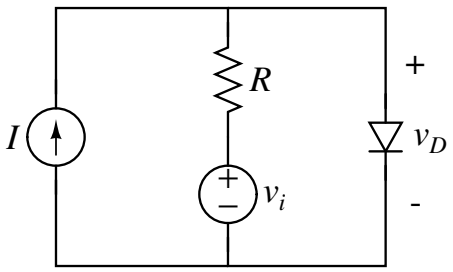
Massachusetts Institute of Technology
Department of Electrical Engineering and Computer Science

6.002 – Circuits and Electronics
Spring 2003

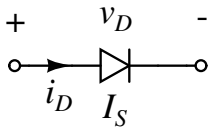
Handout S03-024 - Homework #5

Issued: Wed. Mar 5
Due: Fri. Mar 14

Problem 5.1: A semiconductor diode can be used as a variable attenuator:



In this diagram the current source I establishes the steady DC current in the diode (the operating-point current), while v_i is the input to be attenuated. R is sufficiently large to insure that the operating-point current in the diode is approximately I.



The i-v characteristic of the diode is $i_D = I_S\left(e^{\frac{qv_D}{kT}} - 1\right)$.

(A) Derive an expression for the incremental conductance g of the diode. Assume that $e^{\frac{qv_D}{kT}} >> 1$. That is, the current I is large enough so that the diode is well into the forward, or conducting, region.

(B) Show that g can be expressed as $g = I\left(\frac{q}{kT}\right)$.

(C) Draw a complete incremental (small-signal) model for the circuit above. Explain why the current source does not appear in this model.

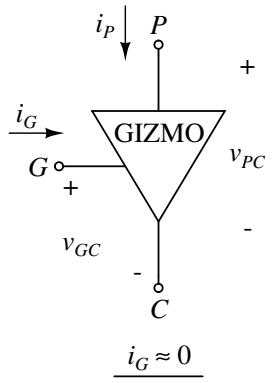
(D) Derive an expression for the attenuation of the circuit. that is, derive an expression for A:

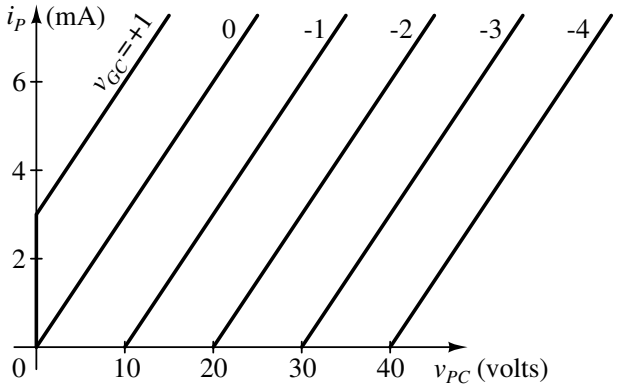
$$A = \frac{v_d}{v_i}$$

where v_d is the incremental component of the diode voltage. Assume $R >> \frac{1}{g}$ and show that the attenuation is proportional to I.

(E) If the magnitude of v_d is too large, this voltage will be distorted because the linear approximation implied in the definition of g becomes invalid. What is a reasonable upper bound for $|v_d|$? **Hint:** Think Taylor series expansion of $i_D = f(v_D)$.

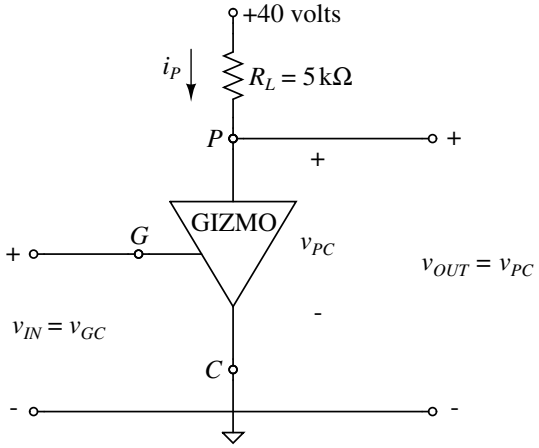
Problem 5.2: The Gizmo whose circuit symbol is shown below is an electronic valve. The output characteristic of the Gizmo is shown as well.





Values of v_{GC} are in volts

The Gizmo functions as an amplifier in the circuit shown below:



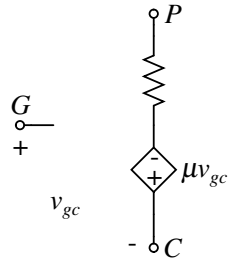
(A) When no signal is present, i.e., when $v_{IN} = V_{IN}$, the circuit is to have a current at P of $i_P = 3\text{mA}$. That is, the quiescent or operating-point current is to be $I_P = 3\text{mA}$.

Specify the operating-point value of V_{IN} that will produce the desired operating point.

Hint: Think load line.

(B) What is the value of V_{PC} at the operating point?

(C) An incremental model for the Gizmo at any operating point in the output characteristics is shown below.



r_p and μ are constants which can be derived directly from the output characteristics above.

(D) Assume $r_p = 1.5\text{k}\Omega$ and $\mu = 15$.
(These are not the correct values corresponding to the output characteristics above, but will do for this part of the problem)

Draw a complete incremental model for the amplifier circuit shown above. Label all component values.

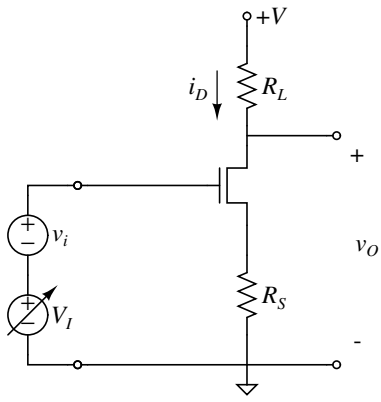
(E) Calculate the incremental voltage gain of this amplifier:

$$A_v = \frac{v_{out}}{v_{in}}$$

Where v_{in} and v_{out} are the incremental components of the input and output voltages respectively.

(F) For extra credit, determine the approximate correct values of r_p and μ from the output characteristics.

Problem 5.3: A FET is used as the control valve in the amplifier circuit shown below.



Note: $v_i \neq v_{gs}$ for this circuit!

V_I provides a steady or DC voltage to establish an operating-point drain current of $I_D = 50\ \mu\text{A}$.

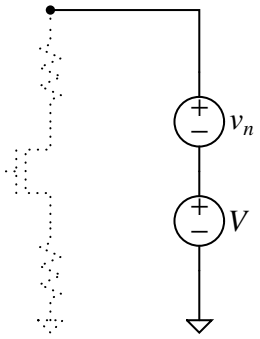
v_i is the incremental input voltage.

v_O is the total output voltage expressed as $v_O = V_O + v_o$, where v_o is the incremental output voltage.

(A) Draw and label the complete incremental model of this amplifier.

(B) Derive an expression for the incremental voltage gain $A_v = \frac{v_o}{v_i}$ in terms of R_S, R_L, and the transconductance g_m.

(C) Assume now that the source of the supply voltage V has been damaged and produces in addition to V a noise source v_n. The defective supply can be modeled as:



Draw and label an incremental model for the amplifier which takes into account this noisy voltage source.

(D) Using that model, determine the component of v_o that results from v_n.

Hint: Think superposition.