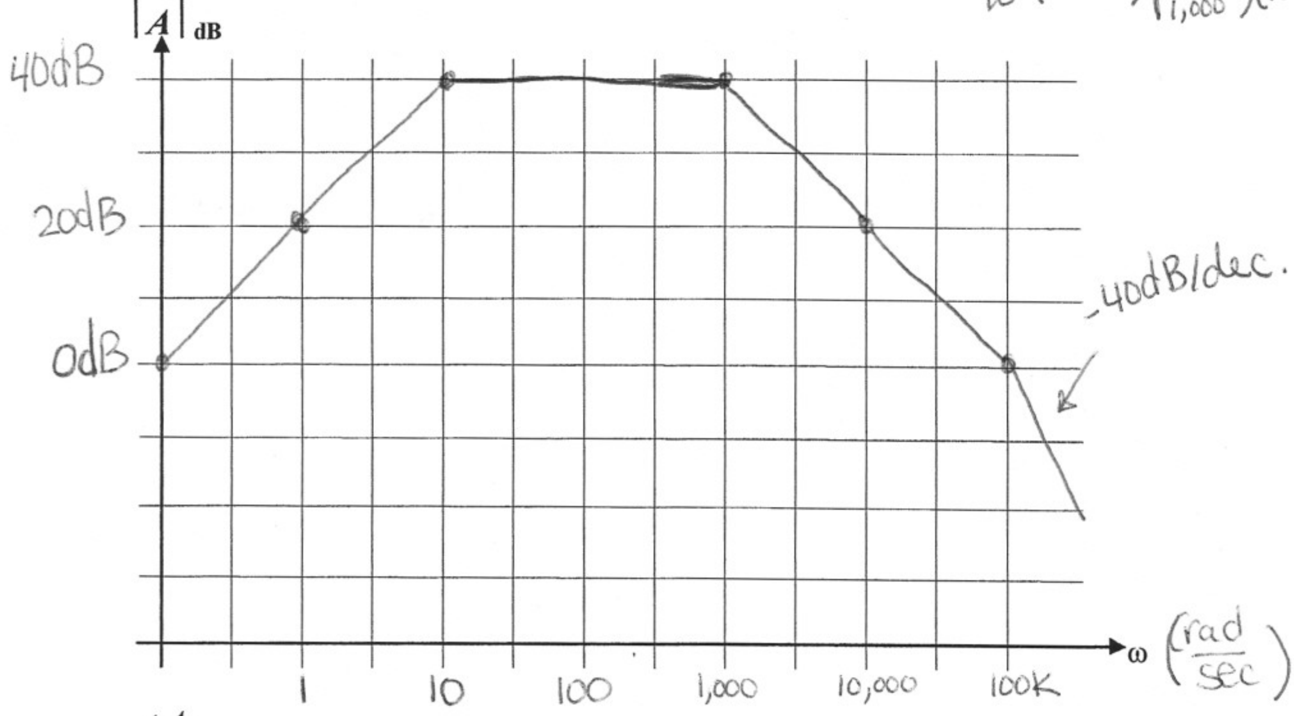
