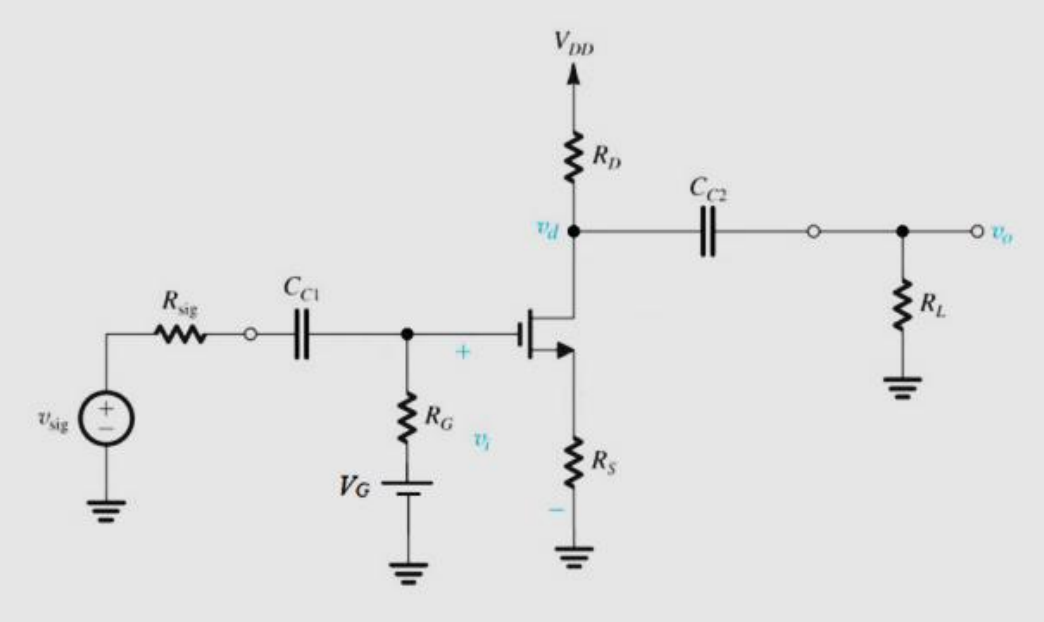
AC Analysis

Single-Ended Amplifier Summary

- Common source amplifier: input at gate, output at drain $(r_o = \infty)$



Cc is a large cap
- **S.C. for AC**
- **O.C. for DC**

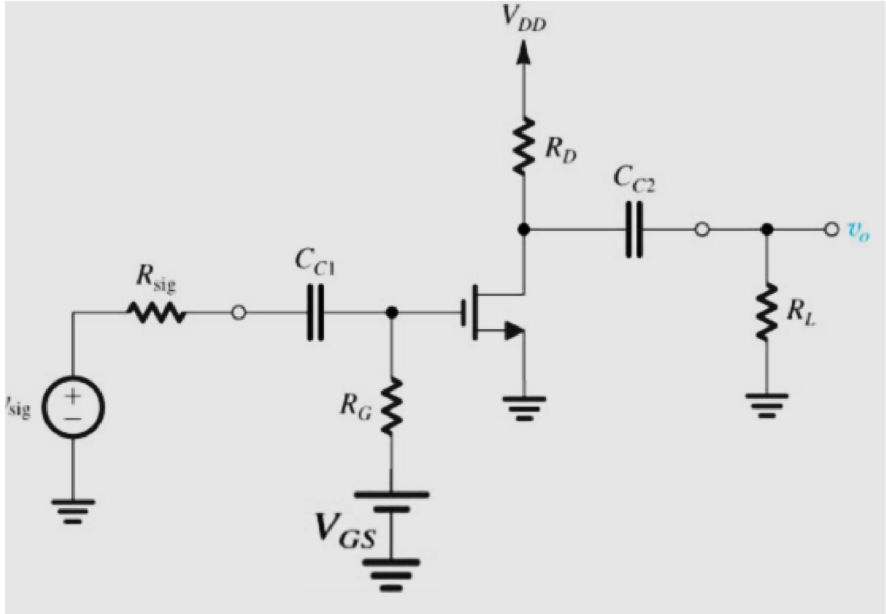


- $R_{in} = R_G$
- $R_{out} = R_D$
- $G_m = -g_m$
- $A_v = -g_m R_D$
- $Gain_{tot} = -\left(\frac{R_G}{R_G+R_{sig}}\right) g_m (R_D||R_L)$

