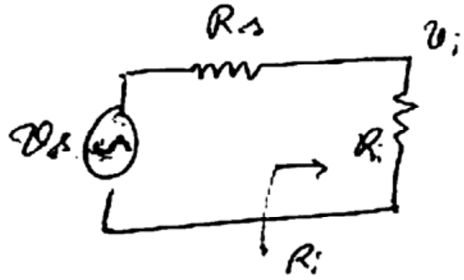
iii) Find the voltage gain $A_{v1}=v_i/v_s$, voltage gain $A_{v2}=v_o/v_i$ and the overall voltage gain $A_v=v_o/v_s$. ***Show the derivation of necessary expressions in your computations*** **(9 marks):**

$A_{v_1} = \dfrac{v_i}{v_s}$



$A_{v_1} = \dfrac{v_i}{v_s} = \dfrac{R_i}{R_i+R_s} = \dfrac{20}{20+80} = \dfrac{20}{100} = \underline{\underline{0.2}}$

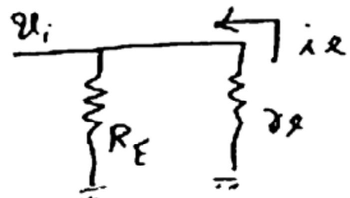
$A_{v_2} = v_o/v_i$

$v_o = -\alpha i_e R_L' \rightarrow (1)$; $R_L' = R_C \| R_L = 4k \| 4k = 2k$

we have

$v_i = -i_e r_e$

$\therefore i_e = -v_i/r_e$



$\therefore$ (1) $\Rightarrow$

$v_o = -\alpha\left(-\dfrac{v_i}{r_e}\right)\cdot R_L'$

$A_{v_2} = v_o/v_i = \dfrac{\alpha R_L'}{r_e} = \dfrac{0.98 \times 2k}{25} = \underline{78.4}$

$\alpha = \dfrac{\beta}{\beta+1} = \dfrac{50}{50+1} = 0.98$

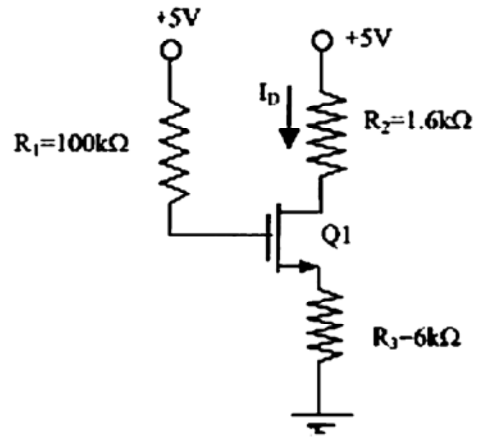
$\therefore A_v = A_{v_1} \times A_{v_2} = 0.2 \times 78.4 = \underline{\underline{15.68}}$

$A_{v1}=$ 0.2

$A_{v2}=$ 78.4

$A_v=$ 15.68

4) MOSFET.



IGNORE λ

a) In the figure above, the transistor has V_t=1V, V_A=~~30V~~ ∞, k_n'=100μA/V^2, L=1μm and W=10μm.

i) Find the bias current I_D (5 marks):

Assume saturation. $I_D = \frac{1}{2} k_n' \frac{W}{L} (V_{GS} - V_t)^2$

$k_n' = 100\mu A$, $\frac{W}{L} = 10$

$\frac{1}{2} k_n' = 0.5 \times 10^{-3}$

$V_{GS} = V_G - V_S$
$= 5 - I_D R_3$
$= 5 - 6\times10^3 \times I_D$

$V_{GS} - V_t = 4 - 6\times10^3 \times I_D$

$(V_{GS} - V_t)^2 = 36\times10^6 \times I_D^2 - 48 I_D \times 10^3 + 16$

$\therefore I_D = 0.5\times10^{-3} [36\times10^6 I_D^2 - 48\times10^3 \times I_D + 16]$

