EECS40 **Spring 2004**

Midterm Exam # 2
April 15, 2004
Time Allowed: 80 minutes

Name: Solution, ____________
Last First

Student ID #:____________, Signature:____________

Discussion Section:____________

This is a closed-book exam, except for use of two 8.5 x 11 inch sheets of your notes. Show all your work to receive full or partial credit. Write your answers clearly in the spaces provided.

Problem #:	Points:
1	/10
2	/20
3	/20
Total	/50

1.

a) (5 points)

A silicon sample is uniformly doped with Boron to a concentration of $10^{16}\ atoms/cm^3$.
Determine the resistivity of the sample at room temperature.
Use electron mobility = $\mu_n = 1000$ cm^2/v-s, hole mobility = $\mu_p = 400$ cm^2/v-s,

$q = 1.6 \cdot 10^{-19}$ C and $n_i = 10^{10}$ at room temperature.

$Na = 10^{16}\ cm^{-3} \qquad p = 10^{16}\ cm^{-3} >> n_i$

p-type :

$$\rho = \frac{1}{qp\mu_p} = \frac{1}{1.6\times10^{-19}C \cdot 10^{16}cm^{-3}\times 400\ cm^2/V\text{-}s} = \frac{1}{0.64}\ \Omega\text{-}cm$$

$$= 1.56\ \Omega\cdot cm$$

b) (5 points)

The same sample is then to be counter doped to a depth of $5\mu m$ with Arsenic atoms to create a resistor technology with resistance of $100\Omega/\square$.

Determine the required Arsenic doping density.

$$R_s = \frac{\rho'}{t}$$

$$\rho' = R_s t = 100\Omega \cdot 5\mu m = 0.05\ \Omega\text{-}cm$$

$\rho' \ll \rho \Rightarrow$ the sample becomes n-type

$$\rho' = \frac{1}{qn\mu_n + qp\mu_p} \doteq \frac{1}{qn\mu_n} = \frac{1}{q(N_d - N_a)\mu_n}$$

$$\therefore\ N_d - N_a = n = \frac{1}{q\mu_n\rho'} = \frac{1}{1.6\times10^{-19}c \times 1000\ cm^2/V\cdot s \times 0.05\Omega\cdot cm}$$

$$= 1.25 \times 10^{17}\ cm^{-3}$$

$$N_d = n + N_a = 1.25\times10^{17}\ cm^{-3} + 10^{16}\ cm^{-3}$$

$$= 1.35\times10^{17}\ cm^{-3}$$

2.

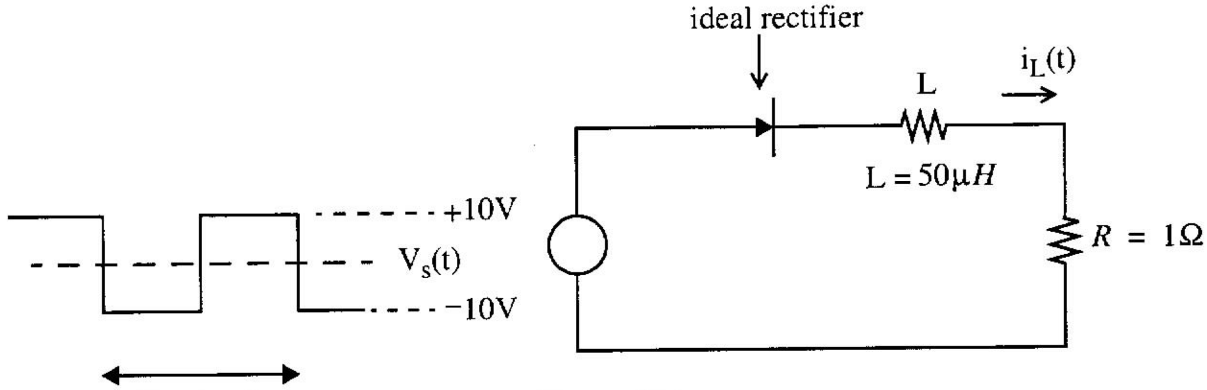
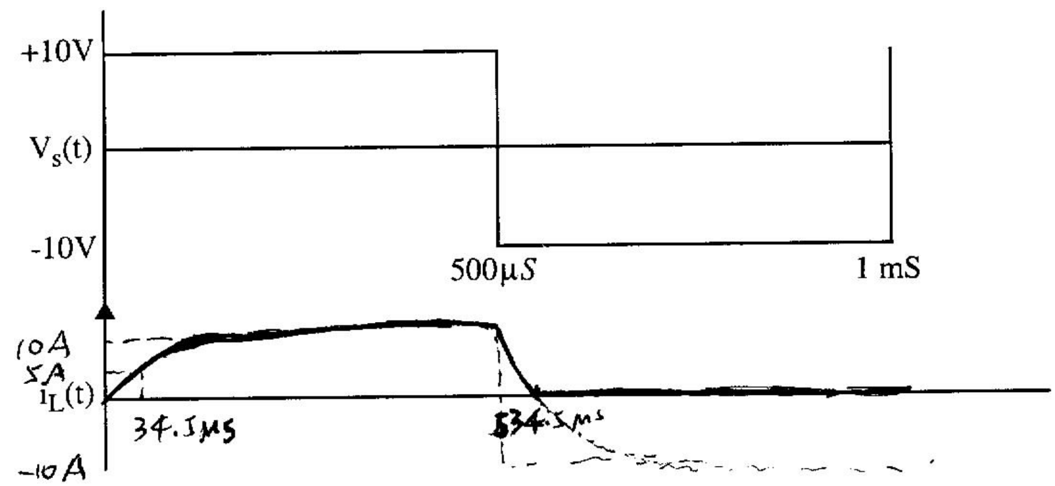


