

Name: _____

Student #: _____

Lab Section: _____

CARLETON UNIVERSITY

FINAL
EXAMINATION
April 18, 2000

Solutions

Duration: 3 hours

Department name and course number: Electronics 97.257

Course Instructor(s): L. Roy, N. Tait Number of students: 266

AUTHORIZED MEMORANDA:

CALCULATOR

Students **MUST** count the number of pages in this examination paper before beginning to write, and report any discrepancies immediately to a proctor. This question paper has

12 pages.

This examination question paper **MAY NOT** be taken from the examination room.

This exam consists of 5 questions, which should be answered on this exam paper in the space provided. Attempt all questions. Marks allocated to each question are indicated. The total number of marks for the examination is 65.

The solution must be clearly indicated. Multiple solutions or solutions that are not clearly identified, will be marked incorrect. Clearly state all assumptions made. Show your work.

Diode:

$$I_D = I_S (e^{V_D/nV_T} - 1)$$

small signal resistance: $r_d = \frac{nV_T}{I_D}$

$$V_T = \frac{kT}{q} = 25mV \text{ at room temperature}$$

Bipolar Transistor:Active mode operation: $V_{BE} = 0.7V$ Saturation mode operation: $V_{CEsat} = 0.2V$

$$i_c = \beta i_b \quad i_e = \alpha i_c \quad i_e = i_b + i_c$$

$$g_m = \frac{I_C}{V_T} \quad r_e = \frac{\beta}{g_m} \quad r_c = \frac{\alpha}{g_m} = \frac{r_x}{\beta + 1}$$

$$r_{e,small} = \frac{V_T}{I_E} \quad r_{c,small} = \frac{\beta}{g_m}$$

Operational Amplifier:

$$V_o = A(V_+ - V_-) \quad R_i = \infty \quad R_o = 0$$

MOSFET:

$$I_{DS} = K \left[(V_{GS} - V_T) V_{DS} - \frac{V_{DS}^2}{2} \right]$$

$$I_{DS} = K \frac{(V_{GS} - V_T)^2}{2} \quad K = \frac{W}{L} \mu C_{ox}$$

$$V_{DS,sat} = V_{GS} - V_T \quad g_m = K(V_{GS} - V_T)$$

$$K = \frac{W}{L} k' \quad g_{m0} = \chi g_m \quad r_o = \frac{V_A}{I_D}$$

$$r_{DS,sat} = \frac{1}{K(V_{GS} - V_T)} \quad g_m = \sqrt{2KI_{DS}}$$

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1.) (12 marks) General short answer questions.

a) Which MOSFET amplifier configuration would you choose to obtain large positive voltage gain?

① common gate.

b) What is the difference between an enhancement and a depletion mode MOSFET?

$\frac{1}{2}$ enhancement - no channel when $V_{GS} = 0V$
 $\frac{1}{2}$ depletion - channel exists when $V_{GS} = 0V$
 ①

c) What is the difference in the mode of operation of a Zener diode and a regular junction diode?

$\frac{1}{2}$ Zener diode operates in reverse breakdown
 $\frac{1}{2}$ junction diode operates in forward bias (conduction)

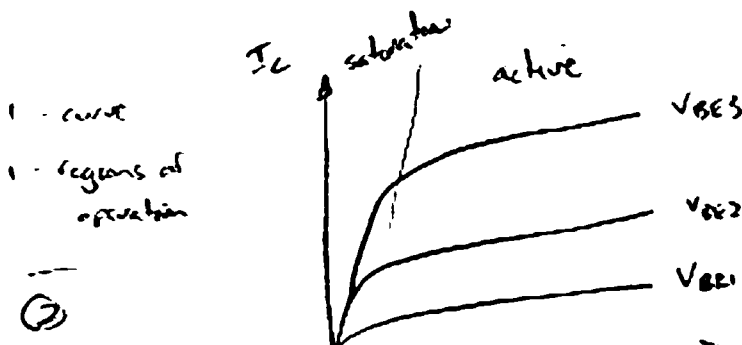
 ①

d) Describe three regions of operation for a n-channel MOSFET, in terms of the voltages that would be applied to the terminals.

2 - voltage conditions 1 - regions of op	$V_{GS} < V_T$	any V_{DS}	cutoff
	$V_{GS} > V_T$	$V_{DS} < V_{GS} - V_T$	triode
	$V_{GS} > V_T$	$V_{DS} > V_{GS} - V_T$	saturation

②

e) Sketch I_C vs V_{CE} for a BJT for several values of V_{BE} , indicating modes of operation.



