Exercise 6.1 (Dependent sources) : Determine the Thevenin equivalent network for each network shown below. Note that these networks contain dependent sources.

(A) \[ R \]

(B) \[ \alpha v \]

(C) \[ R_1 \]

Exercise 6.2 (Nonlinear circuits) : The current-voltage characteristic of a photovoltaic energy converter (solar cell) can be approximated by

\[ i = I_1(e^{v/v_T} - 1) - I_2 \]

where the first term characterizes the diode in the dark and \( I_2 \) is a term that depends on light intensity.

Assume \( I_1 = 10^{-9} \) and assume light exposure such that \( I_2 = 10^{-3} \, \text{A} \). Also, suppose that \( v_T = 0.5 \, \text{V} \).

(A) Plot the i-v characteristic of the solar cell. Be sure to note the values of open-circuit voltage and short-circuit current. (Note, however, that the characteristic is clearly nonlinear. Therefore, Thévenin or Norton equivalents do not apply.)

(B) If it is desired to maximize the power that the solar cell can deliver to a resistive load, determine the optimum value of the resistor. How much power can this cell deliver?
**Problem 6.1:** The circuit of a MOSFET inverting amplifier is shown below:

\[ V_S = 20V \]

The desired operating point of the transistor is as follows. \( I_D \) (the DC component of the drain current) is \( 6mA \), and \( V_O \) (the DC component of the drain-to-source or output voltage) is \( 8V \).

(A) What is the proper value of the load resistance \( R \) to achieve this operating point?

(B) Use the square-law current source model for the transistor

\[ i_D = \frac{K}{2}(v_{GS} - V_T)^2 \]

with \( K = \frac{1}{2} \frac{mA}{V} \)

\( V_T = 3V \)

to determine the required value of \( V_I \) to achieve the specified operating point.

(C) What is the transconductance of the transistor at this operating point?

(D) What is the incremental voltage gain \( A = \frac{v_O}{v_i} \)?

**Problem 6.2:** A certain (real) three-terminal device has the incremental model shown below, left. The device to which this model applies is placed in a circuit as shown below, right.

**Device Incremental Model**

**Circuit**
(A) Assume that the DC component of $v_I$ establishes an operating point at which the incremental model shown applies. Draw an incremental model for the circuit and derive an expression for the incremental voltage gain of this circuit,

$$A = \frac{v_o}{v_i}$$

(B) Assume $\beta = 100$, $r_s = 5k\Omega$, and $R_L = 1k\Omega$. Calculate the voltage gain $A$.

(C) Using the incremental model of part (A), derive an expression for the incremental output resistance of the circuit, i.e., the Thevenin equivalent resistance seen looking in at the terminals $aa'$. Hint: Apply an external voltage source at $aa'$ and derive the resulting current at $a'$ or $a$.

(D) Using the parameters in (B) above, calculate the output resistance of the circuit.

**Problem 6.3:** A two-stage amplifier is shown below

The purpose of the voltage divider ($R_1$ and $R_2$) at the left is to establish the proper operating points of the transistors. Assume that the transistors are adequately described by the current source model:

$$i_D = \frac{K}{2} (v_{GS} - V_T)^2$$

Parts (A), (B), (C) assume that no signal is applied. That is, $v_i = 0$.

(A) Determine a value for $v_m$ such that $V_O$, the operating point or DC component of $v_O$, is 5V.

(B) Specify a value for $R_3$ such that $I_{D1}$, the operating point or DC component of $i_{D1}$ (the drain current of the left transistor) is $I_{D1} = 4mA$.

(C) What must be the value of $V_{GS1}$, the operating point or DC component of the gate-to-source voltage ($v_{GS1}$) of the left transistor to establish the above value of $I_{D1}$?

(D) Subject to the constraint $R_1 + R_2 = 10k\Omega$, determine $R_1$ and $R_2$ such that the left transistor is at the desired operating point ($V_{GS1}, I_{D1}$).
(E) Draw and label an incremental or small-signal model which can be used to calculate the incremental component $v_o$ of the output voltage.

(F) Calculate the incremental voltage gain $A = \frac{v_o}{v_i}$ of this circuit at the operating points specified in parts (A) through (C).

**Problem 6.4:** Sketch carefully and dimension the $i - v$ characteristic at the terminals for the circuit below: