

Open books, open notes. Answer all questions.
Use the other side of the paper if you require more space.
Total mark: 50

Name: Solution

Stud. #: _____

1. Question 1 (15 marks)

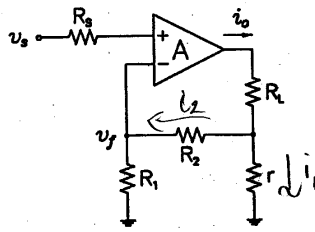
In the non-inverting voltage-to-current converter shown, the basic op-amp has infinite input resistance and zero output resistance. For input v_s and output i_o , find an expression for the feedback factor $\beta = v_f/i_o$. For an open loop gain $A = 10^3$ mA/V, what must β be for a closed-loop gain of 10 mA/V? For this β , find values of R_1 , R_2 , and r to make $i_o/v_s = 10$ mA/V, (while allowing the voltage across R_L to be as large as possible for a given power supply, yet using no resistor smaller than 150 Ω). What is the value of i_o when $v_s = 1$ V?

①

$$i_2 = i_o \frac{r}{r + R_1 + R_2}$$

$$v_f = i_2 R_1 = \frac{r R_1}{r + R_1 + R_2} i_o$$

$$\beta = \frac{v_f}{i_o} = \frac{r R_1}{r + R_1 + R_2}$$



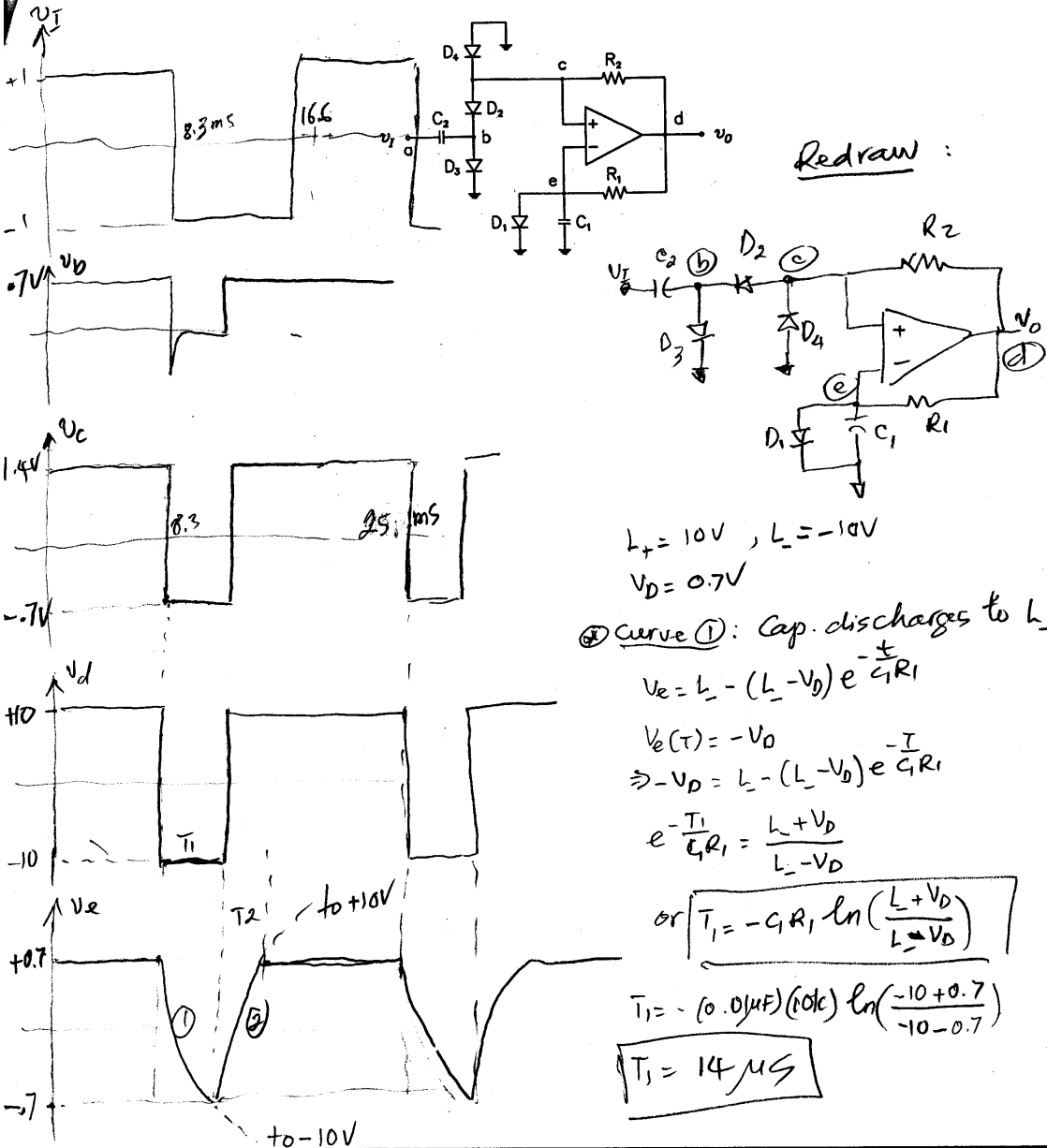
$$\textcircled{*} \left. \begin{array}{l} A_{OL} = 10^3 \text{ mA/V} \\ A_{CL} = 10 \text{ mA/V} \end{array} \right\} A_{CL} = \frac{A_{OL}}{1 + A_{OL} \beta} \text{ or } \beta = \frac{1}{A_{CL}} = \frac{1}{10 \text{ mA/V}} = \frac{100 \text{ V}}{\text{A}} \text{ (99-60 be exact)}$$