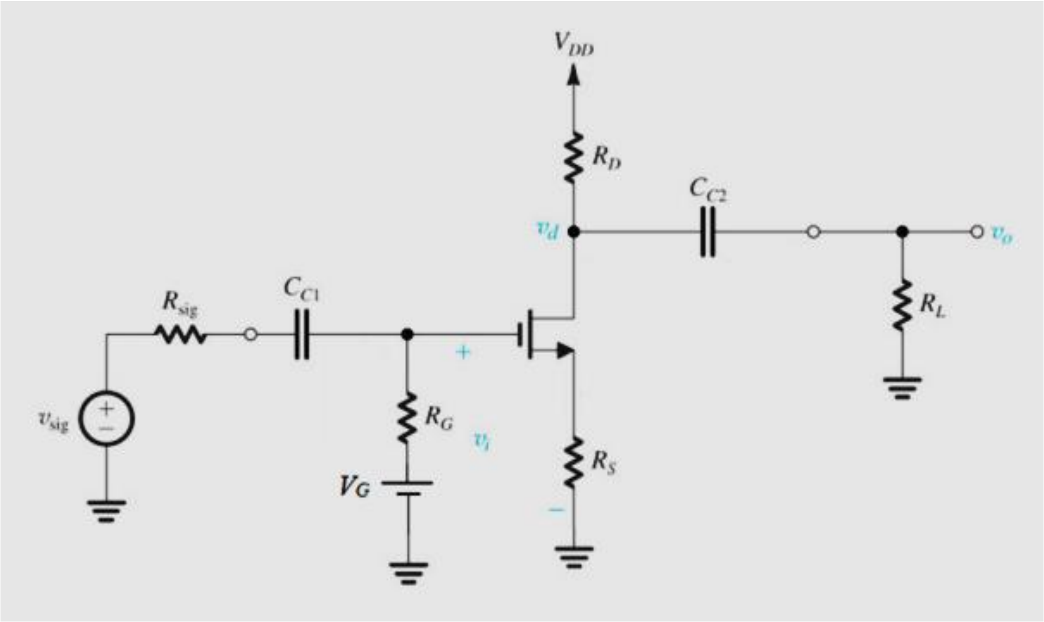
- $R_{in} = R_G$
- $R_{out} = R_D$
- $G_m = -\frac{g_m}{1+g_m R_s}$
- $A_v = -\frac{g_m R_D}{1+g_m R_s}$
- $Gain_{tot} = -\left(\frac{R_G}{R_G+R_{sig}}\right) \frac{g_m}{1+g_m R_s} (R_L||R_D)$

Single-Ended Amplifier Summary

- Common source amplifier: input at gate, output at drain $(r_o \neq \infty)$



Cc is a large cap
- **S.C. for AC**
- **O.C. for DC**

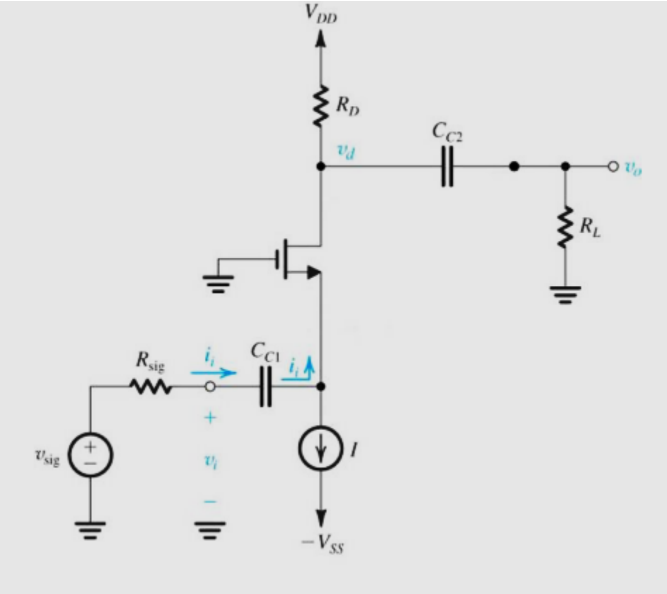


- $R_{in} = R_G$
- $R_{out} = R_D||r_o$
- $G_m = -g_m$
- $A_v = -g_m(R_D||r_o)$
- $Gain_{tot} = -\left(\frac{R_G}{R_G+R_{sig}}\right)g_m(R_D||r_o||R_L)$