1.) Continued

f) What is the body effect in a MOSFET?

①
4
2

X Body & source are not at the same voltage
→ Effectively changes the threshold voltage.

g) Why is input resistance an important parameter for a voltage amplifier?

① Rin determines how an amplifier loads the source.
something about voltage reduction on input.

h) Is a transistor a linear device?

yes - under small signal conditions

no, see I-V curves.

①

i) What is MOSFET an acronym for? ← not well understood

Metal
Oxide
Semiconductor
Field
Effect
Transistor.

①

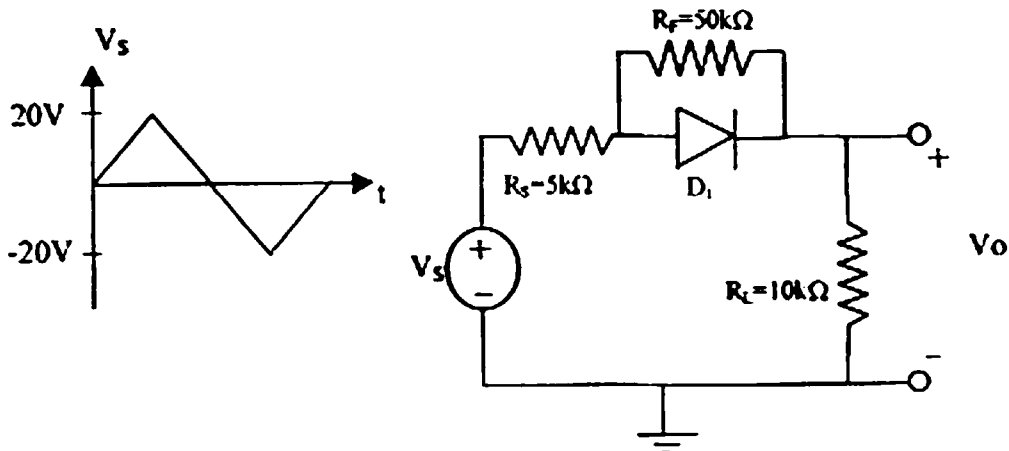
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2.) (15 marks) Diodes.



a) For the circuit shown above V_s is a symmetrical triangular wave of 40V peak to peak and the diode has a voltage drop of 0.7V when conducting.

3

i) Over what range of values of V_s is the diode on? Express V_o in terms of V_s .

$$\text{Diode ON: } V_o = \frac{(V_s - 0.7) R_L}{R_s + R_L} = \underline{\underline{0.667 V_s - 0.467}} \quad (2)$$

$$\text{Remains ON for } V_s > \underline{\underline{0.91V}} \text{ or } V_o > \underline{\underline{0.14V}} \quad (1)$$

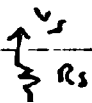
(see below)

ii) Over what range of values of V_s is the diode off? Express V_o in terms of V_s .

?

$$\text{Diode OFF: } \frac{V_o}{V_s} = \frac{R_L}{R_L + R_s + R_F} = \frac{10}{10 + 5 + 50} = \underline{\underline{0.154}} \quad (1)$$