$$\textcircled{*} \text{ Choose } r = 150 \Omega, R_2 = 150 \Omega \Rightarrow 100 = \frac{150 R_1}{300 + R_1} \text{ or } 50 R_1 = 30000 \\ R_1 = 600 \Omega$$

$$\textcircled{*} i_o = A_{CL} v_s = \left(\frac{10 \text{ mA}}{\text{V}} \right) (1 \text{ V}) = \underline{10 \text{ mA}}$$

2. Question 2 (20 marks)

Consider the circuit shown, using diodes which conduct at $V_D = 0.7V$, and an amplifier saturating at $\pm 10V$, with $R_1 = R_2 = 10\text{ K}$ and $C_1 = 10C_2 = 0.01\ \mu F$. Find the output pulse width and frequency, if v_i is a 60 Hz square wave of 2Vpp amplitude. Sketch the waveforms at nodes a through e. What is the smallest input signal required to trigger the circuit? How long does it take for this circuit to be ready for a new input?



④ Curve 2: Cap. charges to V_+

Same $T_1 = T_2$ since discharges from $+0.7V$ to $-0.7V$
and charges from $-0.7V$ to $+0.7V$

$$\therefore \underline{T_2 = 14 \mu s} \text{ (recovering period)}$$

The circuit is ready for the next trigger signal
(negative edge) at $8.3ms + \underline{28 \mu s} = 8.33ms$ (the next
negative edge for $60Hz$ input is at $25ms$)

④ The output has a period of $25ms - 8.3ms = 16.7ms$

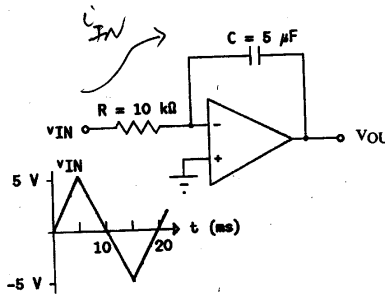
$$f = \frac{1}{T} = \frac{1}{16.7ms} = \underline{60Hz}$$

(note that duty cycle is not 50% as V_{IN})

④ The smallest input signal requires is $1.4V_{pp}$.

3. Question 3 (15 marks)

A 5V peak triangular voltage with a period of 20ms, depicted on the axis shown below, is applied to an ideal op-amp integrator. Sketch v_{OUT} as a function of time. The capacitor has zero initial charge.



$$i_N = \frac{v_{IN}}{R}$$

$$v_C = v_O$$

$$i_N = C \frac{dv_C}{dt} = -\frac{v_{IN}}{R}$$

$$\frac{dv_C}{dt} = -\frac{1}{CR} v_{IN}$$

$$v_O = v_C = -\frac{1}{CR} \int v_{IN} dt$$

⊗ $0 < t < 5\text{ms}$, $v_{IN} = \alpha t$ where $\alpha = \frac{1\text{V}}{\text{ms}}$ and t is in ms

$$RC = (10\text{k})(5\mu\text{F}) = 50\text{ms}$$

$$\Rightarrow v_O = -\frac{1}{RC} \int_0^t \alpha t dt = -\frac{\alpha t^2}{2RC} = -\frac{1\text{V/ms}}{2(50\text{ms})} t^2 = -\frac{t^2}{100\text{ms}^2}$$

$$\left. \begin{array}{l} t=0, v_O=0 \\ t=5\text{ms}, v_O = -\frac{(5\text{ms})^2}{100\text{ms}^2} = -0.25\text{mV} \end{array} \right\} \text{parabola}$$

⊗ $5 < t < 10\text{ms} \Rightarrow v_{IN}$ positive (but returning to zero), v_O will continue increasing negatively but its slope will become more shallow as time progresses $t=10\text{ms} \Rightarrow v_O = -0.5\text{V}$

⊗ Over the next 10ms, during which time v_{IN} become negative, v_O will begin to increase from the negative peak, reaching zero at $t=20\text{ms}$.