- $R_{in} = R_G$
- $R_{out} = R_D||(r_o + (1+g_m r_o)R_s)$
- $G_m = -\frac{g_m}{1+g_m R_s}$
- $A_v = -\frac{g_m}{1+g_m R_s}[R_D||(r_o + (1+g_m r_o)R_s)]$
- $Gain_{tot} = -\left(\frac{R_G}{R_G+R_{sig}}\right)\frac{g_m}{1+g_m R_s}[R_L||R_D||(r_o + (1+g_m r_o)R_s)]$

Single-Ended Amplifier Summary

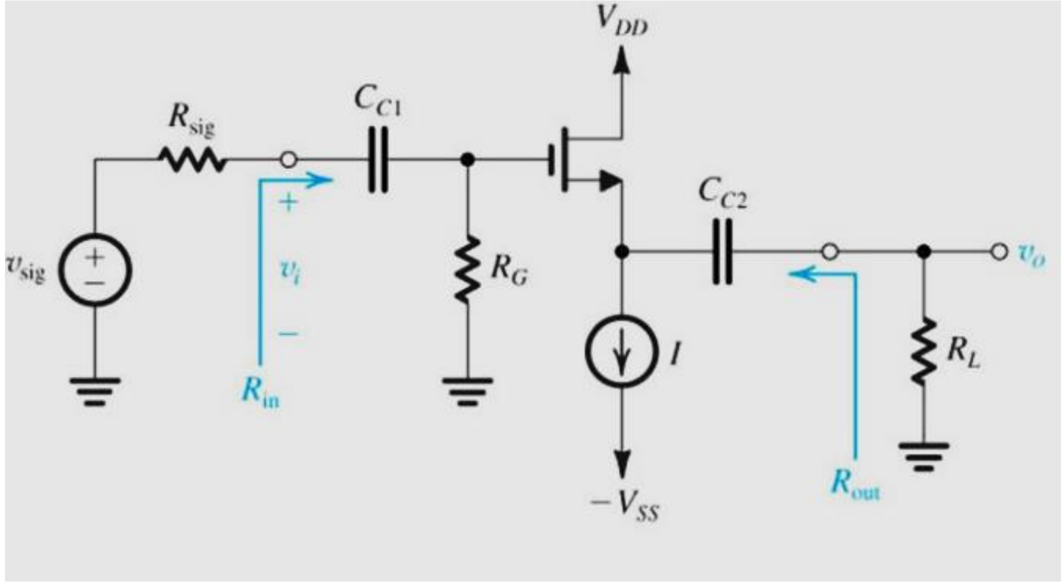
- Common gate amplifier: input at source, output at drain $(r_o = \infty)$



Cc is a large cap
- **S.C. for AC**
- **O.C. for DC**

- $R_{in} = 1/g_m$
- $R_{out} = R_D$
- $G_m = g_m$
- $A_v = g_m R_D$
- $Gain_{tot} = \left(\frac{1/g_m}{1/g_m + R_{sig}}\right) g_m (R_D || R_L)$

- Common drain amplifier (source follower): input at gate, output at source $(r_o = \infty)$



- $R_{in} = R_G$
- $R_{out} = 1/g_m$
- $G_m = g_m$
- $A_v = \frac{g_m}{g_m} = 1$
- $Gain_{tot} = \left(\frac{R_G}{R_G + R_{sig}}\right) g_m \left(R_L || \frac{1}{g_m}\right) = \left(\frac{R_G}{R_G + R_{sig}}\right) \frac{g_m R_L}{1 + g_m R_L}$