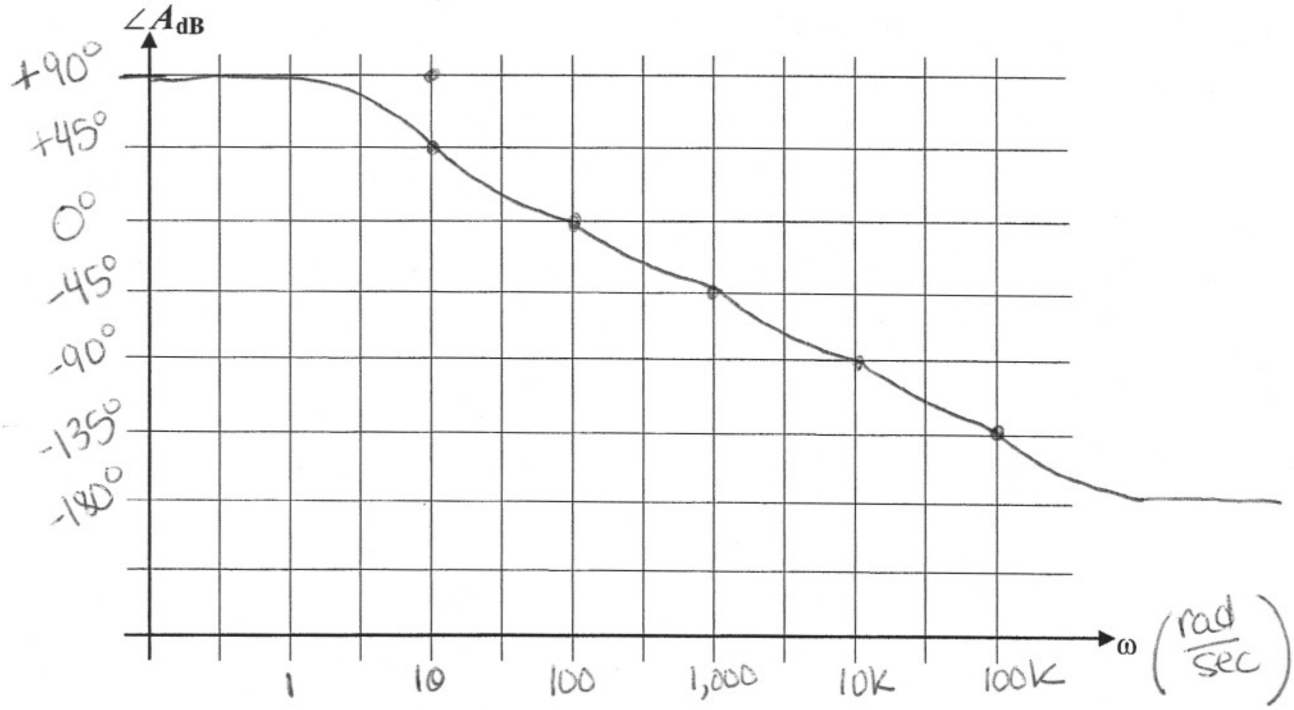
Exam 2 solution