Figure 2(a)

a) (10 points)
The diode in Figure 2(a) is ideal. The waveform $V_S(t)$ is a balanced square wave with amplitude of 10 V and period of 1mS. Take $L = 50\mu H$ and $R = 1\Omega$.

The circuit operates in a periodic steady state. Sketch and carefully dimension one period of the $i_L(t)$ waveform on the axes below. Make reasonable approximations.



$$\tau = \frac{L}{R} = 0.05\,ms$$

$$0.69\,\tau = 0.0345\,ms = 34.5\,\mu s$$

b) (10 points)

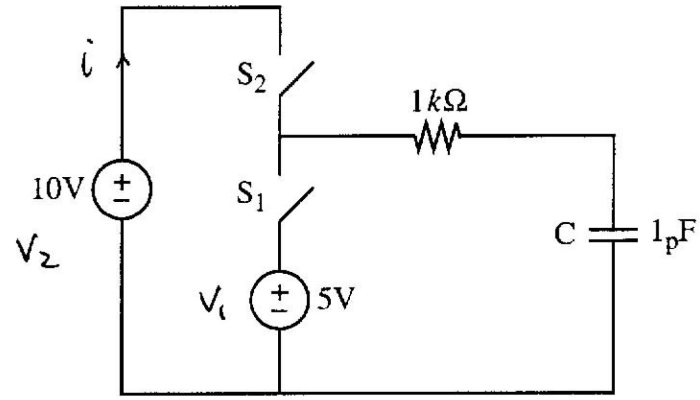


Figure 2(b)

In the circuit of Figure 2(b), switch S_1 is initially closed and the circuit is in equilibrium. Switch S_1 is then opened and switch S_2 is closed for a sufficiently long time so that the circuit can be considered to be in equilibrium. How much energy is dissipated in the $1k\Omega$ resistor during the transient?

Hint: Think in terms of net charge and energy flow. Detailed transient analysis is **NOT** needed.

Energy changed in capacitor

$$\Delta W_c = \frac{1}{2} CV_2^2 - \frac{1}{2} CV_1^2$$

$$= \frac{1}{2} C (100V^2 - 25V^2)$$

$$= \frac{1}{2} \times 10^{-12} F \times 75 V^2$$

$$= 3.75 \times 10^{-11} J$$

Total energy delivered by voltage source V_2 :

$$W_{source} = \int V_2 i \, dt = V_2 \int i dt = V_2 \Delta Q$$

$$= V_2 (CV_2 - CV_1)$$

$$= 5 \times 10^{-11} J$$

Energy dissipated in resistor

$$W_R = W_S - \Delta W_c = 1.25 \times 10^{-11} J$$

3.

