SOLUTIONS – EE42/100 MT #2 FALL 2005

Problem 1 – Short Answers (8 points)

If you make any assumption that you think might be unclear to the grader, mark that question with an asterisk (*) in the right-hand margin and explain your assumption on the back of the page. Note that some of the non-true/ false questions may have more than one correct answer.

[1 pt.] (a) T ✓ F___ The peak value of the AC voltage at the wall outlets in your lab in Cory Hall is 170 volts.

[1 pt.] (b) T___ F ✓ An ideal discharged capacitor is a nonlinear component.

[1 pt.] (c) T___ F X A phasor voltage ***V*** is a function of time.

[1 pt.] (d) Name a component or device that turns a steady current into a steady voltage.

Answer: Resistor

[1 pt.] (e) Name a two-terminal component that can never pass a steady current with a steady voltage applied.

Answer: Capacitor

[2 pts.] (f) Name two components or devices that can increase the amplitude of an AC voltage.

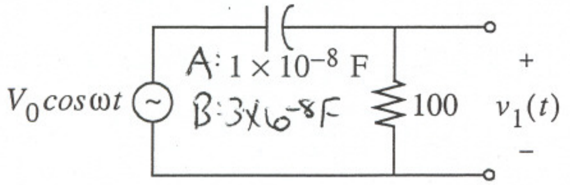
Answer: Transformer; amplifier; MOSFET

[1 pt.] (g) Name a component or device that can use a steady voltage to control a steady current.

Answer: MOSFET; voltage-controlled current source

Problem 2 – Phasors (13 points) KEY

[6 pts.] (a) Determine the Thévenin equivalent of the following circuit using phasors:



where ω = 10^6 rad/sec

$$\underline{V}_{oc} = \underline{V}_{TH} = V_0 \cdot \frac{R}{R+1/j\omega C} = \frac{j\omega RC}{1+j\omega RC} V_0$$

$$= V_0 \cdot \frac{j\omega RC}{1+j\omega RC} \cdot \frac{1-j\omega RC}{1-j\omega RC} = \frac{\omega^2R^2C^2 + j\omega RC}{1+\omega^2R^2C^2}$$

A: $C = 10^{-8}F$, $\omega RC = 1$ B: $C = 3\times10^{-8}F$, $\omega RC = 3$

A: $\boxed{\underline{V}_{TH} = \frac{1+j}{2} V_0}$ $\boxed{\underline{Z}_{TH} = \frac{100-100j}{2}}$

$$\underline{Z}_{TH} = \frac{R \cdot 1/j\omega C}{R + 1/j\omega C} = \frac{R}{1+j\omega RC}$$

(Express answers in simplest rectangular form $A + B_j$.)

$$\underline{Z}_{TH} = \frac{R(1-j\omega RC)}{1+\omega^2R^2C^2}$$

B: $\underline{V}_{TH} = \frac{9+3j}{10} V_0$ $\underline{Z}_{TH} = \frac{100-300j}{10}$

$= 10-30j$

[3 pts.] (b) What is the time average power in the 100 ohm resistor?

A: $\boxed{P_{ave} = }$

$$= \frac{1}{2} Re\left[VI^*\right] = \frac{1}{2} Re\left[\underline{V}_{TH} \cdot \frac{\underline{V}_{TH}^*}{R}\right]$$

$$= \frac{1}{2R} |V_{TH}|^2, \quad |V_{TH}| = \frac{\sqrt{\omega^4R^4C^4 + \omega^2R^2C^2}}{1+\omega^2R^2C^2} |V_0|$$

A: $\frac{1}{200} \cdot \left(\frac{1 \cdot \sqrt{2}}{2} V_0\right)^2 = \frac{V_0^2}{400}$

B: $\frac{1}{200} \cdot \left(\frac{3 \cdot \sqrt{10}}{10}\right)^2 V_0^2 = \frac{9 V_0^2}{2000}$

$$= \frac{\omega RC \sqrt{\omega^2R^2C^2+1}}{1+\omega^2R^2C^2} |V_0|$$

[4 pts.] (c) The output voltage is of the form $v_1(t) = V_1 cos(\omega t + \phi)$. Determine V_1 and ϕ.