$$\text{Remains OFF for } V_{RF} < 0.7V$$



$$V_{RF} = R_F \cdot V_s = 50 \cdot V_s = 0.769V$$

$$\text{or } V_o < 0.154(0.91) = \underline{\underline{0.14V}}$$

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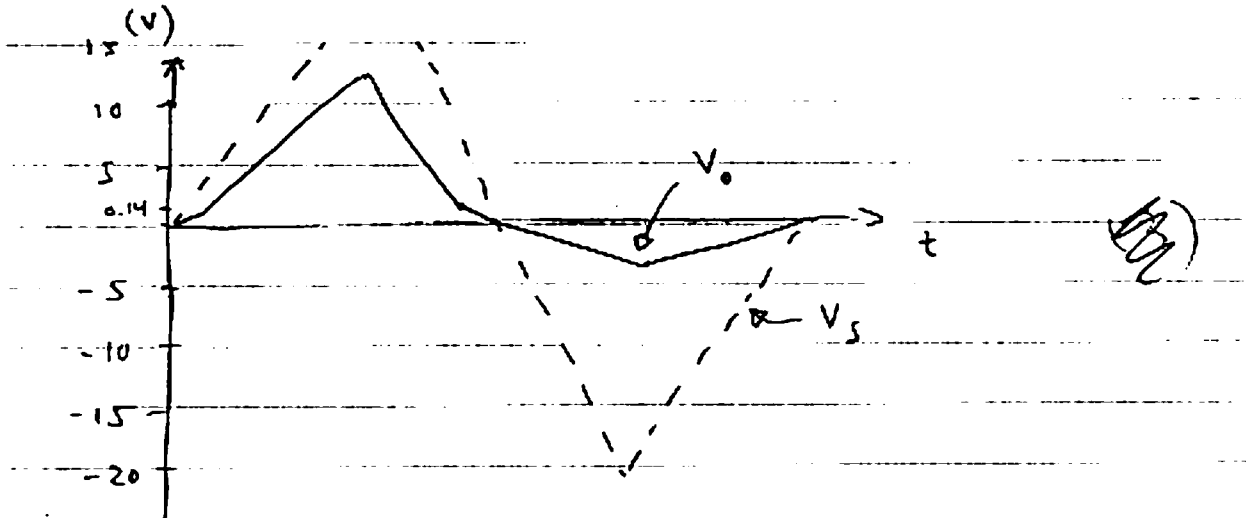
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2.) Continued

*as a function of time*iii) Sketch the output waveform V_o and indicate the peak voltages.

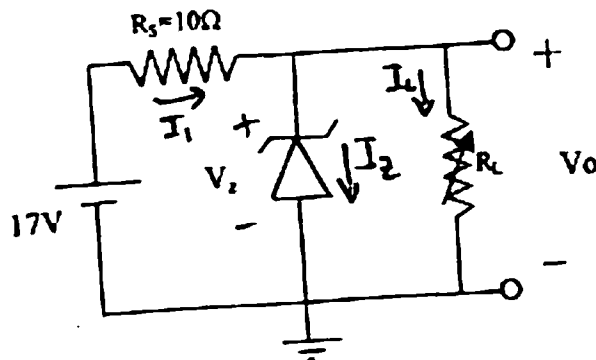
(3)



$$V_{o\max} = 0.667(20) - 0.467 = 12.9 \text{ V}$$

$$V_{o\min} = 0.154(-20) = -3.1 \text{ V}$$

2.) Continued



b) In the Zener diode circuit shown above $V_Z = 12V$ for $1mA < I_Z < 600mA$. Determine:
i) the output voltage V_O when $R_L = 500\Omega$,

2

$R_L = 500\Omega$

Assume $I_Z \geq 1mA \Rightarrow V_O = V_Z = 12V$ (1)

check: $I_1 = \frac{17-12}{10} = 500mA$

$I_L = \frac{12}{500} = 24mA$

$I_Z = I_1 - I_L = 476mA$ Ok (1)

ii) the maximum power that the diode should be able to dissipate and the value of R_L for which this power occurs,

2

max power dissipated in Zener when $R_L = \infty$ (1)

$\Rightarrow P_{Zener} = V_Z I_Z = 12(0.5) = 6W$ (1)

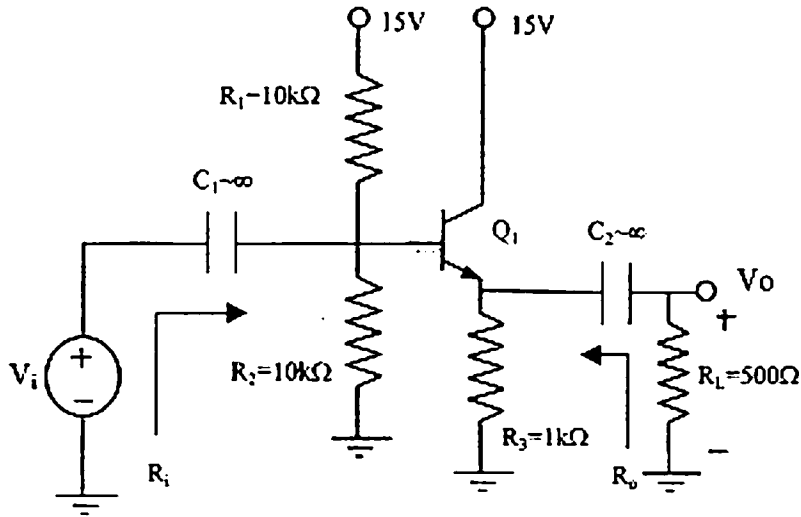
iii) the output voltage V_O when $R_L = 10\Omega$.