Problem 1 – (20 points) An amplifier has the following transfer function:

$$A(s)=\frac{10s}{(s/10+1)(s/1{,}000+1)(s/100{,}000+1)}\frac{V}{V} = \frac{10\cdot s\cdot 10}{\frac{s}{10}\left(1+\frac{10}{s}\right)\left(\frac{s}{1{,}000}+1\right)\left(\frac{s}{100K}+1\right)}$$





(b) What is β for A_f=20dB? ____________________

(c) What is the *lowest* closed-loop gain A_f for which this amplifier has acceptable stability (having a phase margin of at least 45°)? A_f= ____ 0.7 V/V

(b) $A_f = +20dB = 10\,V/V = \frac{100}{1+100(\beta)} \Rightarrow \beta(100) = \frac{\frac{100}{10}-1}{100} = \boxed{0.09}$

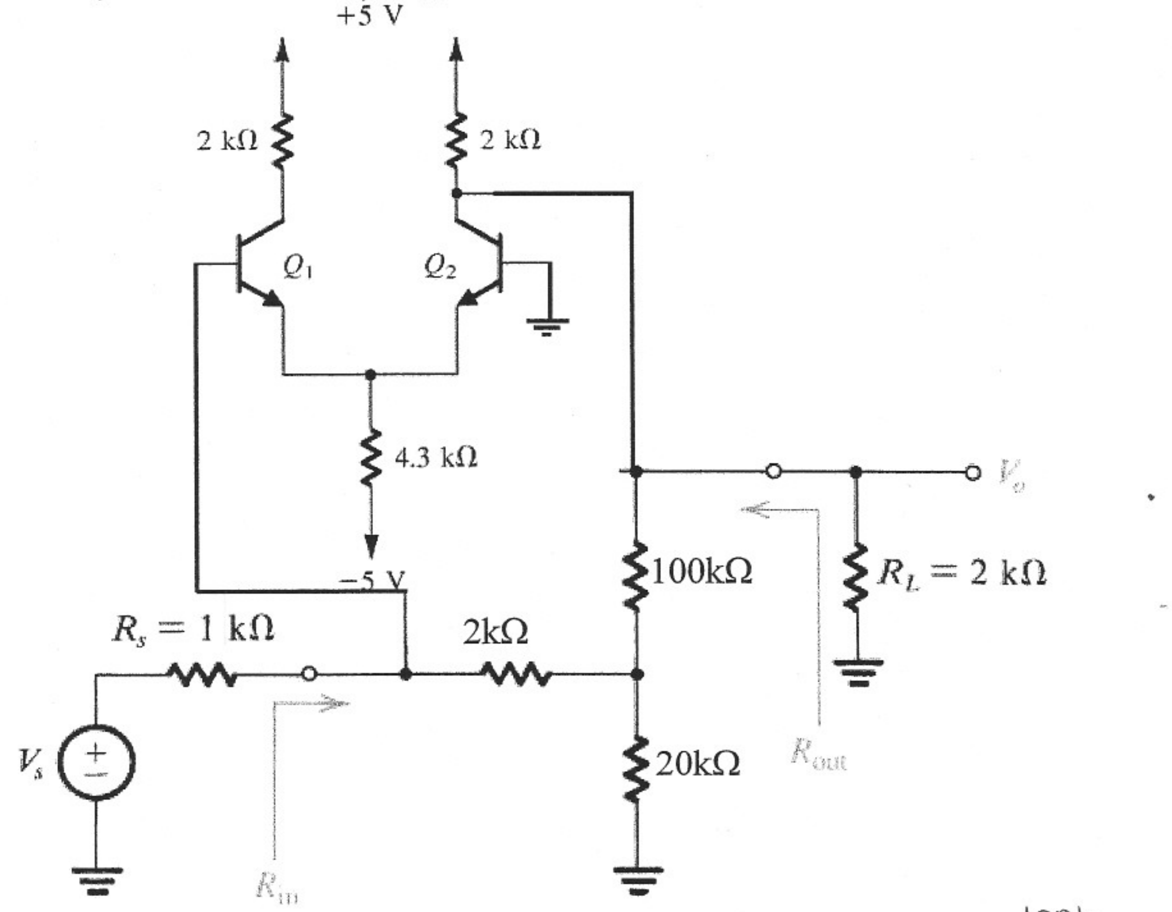
(c) $f = 100K$ for $PM = 45° \Rightarrow |A\cdot\beta| = 1 = \frac{100\cdot\beta}{\sqrt{1^2+\left(\frac{10}{100K}\right)^2}\sqrt{\left(\frac{100K}{1K}\right)^2+1^2}\cdot\sqrt{2}}$

$\therefore \beta = 1.41 \Rightarrow A_f = \frac{100}{1+100(1.41)}$

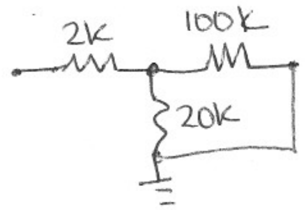
Problem 2 - (20 points) What type of feedback topology is shown below (e.g., series-series, shunt-series,...)?

shunt-shunt

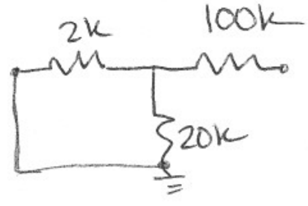
Draw three pictures showing the circuit configurations used for measuring β, R_{11}, and R_{22} for the feedback network shown, and find values for β, R_{11}, and R_{22}.