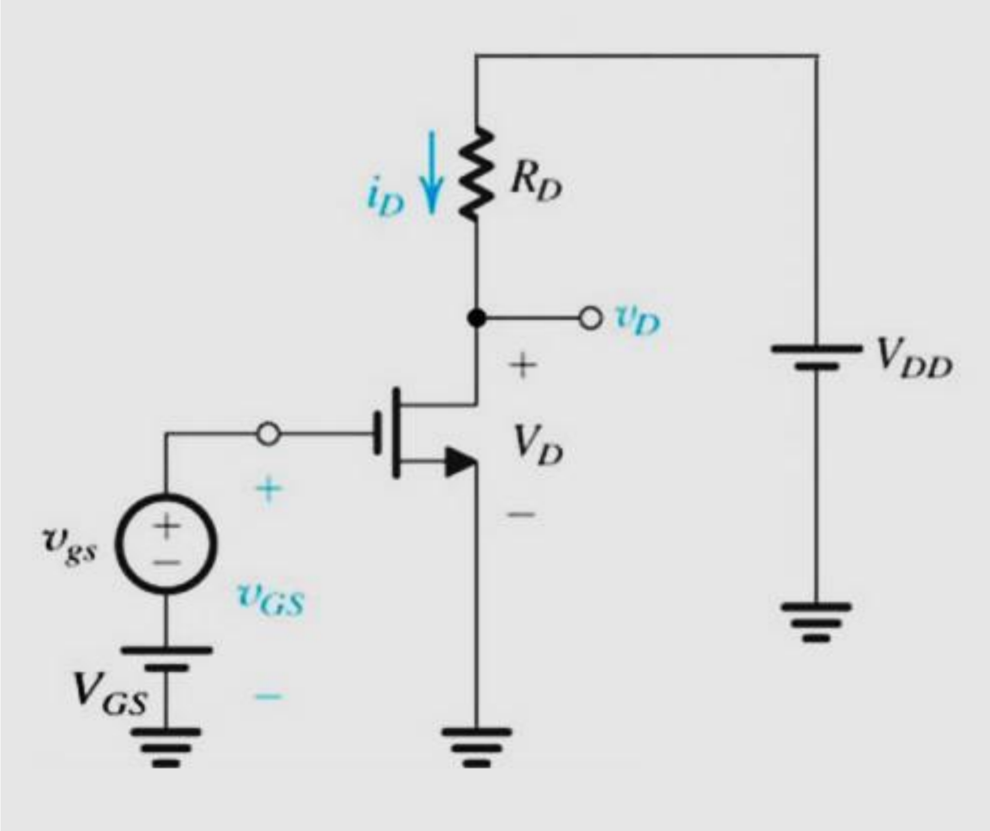
Example 1

- Calculate amplifier gain given that:

$$K' = \frac{0.2mA}{V^2}, V_{TH} = 0.5V, V_{DD} = 2V, V_{GS} = 1V, R_D = 4k\Omega, \frac{W}{L} = 10$$

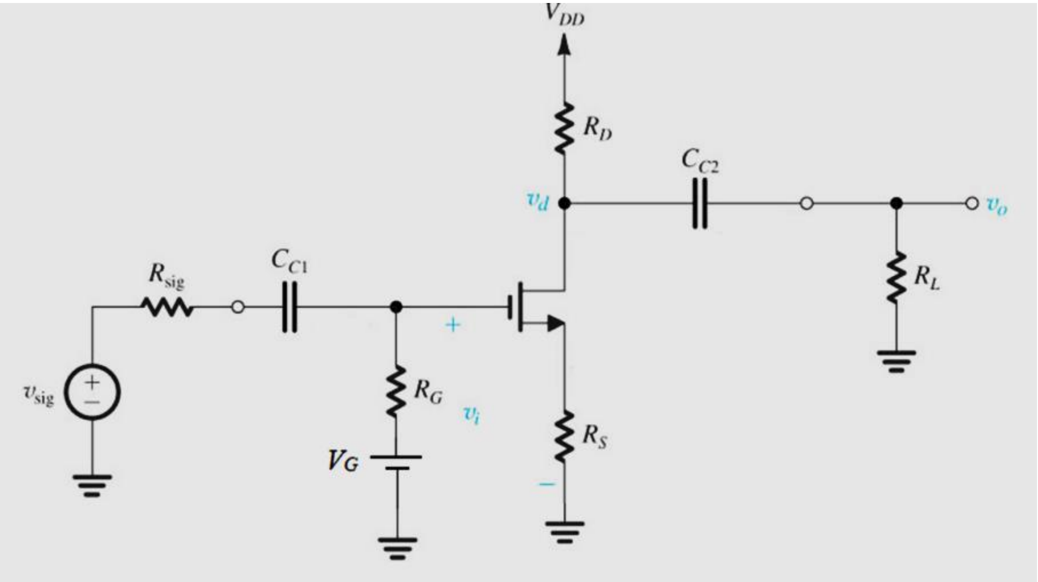
- Solution:

  - $I_D = \frac{k}{2}(V_{GS} - V_t)^2 = 0.25mA$
  - $V_D = V_{DD} - I_D R_L = 1V > V_{GS} - V_t$ (sat region)
  - $g_m = K(V_{GS} - V_t) = 1mA/V$
  - $Gain = -g_m R_L = -4$



