Homework 5 – Solutions

Problems (not review questions): 7.25, 7.30 (use T-model), 7.32, 7.59, 7.64, 7.71

7.25 Consider the FET amplifier of Fig. 7.10 for the case $V_t = 0.4$ V, $k_n' = 5$ mA/V^2, $V_{GS} = 0.6$ V, $V_{DD} = 1.8$ V, and $R_D = 10$ kΩ.

(a) Find the dc quantities I_D and V_{DS}.

(b) Calculate the value of g_m at the bias point.

(c) Calculate the value of the voltage gain.

(d) If the MOSFET has $\lambda = 0.1$ V^{-1}, find r_o at the bias point and calculate the voltage gain.

7.25 (a) $I_D = \frac{1}{2}k_n(V_{GS} - V_t^2)$

$= \frac{1}{2} \times 5(0.6 - 0.4)^2 = 0.1$ mA

$V_{DS} = V_{DD} - I_D R_D = 1.8 - 0.1 \times 10 = 0.8$ V

(b) $g_m = k_n V_{OV} = 5 \times 0.2 = 1$ mA/V

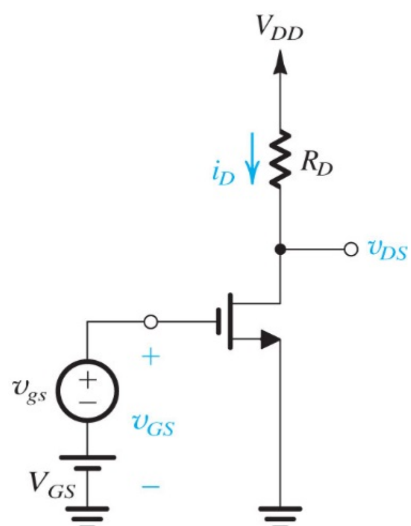
(c) $A_v = -g_m R_D = -1 \times 10 = -10$ V/V

(d) $\lambda = 0.1$ V^{-1}, $\quad V_A = \frac{1}{\lambda} = 10$ V

$r_o = \frac{V_A}{I_D} = \frac{10}{0.1} = 100$ kΩ

$A_v = -g_m(R_D \parallel r_o)$

$= -1(10 \parallel 100) = -9.1$ V/V



7.30 For the NMOS amplifier in Fig. P7.30, replace the transistor with its T equivalent circuit, assuming $\lambda = 0$. Derive expressions for the voltage gains v_s/v_i and v_d/v_i.

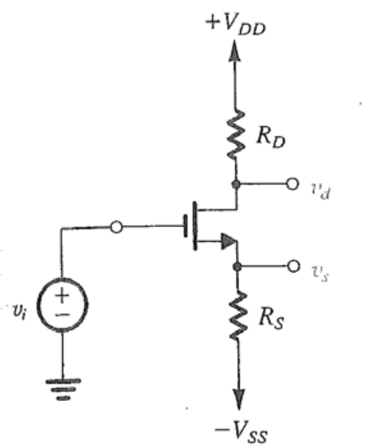
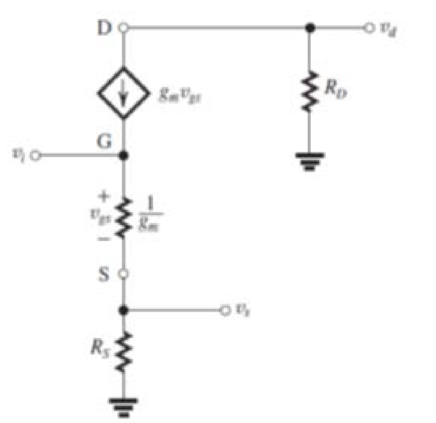


Figure P7.30



$$v_i = (g_m v_{gs})\left(\frac{1}{g_m} + R_S\right)$$

$$v_d = -g_m v_{gs} R_D$$

$$v_s = +g_m v_{gs} R_S$$

$$\therefore \frac{v_s}{v_i} = \frac{R_S}{\frac{1}{g_m} + R_S} = \frac{+g_m R_S}{1 + g_m R_S}$$

$$\frac{v_d}{v_i} = \frac{-R_D}{\frac{1}{g_m} + R_S} = \frac{-g_m R_D}{1 + g_m R_S}$$

7.32 For a 0.18-μm CMOS fabrication process: $V_{tn} = 0.5$ V, $V_{tp} = -0.5$ V, $\mu_n C_{ox} = 400\ \mu\text{A/V}^2$, $\mu_p C_{ox} = 100\ \mu\text{A/V}^2$, $C_{ox} = 8.6\ \text{fF}/\mu\text{m}^2$, V_A (n-channel devices) $= 5L$ (μm), and $|V_A|$ (p-channel devices) $= 6L$ (μm). Find the small-signal model parameters (g_m and r_o) for both an NMOS and a PMOS transistor having $W/L = 10\ \mu\text{m}/0.5\ \mu\text{m}$ and operating at $I_D = 100\ \mu\text{A}$. Also, find the overdrive voltage at which each device must be operating.

