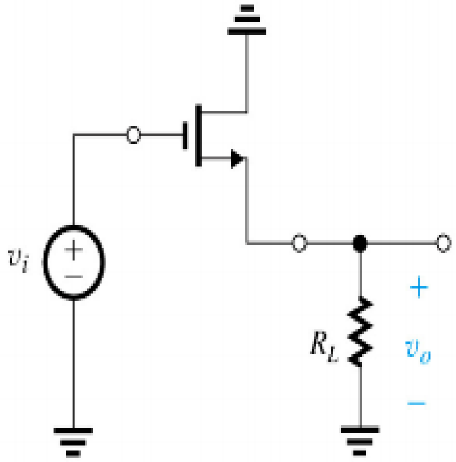
ECE 523/421 - Analog Electronics
University of New Mexico
Solutions Homework 3

Problem 7.90

Show that when ro is taken into account, the voltage gain of the source follower becomes

$$G_v = \frac{v_o}{v_{sig}} = \frac{R_L||r_o}{(R_L||r_o) + \frac{1}{g_m}}$$

Now, with RL removed, the voltage gain is carefully measured and found to be 0.98. Then, when RL is connected and its value is varied, it is found that the gain is halved at RL = 500Ω. If the amplifier remained linear throughout this measurement, what must the values of gm and ro be?



Because drain terminal is connected to ground $R_L||r_o$
And using T-model.
We use a voltage division to determine v_o

$$v_o = v_{sig}\frac{R_L||r_o}{(R_L||r_o) + \frac{1}{g_m}}$$

From this voltage division we obtain G_v

$$G_v = \frac{v_o}{v_{sig}} = \frac{R_L||r_o}{(R_L||r_o) + \frac{1}{g_m}}$$

When we remove R_L

$$G_v = \frac{r_o}{(r_o) + \frac{1}{g_m}}$$

$$G_v = 0.98$$

With $R_L = 500\Omega$

$$G_v = \frac{500||r_o}{(500||r_o) + \frac{1}{g_m}}$$

$$G_v = 0.49$$

From the equation without R_L we found

$$\frac{r_o}{49} = \frac{1}{g_m}$$

Substituting $\frac{r_o}{49} = \frac{1}{g_m}$ in equation with $R_L = 500\Omega$

$$r_o = 25k\Omega$$

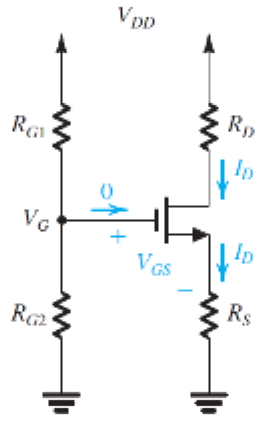
Therefore

$$g_m = \frac{49}{r_o}$$

$$g_m = 1.96 \ {}^{mA}\!/_{V}$$

Problem 7.94

In an electronic instrument using the biasing scheme shown in Fig. 7.48(c), a manufacturing error reduces RS to zero. Let VDD = 15 V, RG1 = 10MΩ, and RG2 =5.1MΩ. What is the value of VG created? If supplier specifications allow k_n to vary from 0.2 to 0.3 mA/V^2 and V_t to vary from 1.0 V to 1.5 V, what are the extreme values of ID that may result? What value of RS should have been installed to limit the maximum value of ID to 1.5 mA? Choose an appropriate standard 5% resistor value (refer to Appendix J). What extreme values of current now result?



(c)

Using voltage division to calculate V_G

$$V_G = V_{DD}\frac{R_{G2}}{R_{G2}+R_{G1}}$$

$$V_G = 15\frac{5.1}{5.1+10} = 5.07V$$

For calculating I_D we use the equation for drain current

$$I_D = \frac{1}{2}(k_n{}')\left(\frac{W}{L}\right)(5.07 - V_t)^2$$

For I_{DMIN} we use $k_n = 0.2$ and $V_t = 1.5V$

$$I_{DMIN} = \frac{1}{2}(0.2)(5.07-1.5)^2$$

$$I_{DMIN} = 1.27\ mA$$

For I_{DMAX} we use $k_n = 0.3$ and $V_t = 1V$

$$I_{DMAX} = \frac{1}{2}(0.3)(5.07-1)^2$$

$$I_{DMAX} = 2.48\ mA$$

Using the equation for drain current for calculating the new V_{GS} using the MAX values for $k_n = 0.3$ and $V_t = 1V$ because this will be the new MAX drain current.