Assume $I_Z < 1mA \Rightarrow$ diode OFF

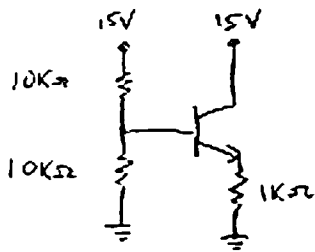
check: if ON we would have $\left\{ \begin{array}{l} V_O = 12V \\ I_L = 12/10 = 1.2A \\ I_Z = 0.5 - 1.2 = -0.7A \end{array} \right.$

\Rightarrow diode OFF (1)

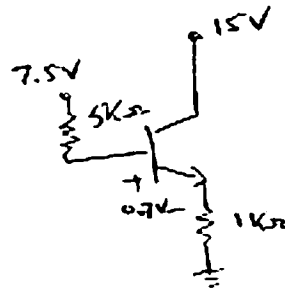
3.) (14 marks) Bipolar Junction Transistor. Use $\beta=100$.



a) Draw the circuit for DC analysis and find I_C .



or better:



assume active

$$I_E \times 1k + 0.7 + I_B \cdot 5k = 7.5V$$

$$I_C \left(\frac{1k}{\alpha} + \frac{5k}{\beta} \right) = 6.8V$$

$$I_C = 6.415mA$$

③

b) Find the values of r_π , g_m , and r_c .

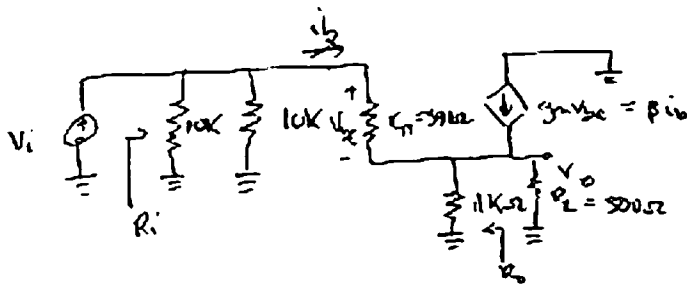
$$r_\pi = \frac{V_T}{I_B} = \frac{25}{0.064} = 391 \Omega$$

②

3.) Continued

c) Draw the small signal circuit for AC analysis (with the equivalent model of your choice). Determine R_i and R_o for small signal operation.

2



$$R_i = 10k \parallel 10k \parallel (r_{\pi} + (\beta+1)(1k \parallel 500\Omega))$$

$$= 5k \parallel (391 + 101 \times 333) = 5k \parallel 34k$$

$$R_i = \underline{4.36 \text{ k}\Omega}$$

$$R_o = 1k \parallel \frac{r_{\pi}}{\beta+1} = \underline{3.86 \Omega}$$

④

d) Determine the small signal AC gain V_o/V_i .

$$V_o = (\beta+1) i_b \times 1k \parallel 500\Omega$$

$$V_i = i_b r_{\pi} + V_o$$

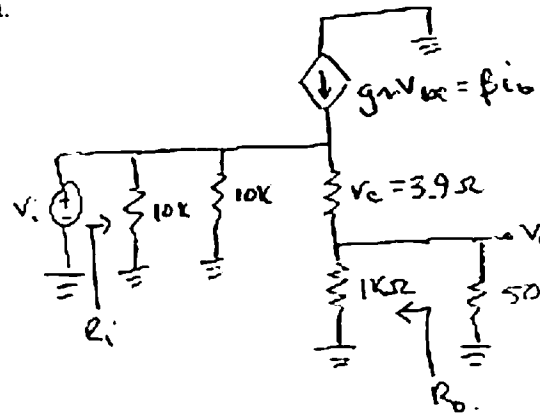
$$\frac{V_o}{V_i} = \frac{(\beta+1) \times 333\Omega}{391\Omega + (\beta+1)333\Omega}$$

$$\frac{V_o}{V_i} = 0.989 \text{ V/V}$$

④

e) Suggest a useful application for this circuit.

