Homework #14

Problems 7.25, 7.30, 7.35, 7.36, and 7.54

Problem 7.25 a,b

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 $\lambda = 0.1\ \text{V}^{-1}$, find r_o at the bias point and calculate the voltage gain.

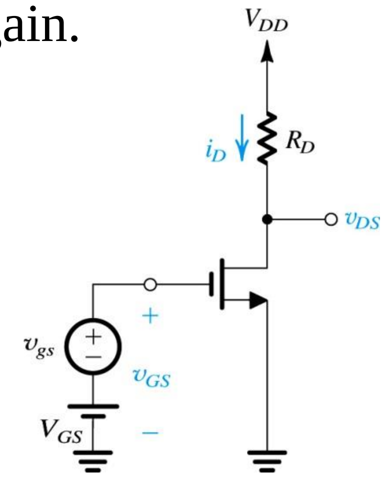


Figure 7.10 Conceptual circuit utilized to study the operation of the MOSFET as a small-signal amplifier.

$$I_D = \frac{1}{2} k_n (V_{GS} - V_t)^2 = \frac{1}{2}\left(5\frac{\text{mA}}{\text{V}^2}\right)(0.6\text{V} - 0.4\text{V})^2 = 0.1\text{mA}$$

$$V_{DS} = V_{DD} - I_D R_D = 1.8\text{V} - (0.1\text{mA})(10\text{k}\Omega) = 0.8\text{V}$$

$$g_m = k_n V_{ov} = k_n (V_{GS} - V_t) = \left(5\frac{\text{mA}}{\text{V}^2}\right)(0.6\text{V} - 0.4\text{V}) = 1\frac{\text{mA}}{\text{V}}$$

Problem 7.25 c,d

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.

(c) Calculate the value of the voltage gain.

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

$$A_v = -g_m R_D = -\left(1\frac{\text{mA}}{\text{V}}\right)10\text{k}\Omega = -10\frac{\text{V}}{\text{V}}$$

$$V_A = \frac{1}{\lambda} = \frac{1}{0.1\text{V}^{-1}} = 10\text{V} \qquad \Rightarrow r_o = \frac{V_A}{I_D} = \frac{10\text{V}}{0.10\text{mA}} = 100\text{k}\Omega$$

$$A_v = -g_m\left(R_D \parallel r_o\right) = -\left(1\frac{\text{mA}}{\text{V}}\right)\left(\frac{10\text{k}\Omega\times100\text{k}\Omega}{10\text{k}\Omega+100\text{k}\Omega}\right) = -9.09\frac{\text{V}}{\text{V}}$$

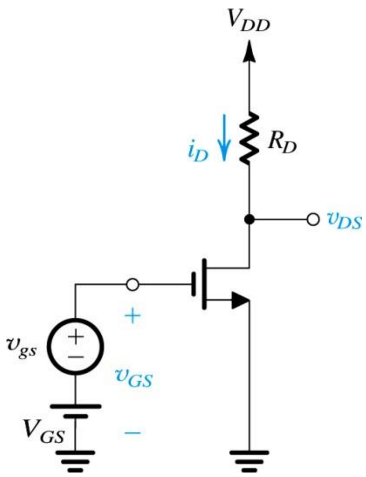


Figure 7.10 Conceptual circuit utilized to study the operation of the MOSFET as a small-signal amplifier.

Problem 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.

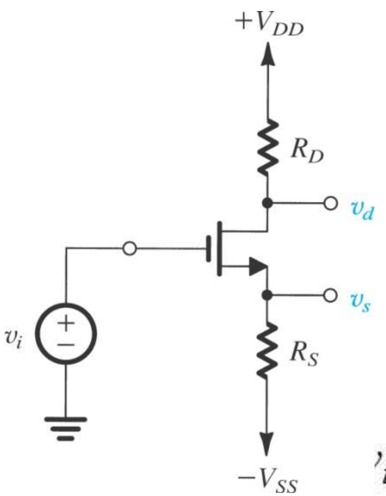
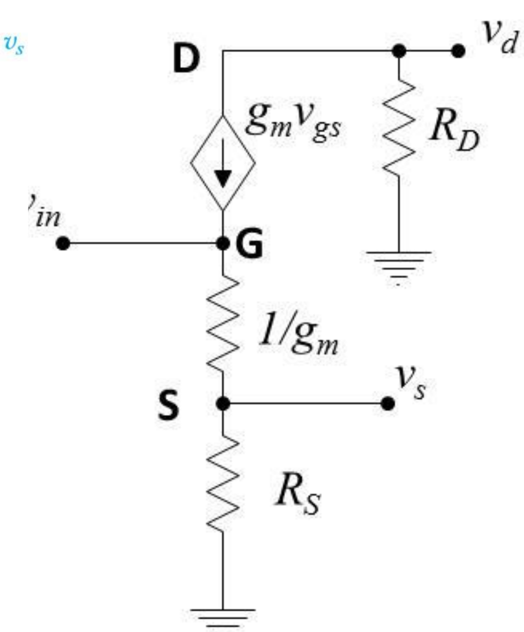


