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

(b) On the same axes, plot $v_{ni}$ in $V/\sqrt{\text{Hz}}$ 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

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

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

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

How should the $W$ and $L$ for each device be chosen to minimize the noise? ($L_2$ and $W_1$ should be large and $L_1$ and $W_2$ should be small)
3. The following MOSFET data are given

<table>
<thead>
<tr>
<th></th>
<th>n-Channel ((M_2))</th>
<th>p-Channel ((M_1))</th>
</tr>
</thead>
<tbody>
<tr>
<td>(\mu_0 C_{ox}/2)</td>
<td>7 (\mu A/ V^2)</td>
<td>3 (\mu A/ V^2)</td>
</tr>
<tr>
<td>(K_f \frac{2}{2\mu_0 C_{ox}^2} \int \frac{df}{20} \int \frac{df}{f})</td>
<td>(380 \times 10^3 (\mu V \times \mu m)^2)</td>
<td>(48 \times 10^3 (\mu V \times \mu m)^2)</td>
</tr>
</tbody>
</table>

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 \(L\):

<table>
<thead>
<tr>
<th>Case 1</th>
<th>(W_1)</th>
<th>(L_1)</th>
<th>(W_2)</th>
<th>(L_2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Case 1</td>
<td>1000 (\mu m)</td>
<td>5 (\mu m)</td>
<td>400 (\mu m)</td>
<td>4 (\mu m)</td>
</tr>
<tr>
<td>Case 2</td>
<td>1000 (\mu m)</td>
<td>5 (\mu m)</td>
<td>200 (\mu m)</td>
<td>8 (\mu m)</td>
</tr>
<tr>
<td>Case 3</td>
<td>500 (\mu m)</td>
<td>10 (\mu m)</td>
<td>400 (\mu m)</td>
<td>4 (\mu m)</td>
</tr>
</tbody>
</table>

\((16.9 \mu V, 8.88 \mu V, \text{and } 33.4 \mu V)\)

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 \(C_{ox}\).

\(<\text{Diagram of the amplifier}\>\)

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

\[i_o^{(sc)} = -g_{m1}(v_i + v_{n1}) + g_{m2}v_{n2}\]

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

\[r_{out} = r_{ds1}\| r_{ds2}\| \frac{1}{g_{m2}(1 + \chi_2)}\]

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

\[v_{o(oc)} = (-g_{m1}(v_i + v_{n1}) + g_{m2}v_{n2}) \times r_{ds1}\| r_{ds2}\| \frac{1}{g_{m2}(1 + \chi_2)}\]
(d) If only flicker noise is modeled, show that the mean-square equivalent noise input voltage is given by

\[ v_{ni}^2 = \frac{Kf_1 \Delta f}{2\mu_n C_{ox}^2 L_1 W_1 f} \left[ 1 + \left( \frac{L_1}{L_2} \right)^2 \right]^{\frac{3}{2}} \]

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? \((L_2 \text{ and } W_1 \text{ should be large and } L_1 \text{ and } W_2 \text{ should be small})\)

5. Repeat problem 3 for part (d) of problem 4. \((14.0 \mu V, 10.3 \mu V, \text{ and } 23.5 \mu V)\)

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 \( L \) in series with the source which will give a resistance looking into \( c_{gs} \) from the gate of 50 \( \Omega \).

(b) Calculate the noise figure of the circuit.