④



$$R_i = 10k \parallel 10k \parallel ((\beta+1)(r_e + 1k))$$

$$= 5k \parallel (101)(3.9k + 333)$$

$$= 4.36 \text{ k}\Omega$$

$$R_o = 1k \parallel r_e = \underline{3.88 \Omega}$$

$$V_o = (\beta+1) i_b (1k \parallel 500\Omega)$$

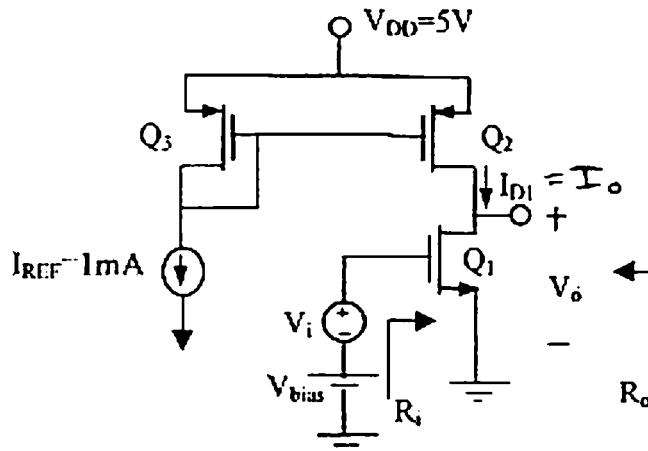
$$V_i = (\beta+1) r_e + V_o$$

So

$$\frac{V_o}{V_i} = \frac{(\beta+1) \times 333}{(\beta+1)(3.9 + 333)}$$

$$\frac{V_o}{V_i} = 0.988 \text{ V/V}$$

4.) (12 marks) MOSFET. All transistors have $V_T=1V$, $V_A=30V$, $k_n' = k_p' = 100\mu A/V^2$, and $L=1\mu m$. Q_1 has $W_1=100\mu m$ and Q_3 has $W_3=50\mu m$. $V_{bias} > V_T$.



- a) Find the width of Q_2 (W_2) such that $I_{D1}=0.5mA$. For this calculation neglect the finite output resistance of the transistors. In order to find W_2 what other assumption has been made regarding
- i) the body contact for each MOSFET
 - ii) the operating mode of each MOSFET.

neglecting finite output resistance of transistors

$$\textcircled{3} I_{D1} = I_o = I_{REF} \frac{(W/L)_2}{(W/L)_3} = 0.5 \text{ mA} \Rightarrow \frac{W_2}{W_3} = 0.5 \rightarrow W_2 = \frac{25}{2} \mu m$$

① All transistors are in saturation mode

① Body contact is at same potential as source

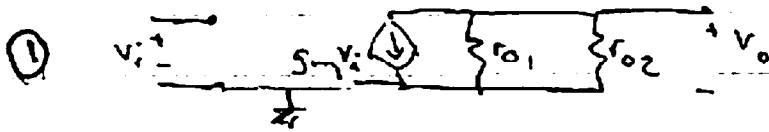
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4.) Continued

- 4 b) Draw the small signal equivalent circuit for AC analysis. Determine g_m and r_{o1} for Q_1 and r_{o2} for Q_2 .



$$g_m = \sqrt{2k_1 I_{D1}} \quad \text{where } k_1 = k' \left(\frac{W}{L} \right)_1 = 0.1 (100) = 10 \frac{\text{mA}}{\text{V}}$$

① $g_m = \sqrt{20(0.5)} = \underline{3.20 \text{ mA/V}}$

① $r_{o1} = \frac{V_A}{I_{D1}} = \frac{30}{0.5} = \underline{60 \text{ k}\Omega}$

① $r_{o2} = \frac{V_A}{I_{D2}} = \frac{30}{0.5} = \underline{60 \text{ k}\Omega}$

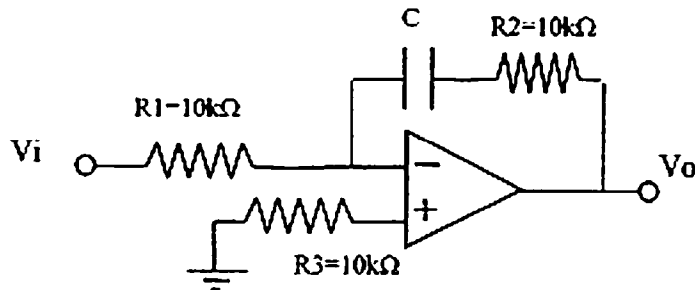
- 3 c) Calculate the small signal gain V_o/V_i and R_i and R_o .

① $\frac{V_o}{V_i} = -g_m (r_{o1} \parallel r_{o2}) = -3.20 (30) = \underline{-95}$

① $R_i = \underline{\infty}$

① $R_o = r_{o1} \parallel r_{o2} = \underline{30 \text{ k}\Omega}$

5.) (12 marks) Operational Amplifier.



- a) Find the input impedance and voltage gain expression for the circuit shown, as a function of radial frequency ω , assuming the op-amp is ideal.