$\boxed{V_1 = |V_{TH}|}$ $\boxed{\phi = \measuredangle V_{TH}}$

$$\measuredangle V_{TH} = \measuredangle \frac{j\omega RC}{\omega^2R^2C^2} = \measuredangle \frac{1}{\omega RC}$$

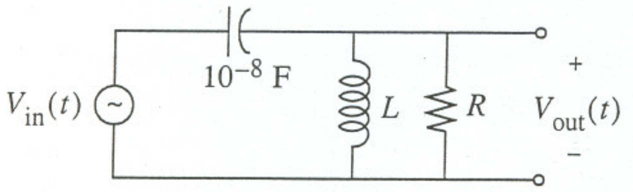
(Express answers in simplest rectangular form $A + B_j$.)

A: $|V_{TH}| = \frac{\sqrt{2}}{2} V_0$ $\measuredangle V_{TH} = \tan^{-1} 1$

B: $|V_{TH}| = \frac{3\sqrt{10}}{10} V_0$ $\measuredangle V_{TH} = \tan^{-1} 1/3$

10:35

Problem 3 – Phasors (18 points)



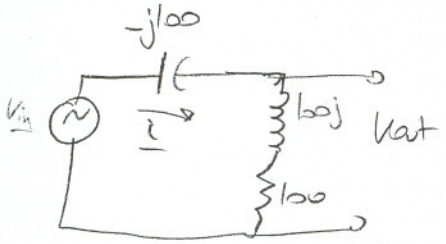
where $V_{in}(t) = cos(\omega t)$ and $L = 2\times10^{-4}$ H, $R = 200\Omega$

[2 pts.] (a) What is $|V_{out}(t)|$ for $\omega = 0$?

$\boxed{0}$ Since C is open circuit

[2 pts.] (b) What is $|V_{out}(t)|$ for $\omega \to \infty$?

C is short circuit $\boxed{1}$



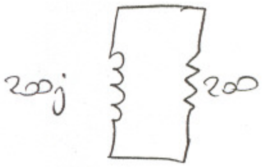
[8 pts.] (c) What is $|V_{out}(t)|$ for $\omega = 10^6$?

$\boxed{\sqrt{2}}$

$i = \frac{V_{in}}{100}$,

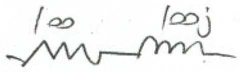
$V_{out} = \frac{V_{in}}{100} \cdot (100 + 100j)$