7.32 For the NMOS device:

$$I_D = 100 = \frac{1}{2}\mu_n C_{ox}\frac{W}{L}V_{OV}^2$$

$$= \frac{1}{2} \times 400 \times \frac{10}{0.5} \times V_{OV}^2$$

$$\Rightarrow V_{OV} = 0.16\ \text{V}$$

$$g_m = \frac{2I_D}{V_{OV}} = \frac{2 \times 0.1\ \text{mA}}{0.16} = 1.25\ \text{mA/V}$$

$$V_A = 5L = 5 \times 0.5 = 2.5\ \text{V}$$

$$r_o = \frac{V_A}{I_D} = \frac{2.5}{0.1} = 25\ \text{k}\Omega$$

For the PMOS device:

$$I_D = 100 = \frac{1}{2}\mu_p C_{ox}\frac{W}{L}V_{OV}^2$$

$$= \frac{1}{2} \times 100 \times \frac{10}{0.5} \times V_{OV}^2$$

$$\Rightarrow V_{OV} = 0.316\ \text{V}$$

$$g_m = \frac{2I_D}{V_{OV}} = \frac{2 \times 0.1}{0.316} = 0.63\ \text{mA/V}$$

$$V_A = 6L = 6 \times 0.5 = 3\ \text{V}$$

$$r_o = \frac{V_A}{I_D} = \frac{3}{0.1} = 30\ \text{k}\Omega$$

7.59 An amplifier with an input resistance of 100 kΩ, an open-circuit voltage gain of 100 V/V, and an output resistance of 100 Ω is connected between a 20-kΩ signal source and a 2-kΩ load. Find the overall voltage gain G_v. Also find the current gain, defined as the ratio of the load current to the current drawn from the signal source.

$$G_v = \frac{R_{\text{in}}}{R_{\text{in}} + R_{\text{sig}}} A_{vo} \frac{R_L}{R_L + R_o}$$

$$= \frac{100}{100 + 20} \times 100 \times \frac{2}{2 + 0.1}$$

$$= 79.4 \text{ V/V}$$

$$i_o = \frac{v_o}{R_L}$$

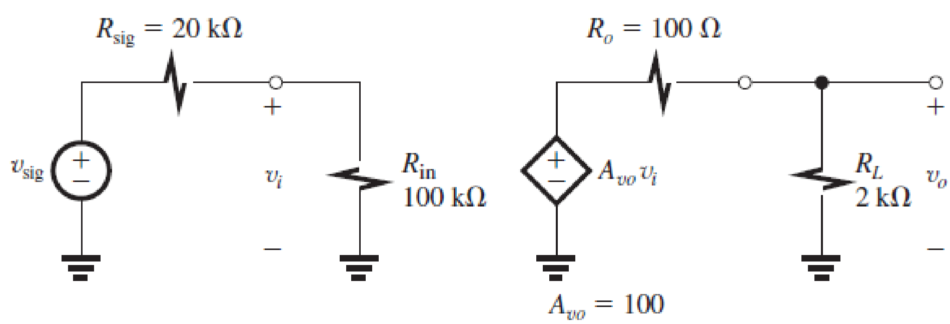
$$i_i = \frac{v_{\text{sig}}}{R_{\text{sig}} + R_{\text{in}}}$$

$$\frac{i_o}{i_i} = \frac{v_o}{v_{\text{sig}}} \frac{R_{\text{sig}} + R_{\text{in}}}{R_L}$$

$$= G_v \frac{R_{\text{sig}} + R_{\text{in}}}{R_L}$$

$$= 79.4 \times \frac{20 + 100}{2} = 4762 \text{ A/A}$$

This figure belongs to Problem 7.59.



7.64 Calculate the overall voltage gain of a CS amplifier fed with a 1-MΩ source and connected to a 10-kΩ load. The MOSFET has $g_m = 2\text{ mA/V}$, and a drain resistance $R_D = 10\text{ k}\Omega$ is utilized.

7.64 $R_{sig} = 1\text{ M}\Omega,\ R_L = 10\text{ k}\Omega$

$g_m = 2\text{ mA/V},\ R_D = 10\text{ k}\Omega$

$$G_v = -g_m(R_D \parallel R_L)$$

$$= -2(10 \parallel 10) = -10\text{ V/V}$$

7.71 A MOSFET connected in the CS configuration has a transconductance $g_m = 5\text{ mA/V}$. When a resistance R_s is connected in the source lead, the effective transconductance is reduced to 2 mA/V. What do you estimate the value of R_s to be?

7.71 $$g_m\big|_{\text{effective}} = \frac{g_m}{1 + g_m R_s}$$

$$2 = \frac{5}{1 + 5R_s}$$

$$\Rightarrow R_s = 0.3\text{ k}\Omega = 300\ \Omega$$