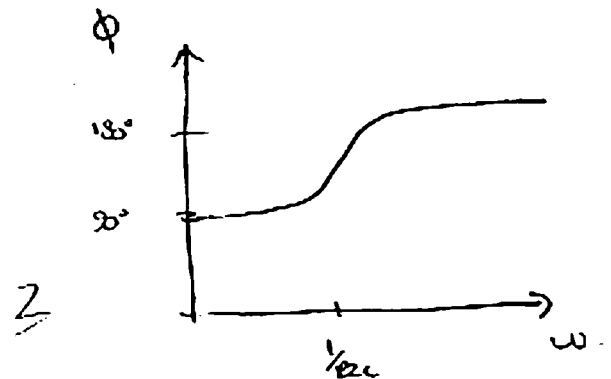
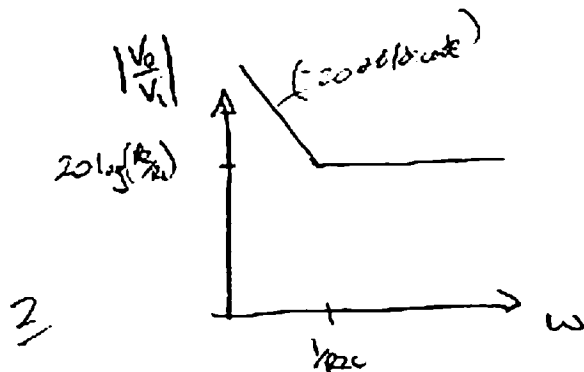
$$1 \quad R_i = \frac{V_i}{I_i} = 10k\Omega$$

$$2 \quad \frac{V_o}{V_i} = - \frac{(R_2 + \frac{1}{j\omega C})}{R_1} = - \frac{R_2}{R_1} \left(1 + \frac{1}{j\omega R_2 C} \right)$$

$$\frac{V_o}{V_i} = - \frac{R_2}{R_1} \left(1 + \frac{\omega_0}{j\omega} \right) \quad \omega_0 = \frac{1}{R_2 C}$$

③

- b) Sketch the magnitude and phase response of gain of the circuit.



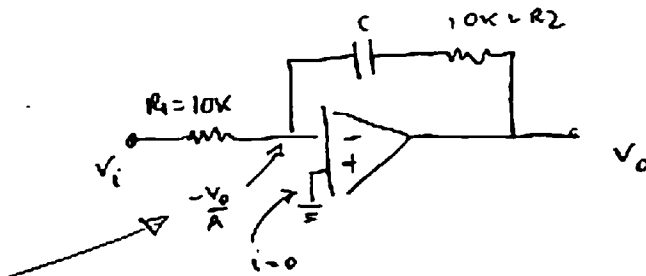
5.) Continued

c) Choose a value of C to give a corner frequency of 20 kHz.

$$\frac{1}{R_2 C} = 20 \text{ kHz} \times 2\pi$$

$$\textcircled{1} \quad C = \frac{1}{20 \text{ k} \times 2\pi \times 10 \text{ k}} = 0.796 \text{ nF} \quad (7.96 \times 10^{-10} \text{ F})$$

d) Calculate the input impedance and voltage gain as a function of radial frequency ω , if the op-amp has a finite open loop gain of 10,000.



$$1. \quad I_i = \frac{1}{R_1} \left(V_i + \frac{V_o}{A} \right)$$

find gain first.

$$1. \quad V_o = -\frac{V_o}{A} - I_i \left(R_2 + \frac{1}{j\omega C} \right)$$

$$V_o \left(1 + \frac{1}{A} \right) = - \left(V_i + \frac{V_o}{A} \right) \frac{R_2}{R_1} \left(1 + \frac{1}{j\omega R_2 C} \right)$$

$$V_o \left(1 + \frac{1}{A} + \frac{1}{A} \left(\frac{R_2}{R_1} \left(1 + \frac{j\omega}{\omega_0} \right) \right) \right) = -V_i \frac{R_2}{R_1} \left(1 + \frac{j\omega}{\omega_0} \right)$$

$$2. \quad A_v = \frac{V_o}{V_i} = \frac{-R_2/R_1 \left(1 + \frac{j\omega}{\omega_0} \right)}{1 + \frac{1}{A} \left(1 + \frac{R_2}{R_1} \left(1 + \frac{j\omega}{\omega_0} \right) \right)}$$

$$\omega_0 = \frac{1}{R_2 C}$$

$\textcircled{4}$

~~(12)~~