$$I_D = \frac{1}{2}(k_n{}')\left(\frac{W}{L}\right)(V_{OV})^2$$

$$V_{OV} = 3.16V$$

$$V_{GS} = 4.16V$$

Then we calculate V_S

$$V_S = V_G - V_{GS}$$
$$V_S = 5.07 - 4.16$$
$$V_S = 0.91V$$

Knowing V_S we can simply calculate R_S

$$R_S = \frac{V_S}{I_{DS}} = \frac{0.91}{1.5mA}$$
$$R_S = 606.6\Omega$$
$$R_S \cong 620\Omega$$

Problem 7.103

Figure P7.103 shows a variation of the feedback-bias circuit of Fig. 7.50. Using a 5V supply with an NMOS transistor for which V_t = 0.8 V, k_n = 8 mA/V^2, and λ=0, provide a design that biases the transistor at ID =1 mA, with VDS large enough to allow saturation operation for a 2V negative signal swing at the drain. Use 22MΩ as the largest resistor in the feedback-bias network. What values of RD, RG1, and RG2 have you chosen? Specify all resistors to two significant digits.

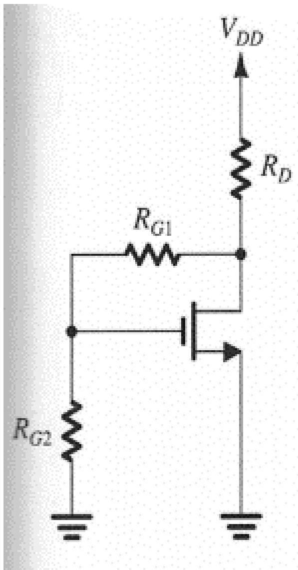


Figure P7.103

Using the equation for the drain current for calculating V_{GS} and then V_G

$$I_D = \frac{1}{2}(k_n{}')\left(\frac{W}{L}\right)(V_{GS} - V_t)^2$$
$$1m = \frac{1}{2}(8m)(V_{GS} - 0.8)^2$$
$$V_{GS} = 1.3V$$
$$V_G = 1.3V$$

Using the condition for V_{DSMIN}

$$V_{DSMIN} = V_{GS} - V_t = 0.5V$$
$$V_{DS} = V_{DSMIN} + 2 = 2.5V$$

Assuming $R_{G2} = 22M\Omega$

$$I = \frac{V_G}{R_{G2}} = \frac{1.3}{22M\Omega} = 5.91x10^{-8}\ A$$

Calculating R_{G1}

$$R_{G1} = \frac{V_{DS} - V_G}{I} = \frac{2.5 - 1.3}{5.91x10^{-8}} = 20.3M\Omega$$
$$R_{G1} = 20M\Omega$$

Calculating R_D

$$R_D = \frac{V_{DD} - V_{DS}}{I_D} = \frac{5 - 2.5}{1x10^{-3}} = 2.5k\Omega$$
$$R_D = 2.5k\Omega$$

Problem 7.120

Figure P7.120 shows a scheme for coupling and amplifying a high-frequency pulse signal. The circuit utilizes two MOSFETs whose bias details are not shown and a 50Ω coaxial cable. Transistor Q1 operates as a CS amplifier and Q2 as a CG amplifier. For proper operation, transistor Q2 is required to present a 50Ω resistance to the cable. This situation is known as "proper termination" of the cable and ensures that there will be no signal reflection coming back on the cable. When the cable is properly terminated, its input resistance is 50Ω. What must gm2 be? If Q1 is biased at the same point as Q2, what is the amplitude of the current pulses in the drain of Q1? What is the amplitude of the voltage pulses at the drain of Q1? What value of RD is required to provide 1-V pulses at the drain of Q2?