$= V_{in} \cdot (1+j)$



$\frac{200\cdot200j}{200+200j} = \frac{200j}{1+j} = \frac{200j(1-j)}{2}$

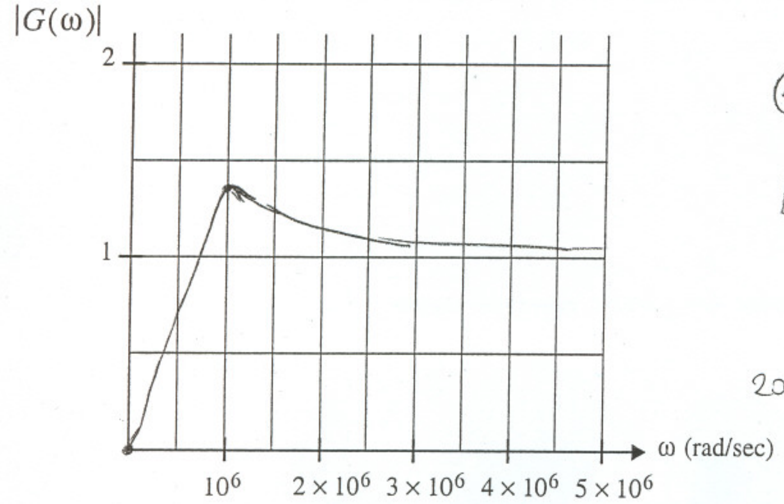
$= 100+100j =$

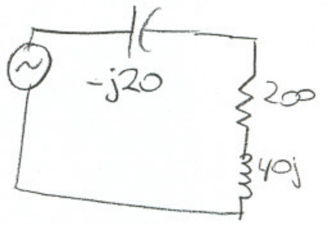


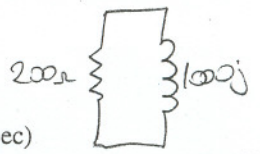
$\left|\frac{V_{out}}{V_{in}}\right|_{\omega=10^6} = \sqrt{2}$

[6 pts.] (d) Let $G(\omega) = \frac{V_{out}}{V_{in}}$. Sketch the general behavior of $|G(\omega)|$ vs. ω on axes provided. (Note linear scales.)

check $G(\omega = 5\times10^6) \simeq 1$







$\frac{200\cdot1000j}{200+1000j} = \frac{1000j}{1+5j}$

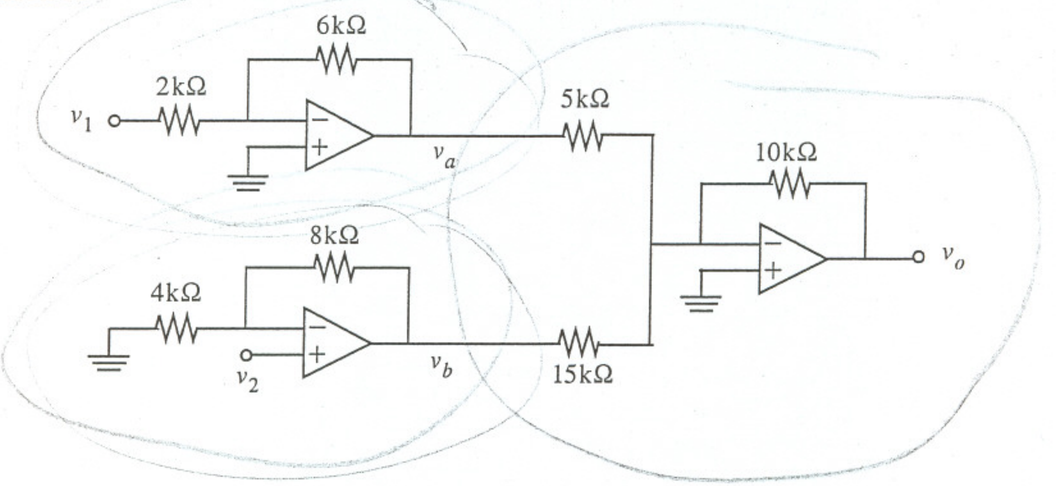
$= \frac{(1000j)(1-5j)}{1+25} = \frac{5000+1000j}{26}$

$\approx 200+40j$

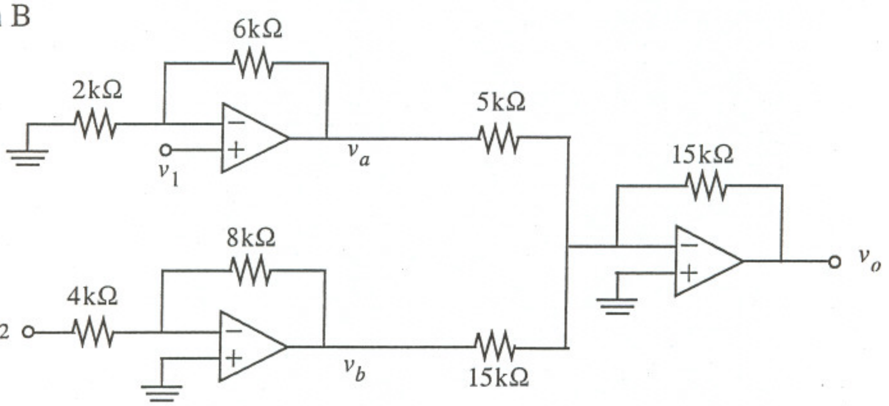
Problem 4 – Short Answers (15 points)