$I_D = 18\times10^3 I_D^2 - 24 I_D + 8\times10^{-3}$

$\therefore 18\times10^3 I_D^2 - 25 I_D + 8\times10^{-3} = 0$

$\therefore I_D = \left.\begin{matrix} 0.89\text{ mA} \\ 0.5\text{ mA}\end{matrix}\right\}$ or

$I_D = 0.5$ mA $V_D = 5 - 1.6 \times 0.5$
$= 5 - 0.8 = 4.2$

$V_D > V_G - V_t \Rightarrow 4.2 > 4$

I_D= 0.5×10^{-3}

ii)) Verify the mode of operation of the transistor and state what mode the transistor is in (3 marks):

$V_{DS} \geq V_{GS} - V_t$ for saturation

$V_D > V_G - V_t$

$4.2 > 5 - 1$

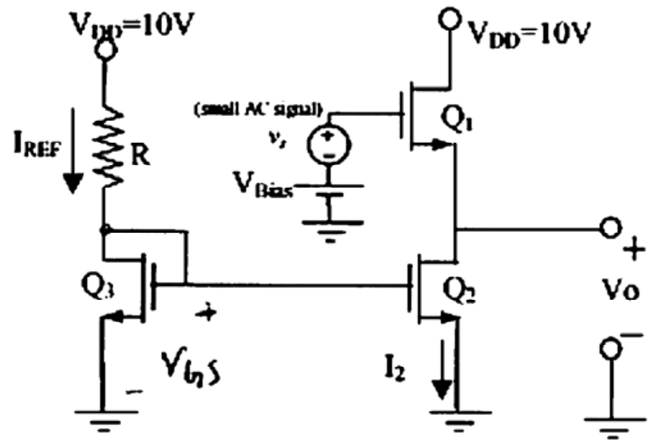
$4.2 > 4$

Mode= SATURATION

Name: R. Ahn Student #: Section:

97.257 *Final Examination, April 12 2002* *Page: 9/12*

4) b) MOSFET *(continued....)*



For the figure on the left, the transistors have

V_t=1V, V_A=30V, k_n'=100μA/V², L_1=1μm, W_1=10μm, L_2=1μm, L_3=1μm, W_3=10μm.

Using these data compute the following:

i) If I_{REF}=1mA, find R (**5 marks**):

$I_{REF} = I_{D3} = \frac{1}{2} k_n' (W/L)_3 (V_{GS} - V_t)^2$

$\therefore 1mA = \frac{1}{2} \times 100 \times 10^{-6} \times 10 \; (V_{GS} - V_t)^2$

$\therefore 1mA = 0.5 \times 10^{-3} \; (V_{GS} - V_t)^2$

$\therefore (V_{GS} - V_t)^2 = 2$

$\therefore V_{GS} - V_t = \pm 1.4 = \underline{1.4}$

$V_{GS} = 1.4 + 1 = 2.4$

$V_3 = 2.4$ V

$\therefore R = \frac{10 - 2.4}{1mA} = 7.6k$

R = 7.6k

ii) If I_2=0.5mA, find W_2 (**3 marks**):

$\frac{I_2}{I_{REF}} = \frac{(W/L)_2}{(W/L)_3}$

$(W/L)_2 = 0.5 \times (W/L)_3 = 0.5 \times 10$

$\therefore (W)_2 = 1\mu m \times 5 = \underline{5\mu m}$

W_2 = 5μm

iii) What is the minimum value of V_o for which I_2=0.5mA (3 **marks**):