$R_{11} \Rightarrow$



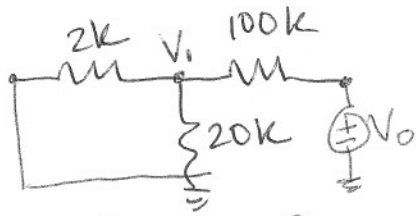
$R_{22} \Rightarrow$



$R_{11} = 2K + (20k \| 100k) \cong \boxed{18.7k}$

$R_{22} = 100k + (2k \| 20k) \approx \boxed{102K}$

$\beta \Rightarrow$



$\beta \equiv \frac{I_f}{V_o} = -\frac{0.02}{2k} = -10\mu$

$\beta \Rightarrow V_1 = \frac{V_o\,(2k \| 20k)}{(2k \| 20k) + 100k}$

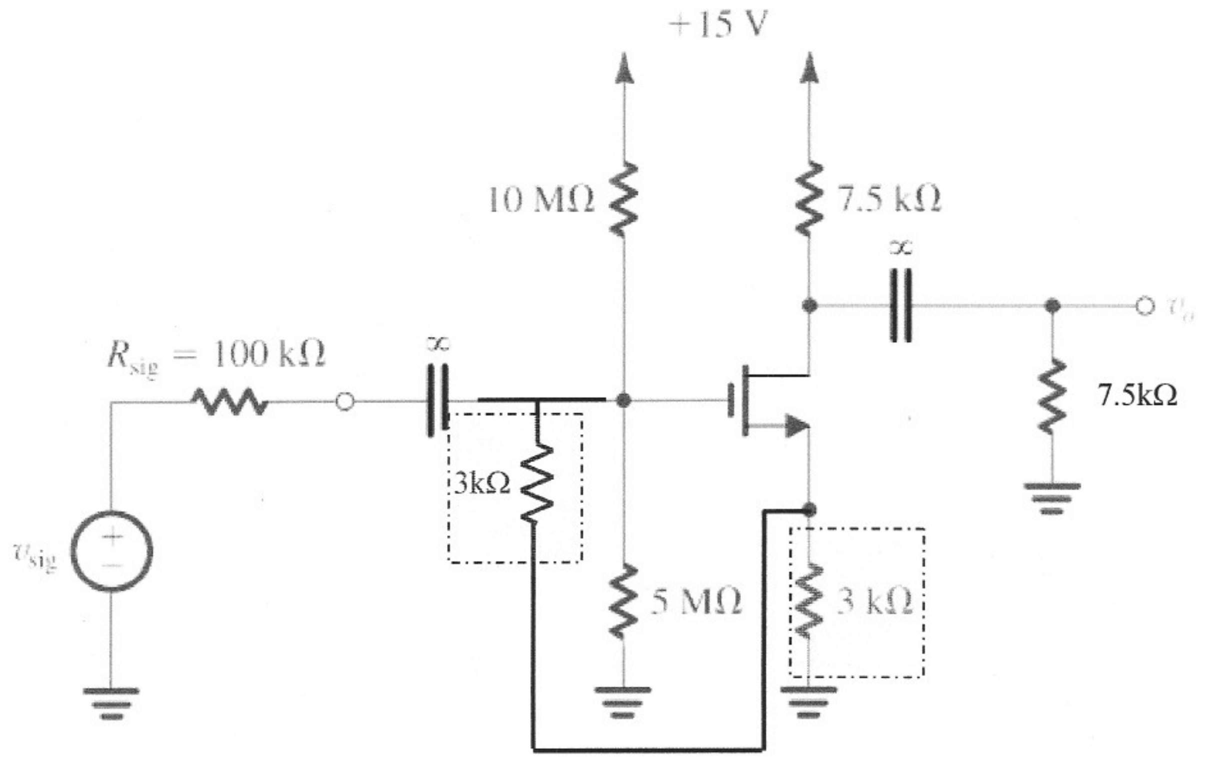
$V_1 = 0.02 V_o$

$V_1 = -I_f (2k)$

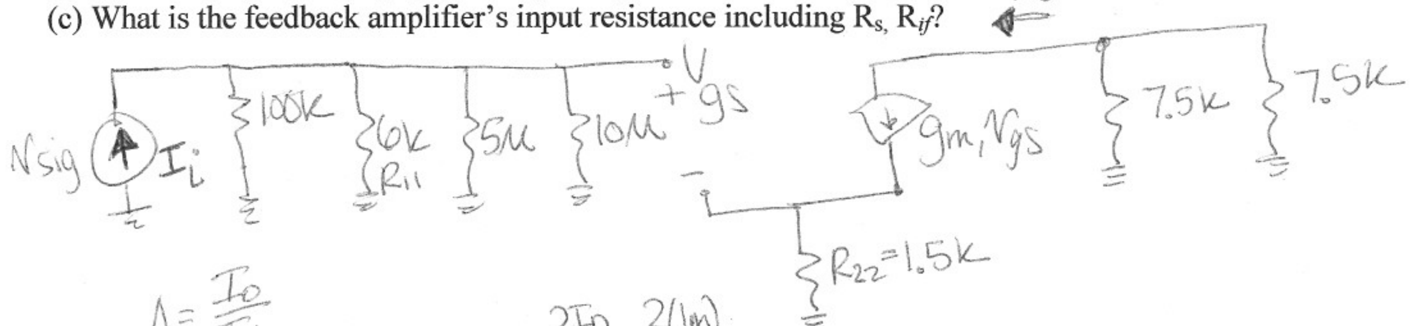
$0.02 V_o = -I_f (2k)$

Problem 3 - (30 points) Assume that the amplifier below is biased at I_D=1mA, V_{GS}=2V, V_t=1V. Ignore λ.

