Problem 7.1: (A cascode current source/mirror)

Consider the following cascade current source/mirror:

Assume that all NFETs are identical and their characteristics are given by:
- $W = 10 \ \mu m$
- $L = 1 \ \mu m$
- $\mu n C_{ox} = 200 \ \mu A/V^2$
- $\lambda_n = 0.11/V$
- $V_{DD} = 5.0 \ \text{V}$
- $V_{TN} = 0.5 \ \text{V}$
- $I_{REF} = 1 \ mA$

a) Find the voltages $V_1$ and $V_2$. 
b) What is the relationship between voltages $V_3$ and $V_{OUT}$?

It might be obvious that if $V_{OUT} = V_1$ then $I_{OUT} = I_{REF}$. However, when $V_{OUT} \neq V_1$ then $I_{OUT} \neq I_{REF}$.

c) What is the lowest value of $V_{OUT}$ at which at least one NFET goes into the linear region? Which NFET?

d) Using the values of voltages $V_1$ and $V_2$ found in part (a), calculate and plot (not sketch) $I_{OUT}$ vs $V_{OUT}$ with $V_{OUT}$ in the range 0 and 5 Volts.

e) Draw a small signal circuit of the current source when looking in from the output terminals.

f) Use the small signal circuit of part (e) to find and expression for the output resistance $r_{oc}$ of the current source.

g) Assuming $V_{OUT} = V_1$, find the actual numerical value of the output resistance $r_{oc}$ using the expression found in part (f).

**Problem 7.2: (A common gate amplifier)**

Consider the following FET common gate amplifier. The two current sources shown have output resistances $r_{oc}$ equal to infinity.

In answering the following parts, DO NOT MAKE ANY APPROXIMATIONS.

![Circuit Diagram](attachment:image.png)

a) Find the open circuit voltage gain $A_v = \frac{v_{out}}{v_{in}}$.

b) Find the input resistance $R_{in}$ assuming a load resistor $R_L$ is connected at the output.
c) Find the output resistance $R_{out}$ assuming that the input voltage source $v_{in}$ is replaced by a voltage source $v_s$ is in series with a resistor $R_s$. 