$V_{D2} > V_{GS} - V_t$

$\Rightarrow V_{D2} > \underline{1.4}$ V

Minimum V_o= 1.4

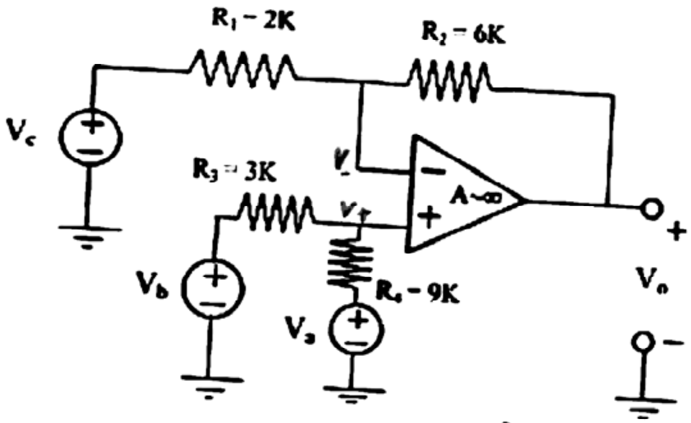
Name: R. Achar
97.257

Student #: ____________

Final Examination, April 12 2002

Section: ______

5) Operational Amplifier



a) For the circuit shown, find the expression for V_o as a function of V_a, V_b and V_c (assume the op amp is ideal) (10 Marks)

⇒ The above ckt. has both the inverting and non-inverting configuration based operations.

→ Analyze individually and use the superposition theorem to get the final output.

V_a $[V_b = 0;\ V_c = 0]$: $V_+ = V_a\left[\frac{3}{3+9}\right] = \frac{V_a}{4}$

$\therefore$ $V_{oa} = \left[1 + 6/2\right]V_+ = 4V_a/4 = V_a$

V_b $[V_a = 0;\ V_c = 0]$: $V_+ = V_b\left[\frac{9}{3+9}\right] = \frac{3}{4}V_b$

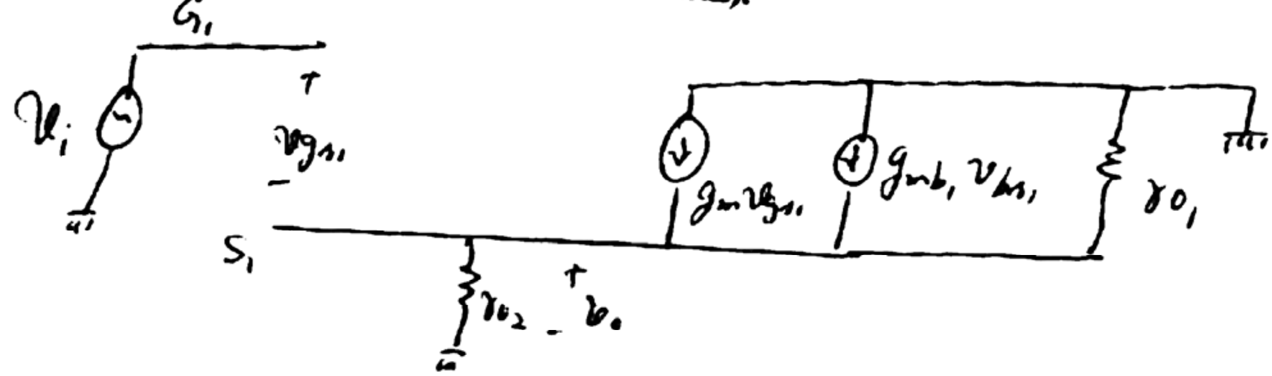
$V_{ob} = \left[1 + 6/2\right]V_+ = 4 \cdot \frac{3}{4}V_b = 3V_b$

V_c $[V_b = 0;\ V_a = 0]$: $V_{oc} = -\frac{6}{2}V_c = -3V_c$

Total $\boxed{V_o = V_a + 3V_b - 3V_c}$

V_o = $\boxed{V_a + 3V_b - 3V_c}$

iv) Draw the small signal equivalent circuit (2 marks):

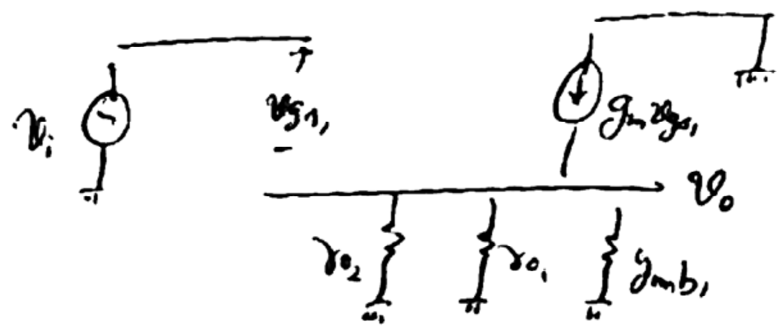


v) If I_2=0.5mA, χ=0.1 and Q_1 is in saturation, find $A_v = v_o/v_i$ (4 marks):