Example 2

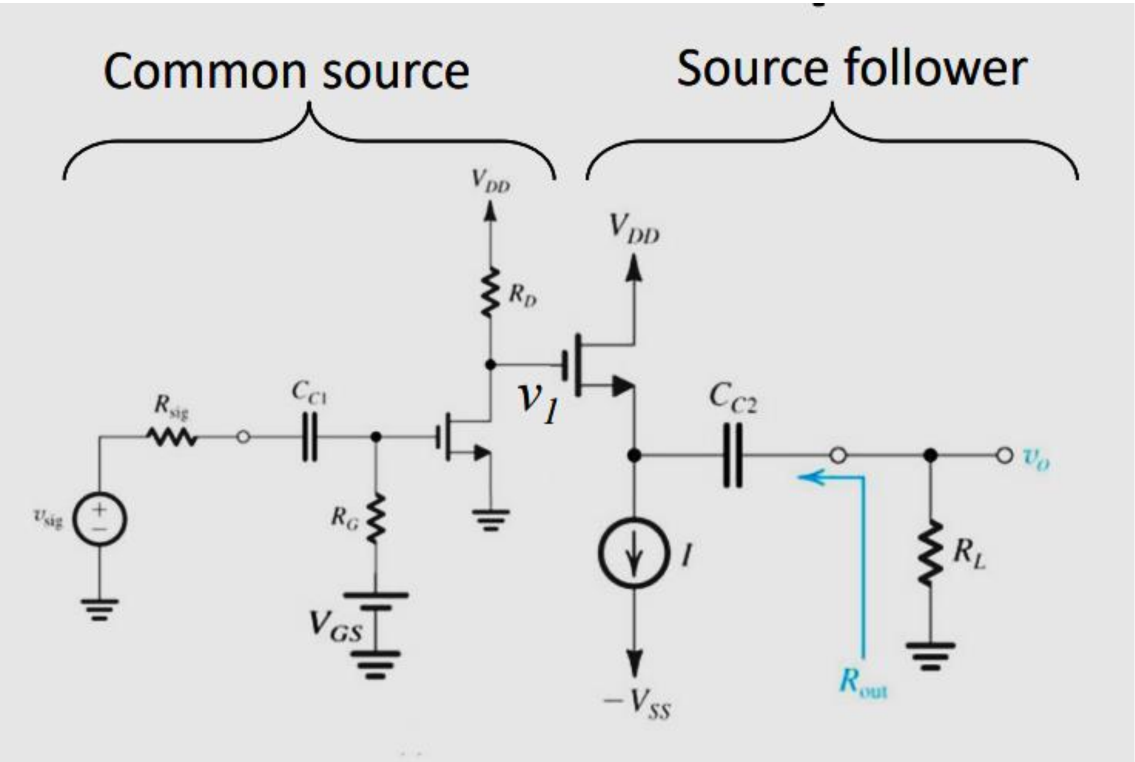
- Calculate amplifier gain.
- DC Analysis:
  - $I_D = \frac{K}{2}(V_{GS} - V_{TH})^2$
  - $V_{GS} = V_G - I_D R_S$
  - $I_D = \frac{K}{2}(V_G - I_D R_S - V_{TH})^2 = 0.5(1.5 - I_D)^2$
  - $I_D^2 - 5I_D + 2.25 = 0$
  - $I_D = 4.5mA \rightarrow \textit{rejected as } V_{DS} < 0$
  - $I_D = 0.5mA$
  - $g_m = \sqrt{2KI_D} = \frac{1mA}{V}$
  - $V_{DS} = V_{DD} - I_D R_D - I_D R_S = 1.5V > V_{GS} - V_{TH}$
- AC Analysis:
  - $A_v = -\frac{g_m R_D}{1+g_m R_s} = -\frac{6}{1+1} = -3V/V$
  - $Gain_{tot} = -\left(\frac{R_G}{R_G+R_{sig}}\right)\frac{g_m}{1+g_m R_s}(R_L||R_D) = -\left(\frac{0.9}{0.9+0.1}\right)\frac{1}{1+1}(9||6) = -1.62V/V$



$R_S = 1K\Omega$
$R_D = 6K\Omega$
$K = \frac{1mA}{V^2}$
$VG = 2V,$
$V_{TH} = 0.5V$
$V_{DD} = 5V$
$R_{sig} = 0.1K\Omega$
$R_G = 0.9K\Omega$
$RL = 9K\Omega$
$\lambda = 0$