The feedback network consists of the two highlighted 3kΩ resistors. R_{11}=6kΩ, R_{22}=1.5kΩ, β=-1/2.



(a) What is A? (Note that $v_s \neq 0$!) shunt-series
(b) What is the closed-loop gain, v_o/v_{sig}, or A_f of the feedback amplifier?
(c) What is the feedback amplifier's input resistance including R_s, R_{if}?



$A = \frac{I_o}{I_i}$

$g_{m1} = \frac{2I_D}{V_{ov}} = \frac{2(1m)}{2-1} = 2mA/V$

$I_o = g_{m1} V_{gs}$

$V_g = I_i(100k \| 6k \| 5M \| 10M) \cong I_i(5650)$

$V_s = g_{m1} V_{gs}(1.5k)$

$V_{gs} = I_i(5650) - g_{m1}(1.5k)V_{gs} \Rightarrow V_{gs} = \frac{I_i(5650)}{1 + g_{m1}(1.5k)} = 1412.5 I_i$

$\frac{I_o}{I_i} = g_{m1}(1412.5) = \boxed{2.825 A/A}$

#3 b. $A_f = \frac{A}{1+A\beta} = \frac{2.825}{1+(2.825)(-\frac{1}{2})} = \boxed{-6.85\ A/A}$

$A_f = \frac{I_o}{I_{sig}}$

$I_{sig} = \frac{V_{sig}}{100k}$

$V_o = -I_o\left(\frac{7.5k}{2}\right) \Rightarrow I_o = -267\mu V_o$

$A_f = \frac{I_o}{I_{sig}} = \frac{-267\mu V_o \cdot 100k}{V_{sig}} = -6.85$

$\therefore \frac{V_o}{V_{sig}} \cong \boxed{0.3\ V/V}$

c. $R_i = (100k \| 6k \| 5M \| 10M) = 5650$

$R_{if} = \frac{5650}{1+A\beta} = \boxed{13.6k\Omega}$

Problem 4 – (15 points)
The datasheet of the PN2222A bipolar transistor contains the following information:

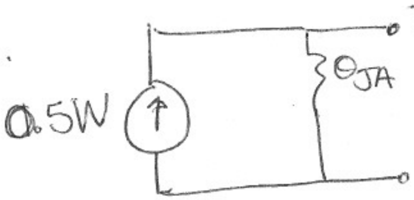
Maximum allowable junction temperature $T_{Jmax} = 150°C$
Maximum power dissipation $P_{Dmax} = 1.5$ W at case temperature $T_C = 25.5°C$
Junction-to-case thermal resistance $\theta_{JC} = 83$ °C/W
Junction-to-ambient thermal resistance $\theta_{JA} = 200$ °C/W

(a) What is the maximum ambient temperature to ensure safe operation at 0.5W? (Note that we are not using a heat sink in this problem.)

(b) Find the case-to-ambient thermal resistance θ_{CA}.

(c) Assuming an ambient temperature of 25°C, what is the case temperature T_C when the transistor dissipates 100mW?

a.



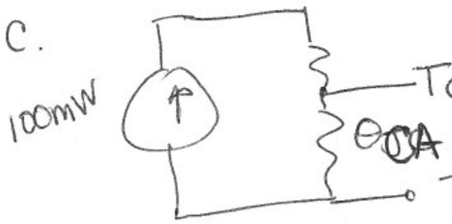
$T_A = T_J - \theta_{JA}(0.5W) = 150 - 200(0.5)$

$\boxed{T_A = 50°}$

b. $(\theta_{CA} + \theta_{JC}) = \theta_{JA} \Rightarrow \theta_{CA} = \theta_{JA} - \theta_{JC} = 200 - 83$

$= \boxed{117° C/W}$

c.