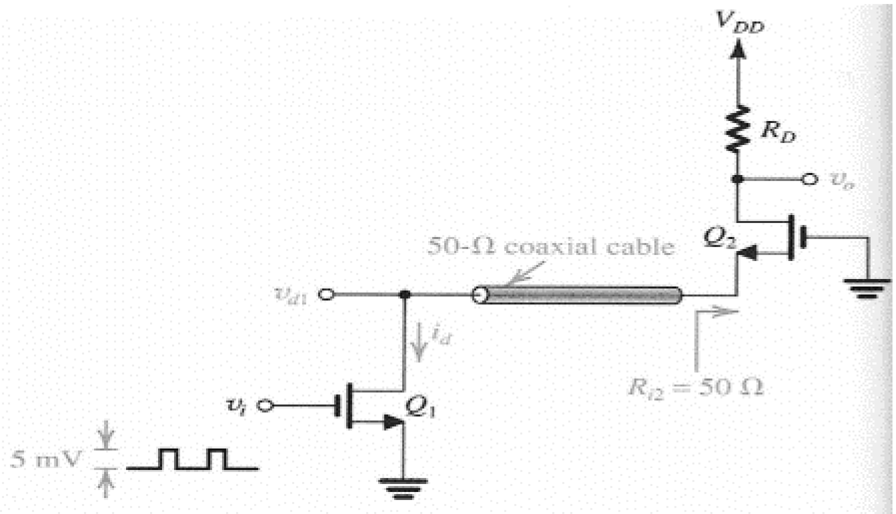


Figure P7.120

Calculating g_{m2}

$$R_{i2} = \frac{1}{g_{m2}} = 50\Omega$$

$$g_{m2} = \frac{1}{R_{i2}} = 20\,{}^{mA}\!/_{V}$$

If Q1 is biased at the same point as Q2 then $g_{m2} = g_{m1}$

$$i_{D1} = g_{m1}v_i = 20x5 = 1x10^{-4}A$$

$$i_{D1} = 0.1mA$$

$$v_{D1} = i_{D1}x\ 50 = 5x10^{-3}V$$

$$v_{D1} = 5\ mV$$

In order to have $v_{D2} = v_o = 1V$

$$R_D = \frac{v_o}{i_D} = \frac{1}{0.1mA} = 10k\Omega$$

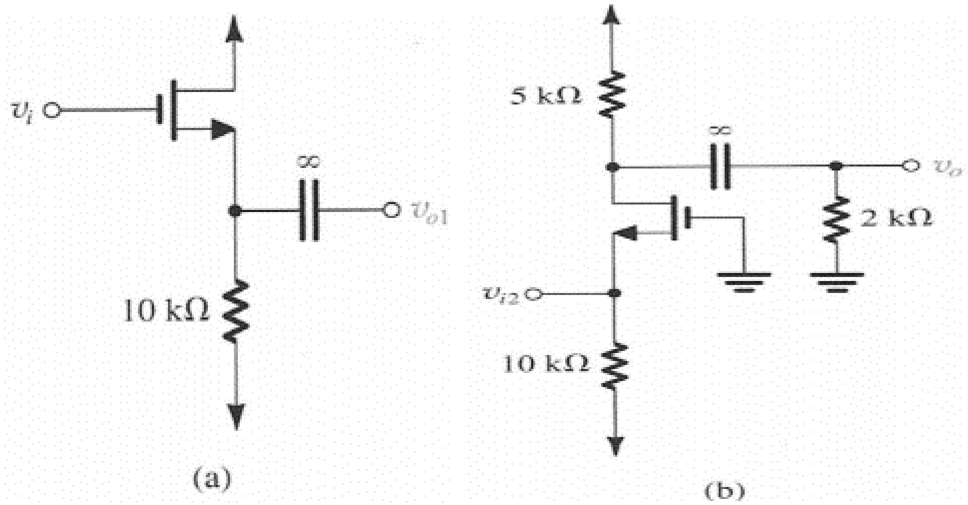
$$R_D = 10k\Omega$$

Problem 7.122

(a) The NMOS transistor in the source-follower circuit of Fig. P7.122(a) has gm = 10 mA/V and a large ro. Find the open-circuit voltage gain and the output resistance.

(b) The NMOS transistor in the common-gate amplifier of Fig. P7.122(b) has gm = 10 mA/V and a large ro. Find the input resistance and the voltage gain.

(c) If the output of the source follower in (a) is connected to the input of the common-gate amplifier in (b), use the results of (a) and (b) to obtain the overall voltage gain v_o/v_i.



(a) For the source follower using T model and voltage division

$$v_{o1} = v_i \frac{R_S}{R_S + \frac{1}{g_m}} = v_i \frac{10k}{10k + \frac{1}{10m}} = v_i \frac{10k}{10.1k}$$