A circuit made with three ideal op amps is shown below:

version A



version B



[6 pts.] **(a)**Of what three basic op-amp circuits is this circuit composed? (Circle them individually.)

Sub-circuit with output v_a is an inverting amplifier

Sub-circuit with output v_b is non- inverting amplifier

Sub-circuit with output v_o is Inverting summing amplifier

[9 pts.] **(b)**Find the voltages v_a, v_b, and v_o in terms of v_1 and v_2. Make your methods clear to the grader.

v_a = $-3v_1$ $\qquad \frac{V_1}{2k} = -\frac{V_a}{6k}, \; V_a = -3V_1$

v_b = $3v_2$ $\qquad v_b \cdot \frac{4}{12} = v_2, \; v_b = 3v_1$

v_o = $6v_1 - 2v_2$

$$-\frac{v_o}{10k} = \frac{v_a}{5k} + \frac{v_b}{15k}$$

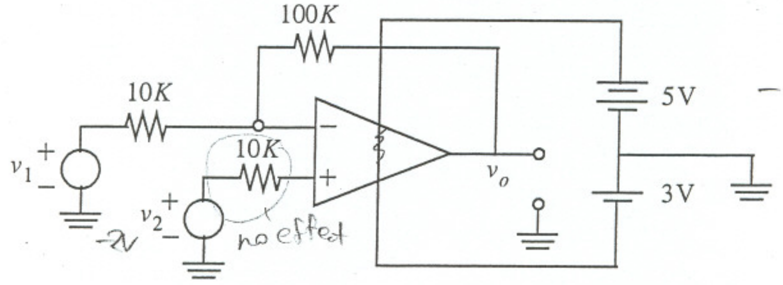
$$v_o = -2v_a - \frac{2}{3}v_b$$

$$= 6v_1 - 2v_2$$

Problem 5 (20 points)

An ideal op amp is shown with its input sources and its power supplies.