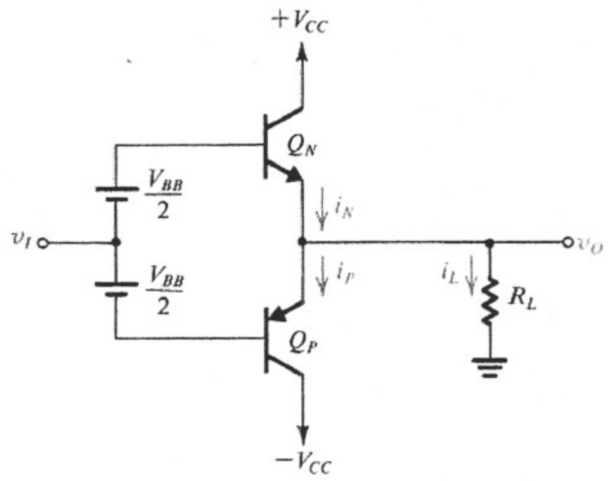


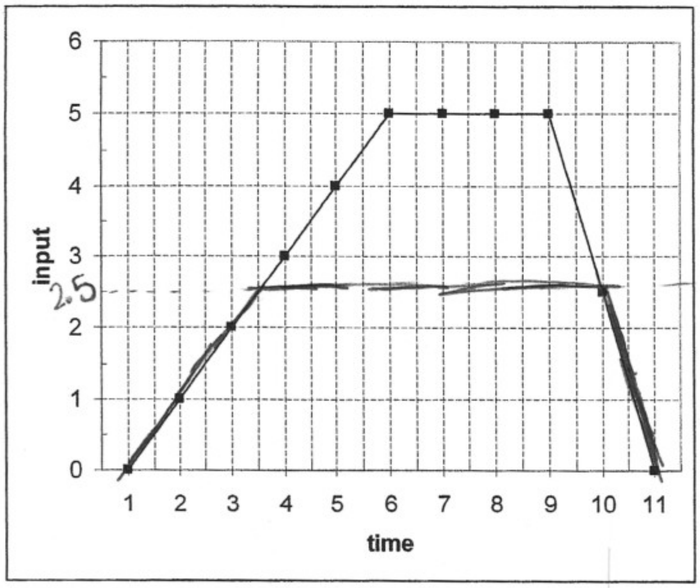
$T_C = T_A + \theta_{CA}(100m) = 25 + (117°)(100m)$

$\boxed{T_C = 36.7°}$

Problem 5 – (15 points)

(a) The following output stage has an input, v_i, shown below. Assume the transistors are biased for the correct operation. Vcc = 3V, V_{BE}=0.5V(constant), and V_{CEsat}=0.5V What is the output v_o?

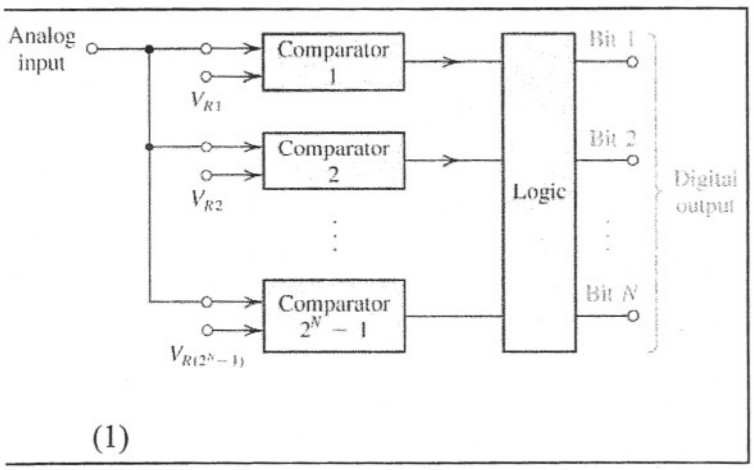




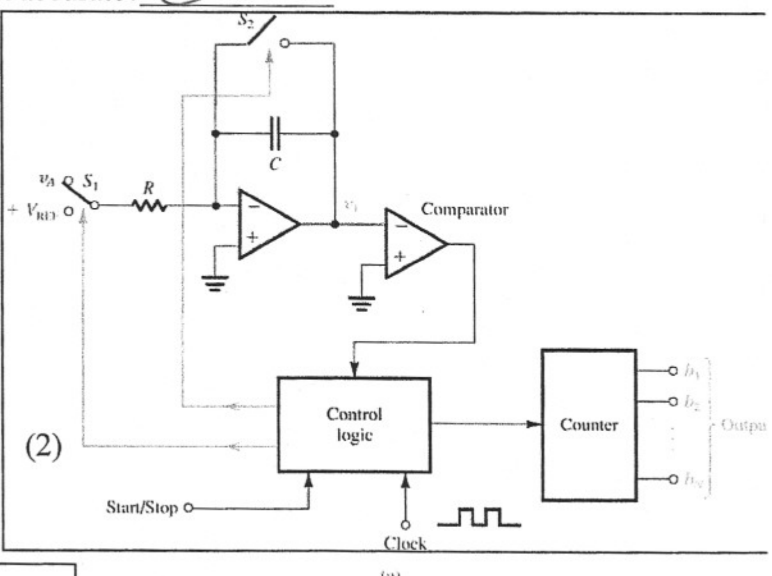
(b) (i) Which analog converter below is the fastest? ①