Figure P7.30



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

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

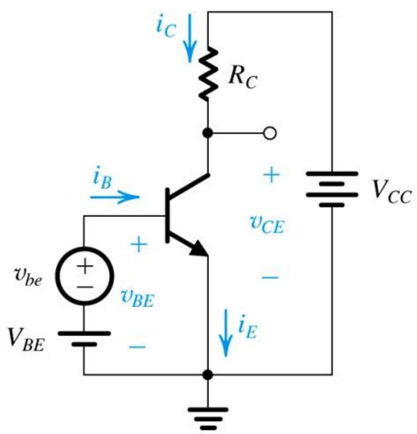
$$v_s = g_m v_{gs} R_S$$

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

$$\frac{v_d}{v_{in}} = \frac{-g_m v_{gs} R_D}{g_m v_{gs}\left(\frac{1}{g_m} + R_S\right)} = \frac{-g_m R_D}{1 + g_m R_S}$$

Problem 7.35

An *npn* BJT with grounded emitter is operated with V_{BE} = 0.700 V, at which the collector current is 0.5 mA. A 5-kΩ resistor connects the collector to a +5 V supply. What is the resulting collector voltage V_C? Now, if a signal applied to the base raises v_{BE} to705 mV, find the resulting total collector current i_C and total collector voltage v_C using the exponential i_C–v_{BE} relationship. For this situation, what are v_{be} and v_c? Calculate the voltage gain v_c/v_{be}. Compare with the value obtained using the small-signal approximation, that is,$-g_m R_C$.



(a)

$$V_C = V_{CC} - I_C R_C = 5.0\text{V} - (0.5\text{mA})(5\text{k}\Omega) = 2.5\text{V}$$

$$I_{C2} = I_{C1} e^{(V_{BE2} - V_{BE1})/V_T} = (0.5\text{mA}) e^{(0.705\text{V} - 0.700\text{V})/0.025\text{V}} = 0.611\text{mA}$$

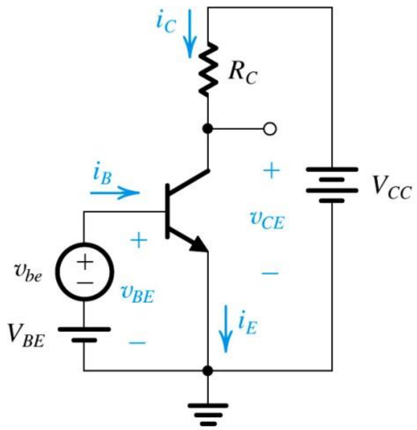
$$V_{C2} = V_{CC} - I_{C2} R_C = 5.0\text{V} - (0.611\text{mA})(5\text{k}\Omega) = 1.945\text{V}$$

$$v_{be} = V_{BE2} - V_{BE1} = 0.705\text{V} - 0.700\text{V} = 5.0\text{mV}$$

$$v_c = V_{C2} - V_{C1} = 1.95\text{V} - 2.5\text{V} = -0.55\text{V}$$

Problem 7.35

An *npn* BJT with grounded emitter is operated with V_{BE} = 0.700 V, at which the collector current is 0.5 mA. A 5-kΩ resistor connects the collector to a +5 V supply. What is the resulting collector voltage V_C? Now, if a signal applied to the base raises v_{BE} to705 mV, find the resulting total collector current i_C and total collector voltage v_C using the exponential i_C–v_{BE} relationship. For this situation, what are v_{be} and v_c? Calculate the voltage gain v_c/v_{be}. Compare with the value obtained using the small-signal approximation, that is,$-g_mR_C$.