version A



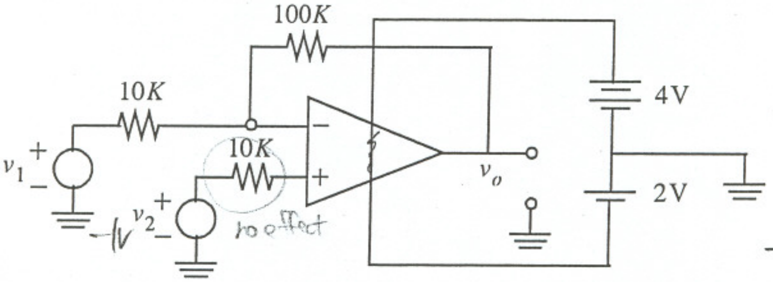
$-3V < v_o < 5V$

$-3V < -10v_1 - 22 < 5V$

$19V < -10v_1 < 27V$

$-1.9V > v_1 > -2.7V$

version B



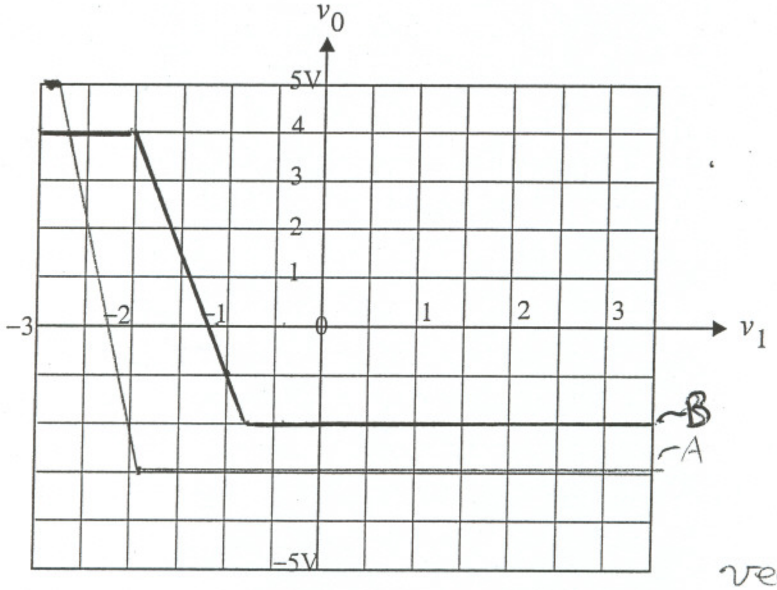
$-2V < v_o < 4V$

$-2V < -5v_1 - 6 < 4V$

$4V < -5v_1 < 10V$

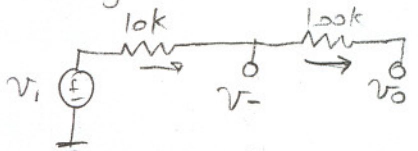
$-4/5 > V_1 > -2V$

Given $v_2 = \{-2V, -1V\}$ plot V_0 vs. V_1 for $-3 \le v_1 \le 3$ volts.



Version A

in negative feedback $v- \approx v+$

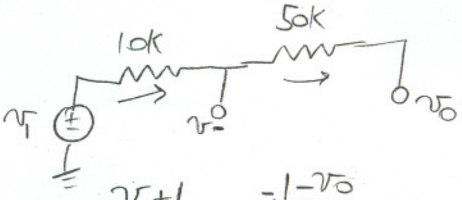


$$\boxed{v_o = -10v_1 - 22}$$

$$\frac{v_1 - (-2V)}{10k} = \frac{-2V - v_o}{100k}$$

$$10(v_1 + 2) = -2 - v_o$$

version B



$$\frac{v_1 + 1}{10k} = \frac{-1 - v_o}{50k}$$

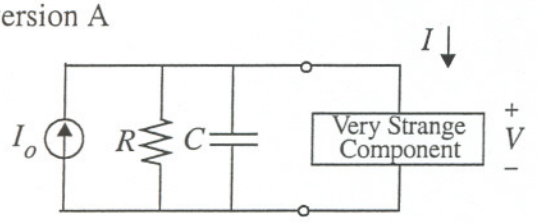
$$5(v_1 + 1) = -1 - v_o$$

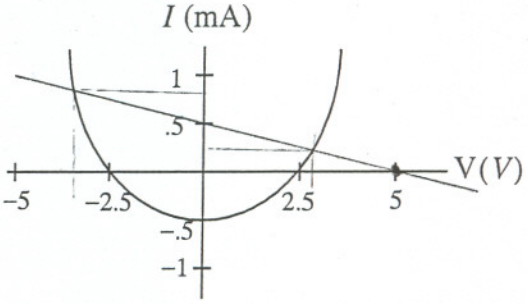
$$v_o = -5v_1 - 6$$

Problem 6 (10 points)

A DC circuit that was connected up one week ago is shown attached to a Very Strange Component whose I-V characteristic is shown. find I and V for this circuit. Make your method clear for the grader and state any assumptions you make.