(ii) Which analog converter below is the slowest? ②

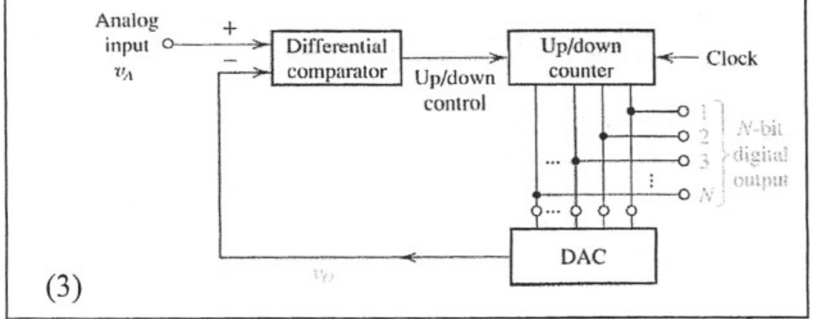
(iii) Which analog converter below is the most accurate? ②



(1)

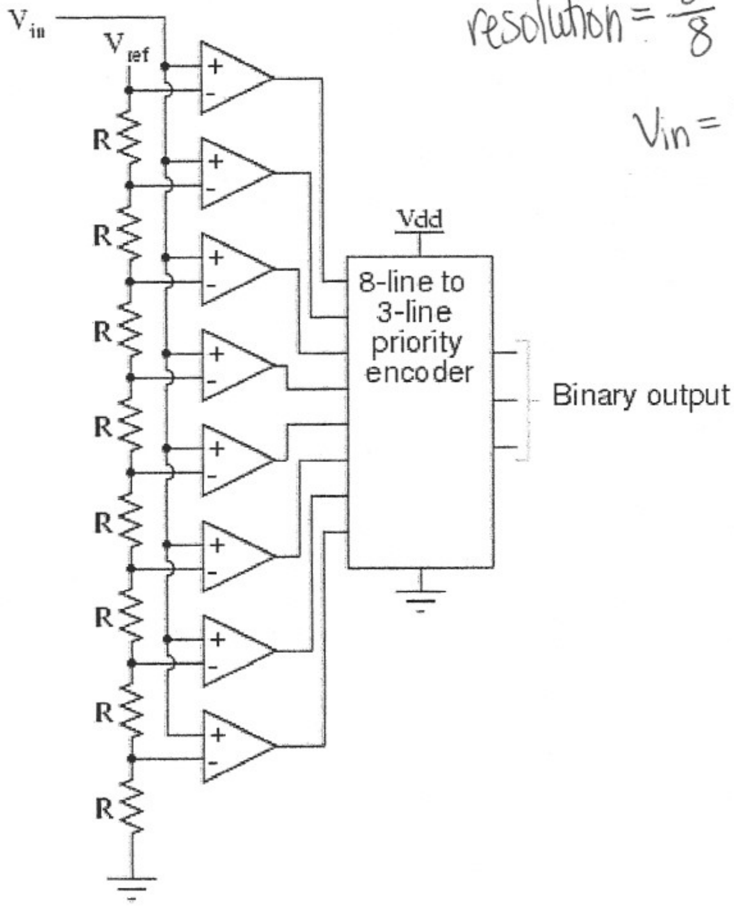


(2)



(3)

(c) An analog signal in the range of 0 to +5V is to be digitized. If the circuit shown below is used, what is the resolution of the conversion? If $V_{in} = 3V$, what is the binary output?



resolution $= \frac{5}{8}$

comparators

$V_{in} = 3$ 11110000 ⇒ 100

$\frac{3}{5/8} = 4.8$

(d) The rail voltages for the op amp shown below are ±2V. Sketch the output seen for the input below. Assume $R_1 = R_2$.

$$V_+ = \frac{V_0(R_1)}{R_1+R_2} = V_0\left(\frac{1}{2}\right)$$

$V_{TH} = 1V$

$V_{TL} = -1V$