(a)

$$A_v = \frac{v_c}{v_{be}} = \frac{-0.55\text{V}}{0.005\text{V}} = -110\frac{\text{V}}{\text{V}}$$

$$g_m = \frac{I_C}{V_T} = \frac{0.5\text{mA}}{0.025\text{V}} == 20\frac{\text{mA}}{\text{V}}$$

$$A_v = -g_mR_C = -\left(20\frac{\text{mA}}{\text{V}}\right)5\text{k}\Omega = -100\frac{\text{V}}{\text{V}}$$

$$A_v = \frac{-100\frac{\text{V}}{\text{V}} - \left(-110\frac{\text{V}}{\text{V}}\right)}{-110\frac{\text{V}}{\text{V}}} = \frac{10}{-110} = -9.09\%$$

Problem 7.36

A transistor with $\beta = 100$ is biased to operate at a dc collector current of 0.5 mA. Find the values of g_m, r_π, and r_e. Repeat for a bias current of 50 μA.

I_C = 0.5 mA

$$g_m = \frac{I_C}{V_T} = \frac{0.5\text{mA}}{0.025\text{V}} = 20\frac{\text{mA}}{\text{V}}$$

$$r_\pi = \frac{\beta}{g_m} = \frac{100}{20\,\text{mA/V}} = 5\text{k}\Omega$$

$$r_e = \frac{r_\pi}{\beta+1} = \frac{5\text{k}\Omega}{101} = 49.5\Omega$$

I_C = 0.05 mA

$$g_m = \frac{I_C}{V_T} = \frac{0.05\text{mA}}{0.025\text{V}} = 2.0\frac{\text{mA}}{\text{V}}$$

$$r_\pi = \frac{\beta}{g_m} = \frac{100}{2.0\,\text{mA/V}} = 50\text{k}\Omega$$

$$r_e = \frac{r_\pi}{\beta+1} = \frac{50\text{k}\Omega}{101} = 495\Omega$$

Problem 7.54

In the circuit shown in Fig. P6.101, the transistor has a β of 200. What is the dc voltage at the collector? Replacing the BJT with one of the hybrid-π models (neglecting ro), draw the equivalent circuit of the amplifier. Find the input resistances R_{ib} and R_{in} and the overall voltage gain (v_o/v_{sig}). For an output signal of ±0.4 V, what values v_{sig} and v_b are required?

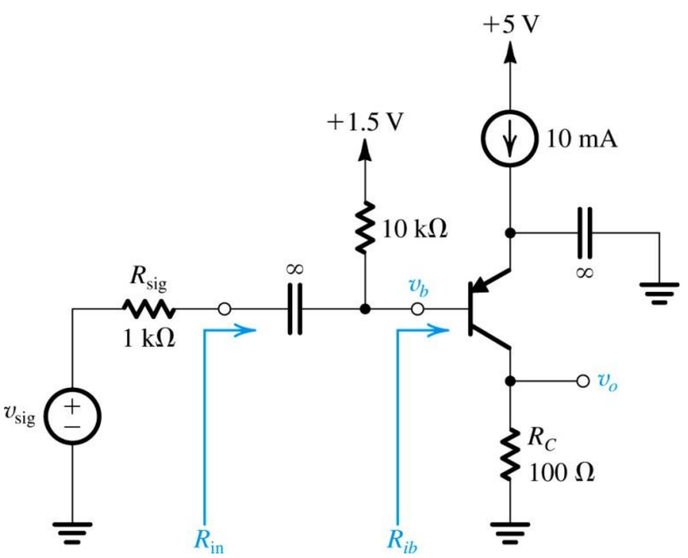


Figure P7.54

$$I_E = 10\text{mA} \qquad I_C = \alpha I_E = \frac{\beta}{\beta+1}10\text{mA} = 9.95\text{mA}$$

$$V_C = I_C R_C = 9.95\text{mA} \times 100\Omega = 0.995\text{V}$$

$$R_{ib} = r_\pi = \frac{V_T}{I_B} = \beta\frac{V_T}{I_C} = 502.5\Omega$$

$$R_{in} = r_\pi \parallel R_B = 502.5\Omega \parallel 10\text{k}\Omega = 478.5\Omega$$

$$G_v \equiv \frac{v_o}{v_{sig}} = -\frac{R_{in}}{R_{in}+R_{sig}}g_m(R_C \parallel R_L \parallel r_o)$$

$$g_m = \frac{I_C}{V_T} = 398\text{ mA/V} \qquad R_C \parallel R_L \parallel r_o = R_C$$

$$G_v = -12.87\text{ V/V}$$