version A





I_o = 0.5 mA
R = 10kΩ
C = 300μF

I = 0.3mA

V = 2.7V

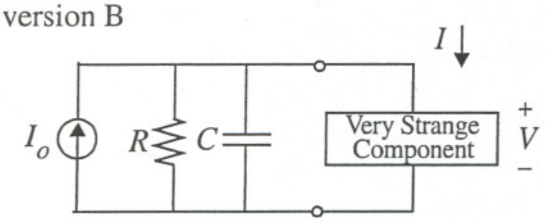
or I = 0.8mA   V = -3.5V

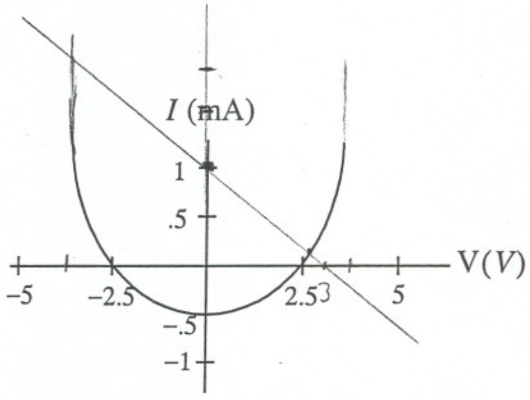
Bistable - circuit could be in either state.

load line by KCL

$I_0 - \frac{V}{R} - I = 0, \; I = I_0 - \frac{V}{R}$

version B





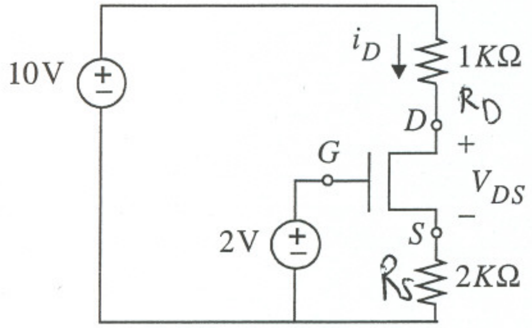
I_o = 1 mA
R = 3kΩ
C = 100μF

I = 0.1mA

V = 2.6V

or I = 2mA   V = -3.7V

Problem 7 (16 points) KEY



$V_{t_0} = 1\text{V}$ (threshold voltage)

$K = \frac{500\mu\text{A}}{V^2}$

[3 pts.] (a) What is i_D as a function of V_{DS}?

~~By KVL~~

$i_D = \frac{10V - V_{DS}}{3k\Omega}$

[3 pts.] (b) What is V_{GS} as a function of i_D?

$V_{GS} = 2V - i_D(2k\Omega)$

[10 pts.] (c) What is V_{DS} at quiescent point?

(Hint: $i_D = K(V_{GS} - V_{t_0})^2$. If needed, you may use $\sqrt{2} \approx 1.4$, $\sqrt{3} \approx 1.7$.)

$V_{DS} \approx 9.46$ volts

$i_D = K(V_{GS} - V_{t_0})^2$

consubstitute $i_D = \frac{2V - V_{GS}}{2000}$ from (b).

$$\frac{2V - V_{GS}}{2000} = K(V_{GS} - 1)^2$$

$$2V - V_{GS} = V_{GS}^2 - 2V_{GS} + 1$$

$$V_{GS}^2 - V_{GS} - 1V = 0$$

$$V_{GS} = \frac{1 \pm \sqrt{1+4}}{2} = \frac{1 \pm \sqrt{5}}{2}$$

$\sqrt{5} \simeq 2.2$, so $V_{GS1} = \frac{1}{2}(1 - 2.2) < 0$ not possible.

$$V_{GS2} = \frac{1}{2}(1 + 2.2) = \frac{3.2}{2} = 1.6V.$$

Now solve for i_D

$i_D = K(1.6 - 1)^2$ (note $6 \times 6 = 36$)

$= (500 \times 10^{-6})(0.36)$ $\left(\begin{array}{r}18\\ 2\overline{)36}\end{array}\right)$

$= (1000 \times 10^{-6})(0.18)$

$= 0.18mA.$

Now

$V_{DS} = 10V - (3000)(0.18mA)$ $(2 \times 3 \times 9 = 54)$

$= 10V - 0.54 = 9.46$