$$G_v = 0.99$$

$$R_{out} = \frac{1}{g_m} || r_o$$

Since r_o is very large

$$R_{out} = \frac{1}{g_m} = \frac{1}{10m} = 100\Omega$$

(b) For the common gate circuit and since r_o is very large

$$R_{in} = \frac{1}{g_m}$$

$$R_{in} = \frac{1}{g_m} = \frac{1}{10m} = 100\Omega$$

Using T model and voltage division

$$v_o = v_{i2}\frac{R_D||R}{\frac{1}{g_m}} = v_i\frac{5k||2k}{\frac{1}{10m}}$$

$$G_v = 14.3$$

(c) If we connect both stages together. For the first step

$$A_{v1} = A_{v1}\frac{R_L}{R_L + R_{out}}$$

Where R_L is R_{in} of the second stage

$$A_{v1} = 1\frac{100}{100 + 100}$$

$$A_{v1} = 0.5$$

For the second stage

$$A_{v2} = 14.3$$

Overall gain

$$A_v = A_{v1}A_{v2} = 7.15$$

Problem 7.123

The MOSFET in the amplifier circuit of Fig. P7.123 has $V_t = 0.6$ V, $k_n = 5$ mA/V^2, and VA = 60 V. The signal v_{sig} has a zero average.

a) **It is required to bias the transistor to operate at an overdrive voltage VOV = 0.2 V. What must the dc voltage at the drain be? Calculate the dc drain current ID taking into account VA. Now, what value must the drain resistance RD have?**
b) **Calculate the values of gm and ro at the bias point established in (a).**
c) **Using the small-signal equivalent circuit of the amplifier, show that the voltage gain is given by**

$$\frac{v_o}{v_{sig}} = -\frac{R_2/R_1}{1 + \dfrac{1 + R_2/R_1}{g_m(R_D||r_o||R_2)(1 - 1/g_m R_2)}}$$

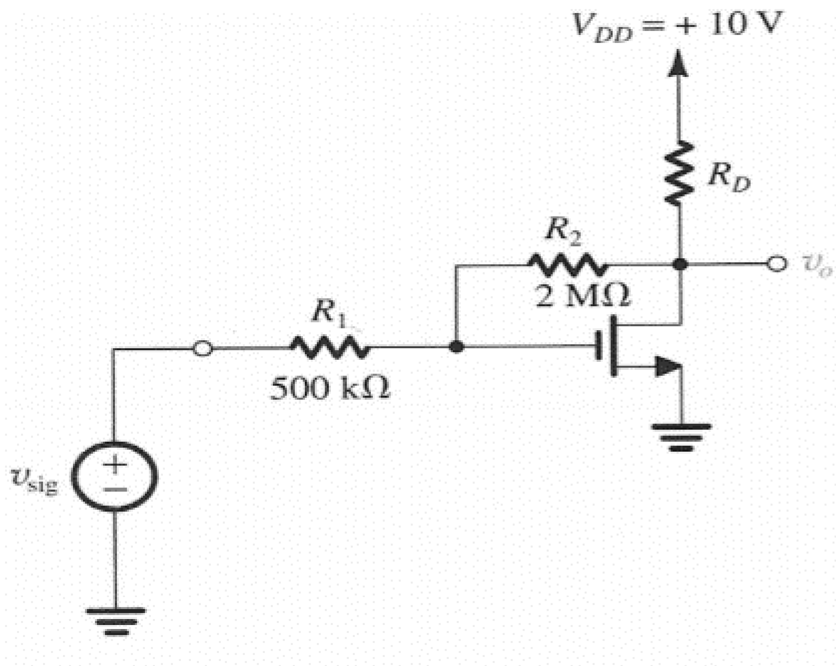


Figure P7.123

a) At DC, $v_{sig} = 0$ shortcircuit. Also

$$V_{GS} = V_{OV} + V_t$$
$$V_{GS} = 0.8V$$

From the voltage division between R_1 and R_2

$$V_{GS} = V_D \frac{R_1}{R_1 + R_2}$$
$$V_D = 4V$$

Using the equation for the drain current taking in account VA

$$I_D = \frac{1}{2}(k_n)(V_{OV})^2 \left(1 + \frac{V_{DS}}{VA}\right)$$
$$I_D = \frac{1}{2}(5)(0.2)^2 \left(1 + \frac{4}{60}\right)$$
$$I_D = 0.107\ mA$$

Now we have the voltage and current going through R_D

$$R_D = \frac{V_{DD} - V_D}{I_D} = \frac{10 - 4}{0.107\ mA}$$
$$R_D = 56\ k\Omega$$

b) The equation for g_m

$$g_m = \frac{2I_D}{V_{ov}} = \frac{2x0.107\ mA}{0.2}$$
$$g_m = 1.07\ {}^{mA}/_{V}$$

The equation for

$$r_o = \frac{VA}{I_D} = \frac{60}{0.107\ mA}$$
$$r_o = 560.7k\Omega$$