Example 3

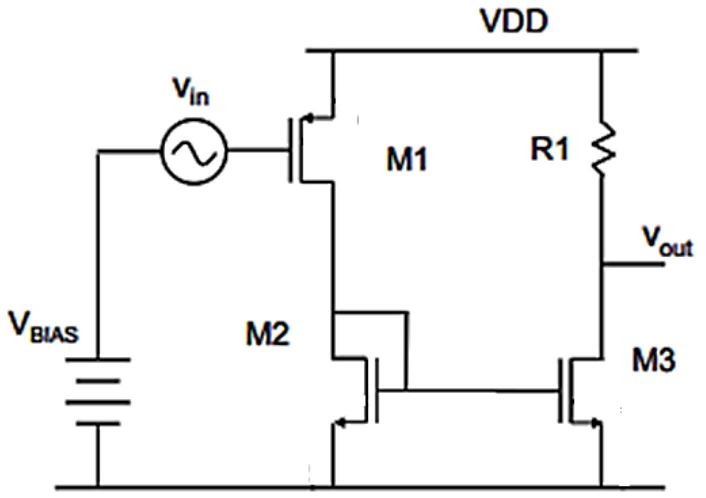
- Calculate the overall gain.
- Assume that both transistors has $gm = 10mA/V, RD = 1K\Omega$, $Rsig = 0\Omega$, $RL = 100\Omega$



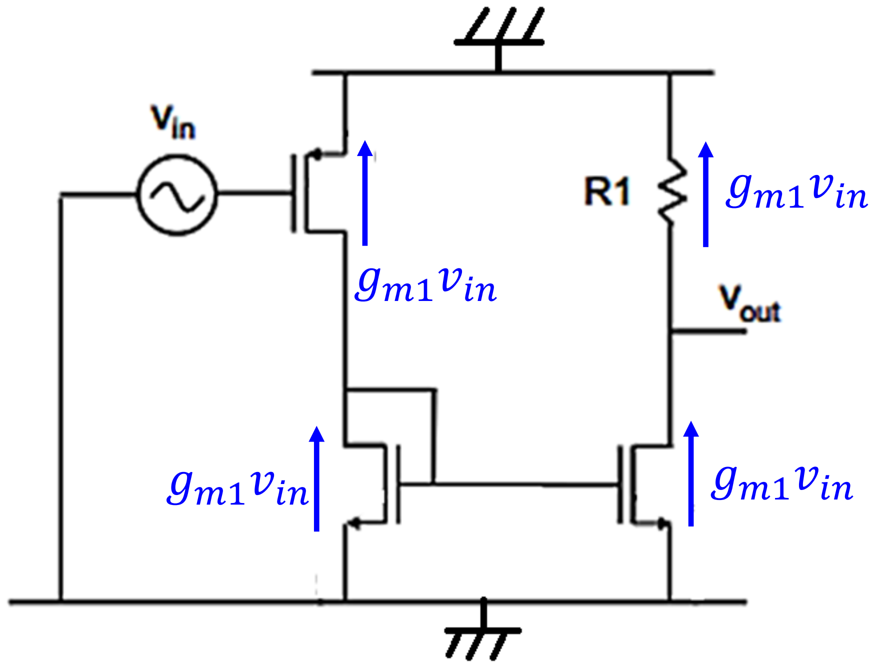
- Solution:
- $Gain_{tot} = \frac{v_o}{v_i} = \frac{v_o}{v_1} \times \frac{v_1}{v_i}$
- $\frac{v_1}{v_i} = -g_m R_D = -10V/V$
- $\frac{v_o}{v_i} = \frac{g_m R_L}{1+g_m R_L} = 0.5V/V$
- $Gain_{tot} = \frac{v_o}{v_i} = \frac{v_o}{v_1} \times \frac{v_1}{v_i} = -5V/V$

Example 4

- Derive an expression for the voltage gain. Assume M2 and M3 are identical. All transistors are in saturation. Ignore channel length modulation.



- Solutions:
- $A_v = g_m R_1$



Example 5

- What is the small signal voltage gain?
- Assume all transistors are in saturation.
- Assume r_{o2}, r_{o3} and r_{o4} are very large.

- Solution:
- $A_v = -g_{m4} r_{o1}$