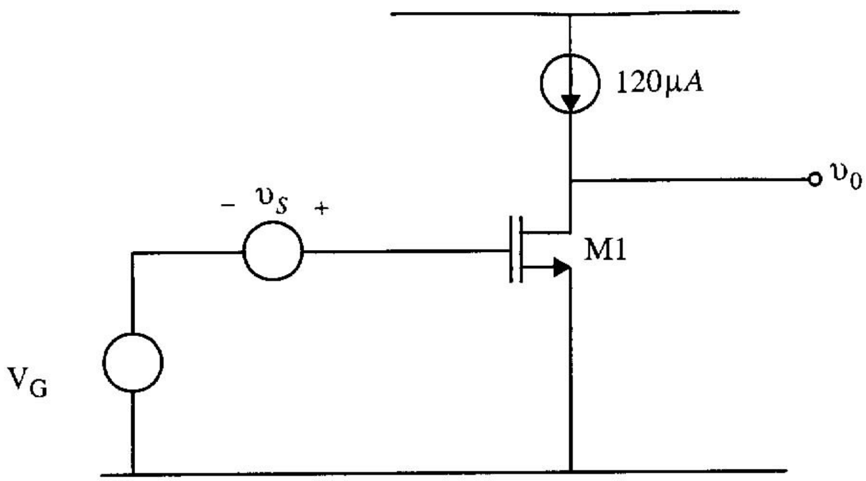


Figure 3

$\lambda = 0.1V^{-1}$

$V_T = 0.5V$

$k' = 100\mu A/V^2$

$\frac{W}{L} = 2$

Mosfet M1 in Figure 3 is modeled by $i_D = \frac{1}{2}k'\frac{W}{L}(v_{GS} - V_T)^2(1 + \lambda v_{DS})$ in saturation with parameters listed in Figure 3.

a) (5 points)
Determine the requires bias voltage V_G so that M1 is biased in saturation with $V_{DS} = 2V$. Take $v_S = 0$ for this calculation.

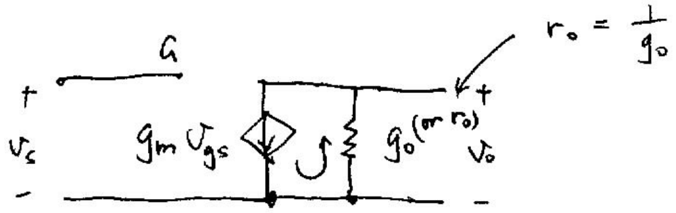
$$i_D = \frac{1}{2} k' \frac{W}{L} (V_{GS} - V_T)^2 (1 + \lambda V_{DS})$$

$$\Rightarrow \quad 120\mu A = \frac{1}{2} \times 100\mu A/V^2 \times 2 \times (V_{GS} - 0.5V)^2 (1 + 0.1V^{-1} \times 2V)$$

$$\Rightarrow \quad V_{GS} = 1.5V$$

b) (10 points)

Draw the small signal model for this circuit. Compute the parameters of this small signal model.



$$g_m = \frac{\partial i_D}{\partial v_{gs}} = k' \frac{W}{L} (V_{GS} - V_T)(1 + \lambda V_{DS})$$

$$= 100 \mu A/V^2 \times 2 \times (1.5V - 1V)(1 + 0.1V^{-1} \times 2V)$$

$$= 2.4 \times 10^{-4} S$$

$$g_o = \frac{\partial i_D}{\partial v_{DS}} = \frac{1}{2} k' \frac{W}{L} (V_{GS} - V_T)^2 \cdot \lambda$$

$$= \frac{1}{2} \times 100 \mu A/V^2 \times 2 \times (1.5V - 1V)^2 \times 0.1 V^{-1}$$

c) (5 points)

$$= 10^{-5} S$$

Determine the small signal gain $A_\upsilon = \frac{\upsilon_0}{\upsilon_S}$.

$$v_o = - g_m v_{gs} \cdot r_o$$

$$= - g_m v_s \cdot \frac{1}{g_o}$$

$$A_v = \frac{v_o}{v_s} = - \frac{g_m}{g_o} = - \frac{2.4 \times 10^{-4} S}{10^{-5} S} = -24$$