$g_m = \sqrt{2 k_n' (W/L) I_{DS}} = \sqrt{2 \times 100 \times 10^{-6} \left(\frac{10}{1}\right) 0.5 \times 10^{-3}} = 10^{-3}\sqrt{10} = 3.1623 \times 10^{-3}$

$g_{mb} = \chi g_m = 0.1 \times 3.1623 \times 10^{-3} = 0.31623 \times 10^{-3}$

$r_o = \frac{V_A}{I_D} = \frac{30}{0.5 \times 10^{-3}} = 60k$



$R_s' = r_{o2} \| r_{o1} \| \frac{1}{g_{mb1}}$

$= 60k \| 60k \| \frac{1}{g_{mb1}}$

$= 30k \| 3.1623k$

$= 2.86k$

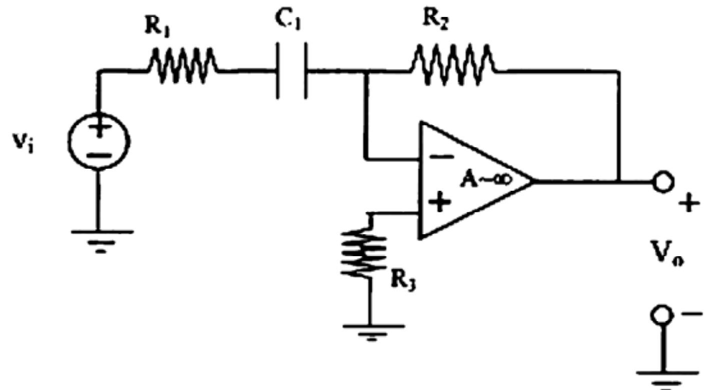
$= v_o + v_{gs1}$ $\qquad v_o = g_m v_{gs1} \cdot R_s'$;

$v_{gs1} = \frac{v_o}{g_m R_s'}$

$v_i = v_o + \frac{v_o}{g_m R_s'}$

$$\frac{v_o}{v_i} = \frac{g_m R_s'}{1 + g_m R_s'} = \frac{3.1623 \times 10^{-3} \times 2.56 \times 10^{3}}{1 + 3.1623 \times 10^{-3} \times 2.56 \times 10^{3}} = A_v = 0.9$$

5) b) Operational Amplifier *(continued....)*



i) For the above circuit, assuming ideal op-amp, derive the gain $H(jw) = Vo(jw)/ Vi(jw)$. Show the steps. **(6 Marks)**

$$H(j\omega) = \frac{V_o(j\omega)}{V_i(j\omega)} = -\frac{Z_2}{Z_1} \quad ; \quad Z_2 = R_2, \quad Z_1 = R_1 + \frac{1}{j\omega C_1}$$

$$H(j\omega) = -\frac{R_2}{R_1 + \frac{1}{j\omega C_1}} = -\frac{(R_2/R_1)}{1 + \frac{1}{j\omega C R_1}}$$

ii) If $R_1 = 5K\Omega$, $R_2 = 15K\Omega$, $R_3 = 10K\Omega$, $C_1 = 1uF$ and frequency is 1MHz, compute the gain-magnitude in DBs and gain-phase in degrees. **(3 Marks)**

$$H(j\omega) = -\frac{15\times10^3}{5\times10^3 + \frac{1}{(j\times6.2832\times10^6\times10^{-6})}}$$

$\omega = 2\pi f = 2\times\pi\times1\times10^6 = 6.2832\times10^6$

$$= -\frac{15\times10^3}{5\times10^3 - j0.1592} = -(3 + 0.0001 i)$$

$|H(j\omega)| = 3$, $\angle\phi = 180^\circ$

$= 20\log(3) = 20\times0.4777$

$|H(jw)|$ = 9.54 DBs DBs

$\angle H(jw)$ = 180° Degrees

iii) What class of filter does the above circuit belong to? **(1 Mark)** High-Pass Filter

End