ECE 6416 Assignment 5

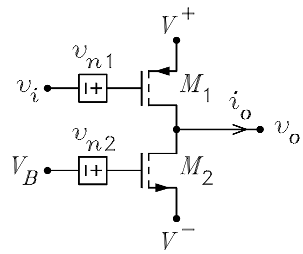
1. A BJT common-emitter amplifier with $R_E = 0$ is biased at $I_C = 0.5\,\text{mA}$. The BJT has a base spreading resistance $r_x = 50\,\Omega$ and a current gain $\beta = 150$. A JFET common-source amplifier with $R_S = 0$ is biased at $I_D = 0.5\,\text{mA}$. The JFET has a threshold voltage $V_{TO} = -2.5\,\text{V}$ and a drain–to-source saturation current $I_{DSS} = 3\,\text{mA}$. Flicker noise can be neglected.

   (a) Solve for the signal source resistance R_s at which the two transistors have the same noise equivalent input voltage v_{ni}. [2905 Ω]

   (b) On the same axes, plot v_{ni} in $\text{V}/\sqrt{\text{Hz}}$ versus R_s for a source resistance in the range 100 Hz to 100 kHz. Use log-log scales with a vertical range from 10^{-9} V to 10^{-7} V.

   (c) On the same axes, plot the noise figure NF versus R_s for the same range of R_s. Use dB-log scales with a vertical range from 0 dB to 10 dB. Is the value of R_s at which the noise figures are equal the same as the value of R_s at which the equivalent noise input voltages are equal?

2. The figure shows a CMOS amplifier consisting of a p-channel input transistor M_1 and an n-channel load transistor M_2 biased by a fixed gate voltage V_B.



   (a) Show that the small-signal voltage gain is given by

$$\frac{v_o}{v_i} = -g_{m1}\left(r_{ds1} \| r_{ds2}\right)$$

   (b) Show that the small-signal short-circuit output current is given by

$$i_{o(sc)} = -g_{m1}\left(v_i + v_{n1}\right) - g_{m2} v_{n2}$$

   (c) If only flicker noise is modeled, show that the mean-square equivalent noise input voltage is given by

$$v_{ni}^2 = \frac{K_{f1}\Delta f}{2\mu_p L_1 W_1 C_{ox}^2 f}\left[1 + \frac{K_{f2}}{K_{f1}}\left(\frac{L_1}{L_2}\right)^2\right]$$

   How should the W and L for each device be chosen to minimize the noise? (Choose $L_2 = L_1\sqrt{K_{f2}/K_{f1}}$ and make L_1 and W_1 large.)

3. The following MOSFET data are given

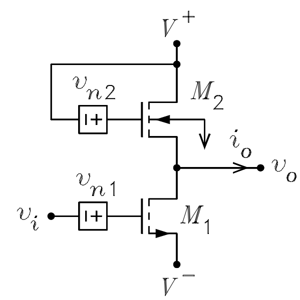
	n-Channel (M_2)	p-Channel (M_1)
$\dfrac{\mu_0 C_{ox}}{2}$	$7\,\mu\mathrm{A/V}^2$	$3\,\mu\mathrm{A/V}^2$
$\dfrac{K_f}{2\mu_0 C_{ox}^2}\displaystyle\int_{20}^{20k}\frac{df}{f}$	$380 \times 10^3\,(\mu\mathrm{V} \times \mu\mathrm{m})^2$	$48 \times 10^3\,(\mu\mathrm{V} \times \mu\mathrm{m})^2$

If the value of C_{ox} is the same for both MOSFETs in the circuit of Problem 2, calculate v_{ni} for the following values of W and L:

	W_1	L_1	W_2	L_2
Case 1	$1000\,\mu$m	$5\,\mu$m	$400\,\mu$m	$4\,\mu$m
Case 2	$1000\,\mu$m	$5\,\mu$m	$200\,\mu$m	$8\,\mu$m
Case 3	$500\,\mu$m	$10\,\mu$m	$400\,\mu$m	$4\,\mu$m

($16.9\,\mu$V, $8.88\,\mu$V, and $33.4\,\mu$V)

4. The figure shows an n-channel NMOS enhancement-mode common-source amplifier with an active n-channel NMOS enhancement-mode load. The two transistors are biased at the same drain current I_D and have the same value for C_{ox}.



(a) Show that the small-signal short-circuit output current is given by

$$i_{o(sc)} = -g_{m1}\left(v_i + v_{n1}\right) + g_{m2} v_{n2}$$

(b) Show that the small-signal output resistance is given by

$$r_{out} = r_{ds1} \| r_{ds2} \| \left(\frac{1}{g_{m2}\left(1 + \chi_2\right)}\right)$$

(c) Show that the open-circuit output voltage is given by

$$v_{o(oc)} = \left(-g_{m1}\left(v_i + v_{n1}\right) + g_{m2} v_{n2}\right) \times r_{ds1} \| r_{ds2} \| \left(\frac{1}{g_{m2}\left(1 + \chi_2\right)}\right)$$

(d) If only flicker noise is modeled, show that the mean-square equivalent noise input voltage is given by

$$v_{ni}^2 = \frac{K_{f1}\Delta f}{2\mu_n C_{ox}^2 L_1 W_1 f}\left[1 + \left(\frac{L_1}{L_2}\right)^2\right]$$

It is obvious that W_1 should be large to minimize the noise. What should L_1 be to minimize the noise? ($L_1 = L_2$)

(e) If only thermal noise is modeled, show that the mean-square equivalent noise input voltage is given by

$$v_{ni}^2 = \frac{4kT\Delta f}{3\sqrt{K_1 I_D}}\left[1 + \sqrt{\frac{L_1 W_2}{L_2 W_1}}\right]$$

How should the W and L for each device be chosen to minimize the noise? (L_2 and W_1 should be large and L_1 and W_2 should be small)

5. Repeat problem 3 for part (d) of problem 4. (14.0 μV, 10.3 μV, and 23.5 μV)

6. A common-source MOSFET amplifier is driven by a source with an output resistance $R_s = 50\,\Omega$. The MOSFET has the parameters $g_m = 2\,\text{mS}$ and $c_{gs} = 1.5\,\text{pF}$. The frequency is $f = 900\,\text{MHz}$. It can be assumed that c_{gd} has been "tuned out" by the addition of a suitable matching network in parallel with the input.

   (a) Calculate the value of an inductor L_s in series with the source which will give a resistance looking into c_{gs} from the gate of $50\,\Omega$. [0.0375 μH]

   (b) Calculate the noise figure NF of the circuit. [8.10 dB]

   (c) If the value of L_s is chosen to make the gate input impedance real, i.e. to cancel c_{gs}, and g_m is varied to obtain an impedance match with the source, calculate the new values of L_s, g_m, and NF. [0.0209 μH, 3.60 mS, 2.22 dB]