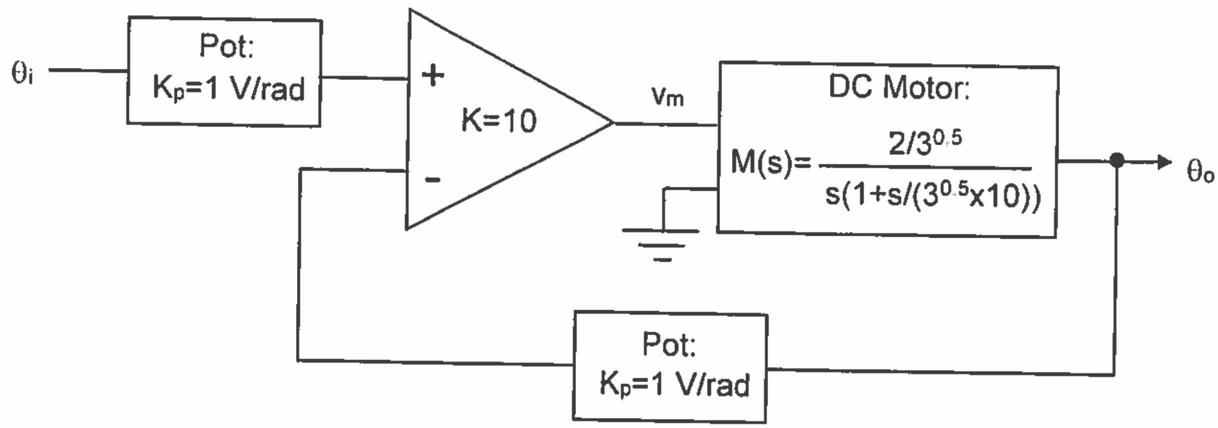
Problem 1 (50 points):

Consider the following closed-loop negative feedback servo position control system comprised of an **ideal** opamp with a constant gain of K=10, a DC motor with the given transfer function, $M(s)=\theta_o/V_m(s)$, and two potentiometers both with K_p=1V/rad.



a) Sketch the equivalent feedback block diagram of this closed-loop servo system.

b) Determine the closed-loop transfer function, $A_f(s)=\theta_o/\theta_i(s)$. (Be sure to properly "simplify" your final expression).

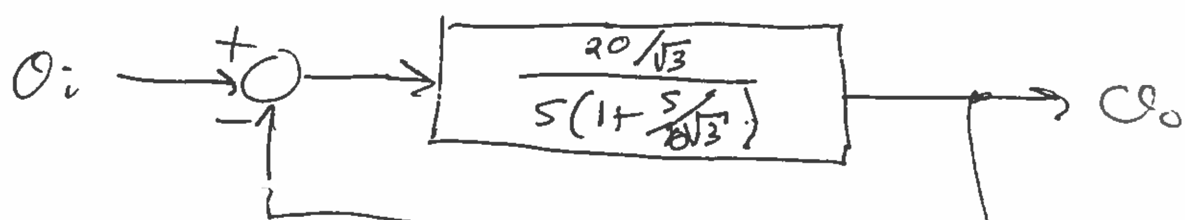
c) Determine the Loop Gain, LG(s).

d) Calculate the PM.

e) **Optional extra credit (10 points, no partial credit):**

Calculate the GM. (Please justify your answer by showing your work).

a.)



b.) $$A_f(s) = \frac{\frac{20/\sqrt{3}}{s(1+s/10\sqrt{3})}}{1+\frac{20/\sqrt{3}}{s(1+s/10\sqrt{3})}}$$

$$A_f(s) = \frac{1}{\frac{s^2}{200}+\frac{\sqrt{3}}{20}s+1}$$

c.) $$LG(s) = \frac{\frac{20}{\sqrt{3}}}{s\left(1 + \frac{s}{10\sqrt{3}}\right)}$$

d.) $$PM = 180^\circ - |\measuredangle LG(j\omega_1)|$$

$$|LG(j\omega_1)| = 1 = \frac{\left(\frac{20}{\sqrt{3}}\right)^2}{\omega_1^2\left[1 + \frac{\omega_1^2}{300}\right]}$$

$$\frac{\omega_1^4}{300} + \omega_1^2 - \left(\frac{20}{\sqrt{3}}\right)^2 = 0$$

$$\omega_1^2 = \frac{-1 \pm \sqrt{1 + \frac{4(400)}{3(300)}}}{\frac{2}{300}} = \frac{-1 \pm \frac{5}{3}}{\frac{2}{300}}$$

$$\omega_1^2 = \frac{2/3}{2/300} = 100 \Rightarrow \omega_1 = 10 \text{ rad/sec}$$

$$\measuredangle LG(j\omega_1) = -90^\circ - \tan^{-1}\left(\frac{1}{\sqrt{3}}\right)$$

$$= -90^\circ - 30^\circ = -120^\circ$$

$$\therefore PM = 180^\circ - |-120^\circ| = 60^\circ$$

e.) $$GM = 20 \log\left[\frac{1}{|LG(j\omega_{180})|}\right] = \infty$$

LG never gets to 180°

$$\omega_{180} = \infty \Rightarrow |LG(j\omega_{180})| = 0$$

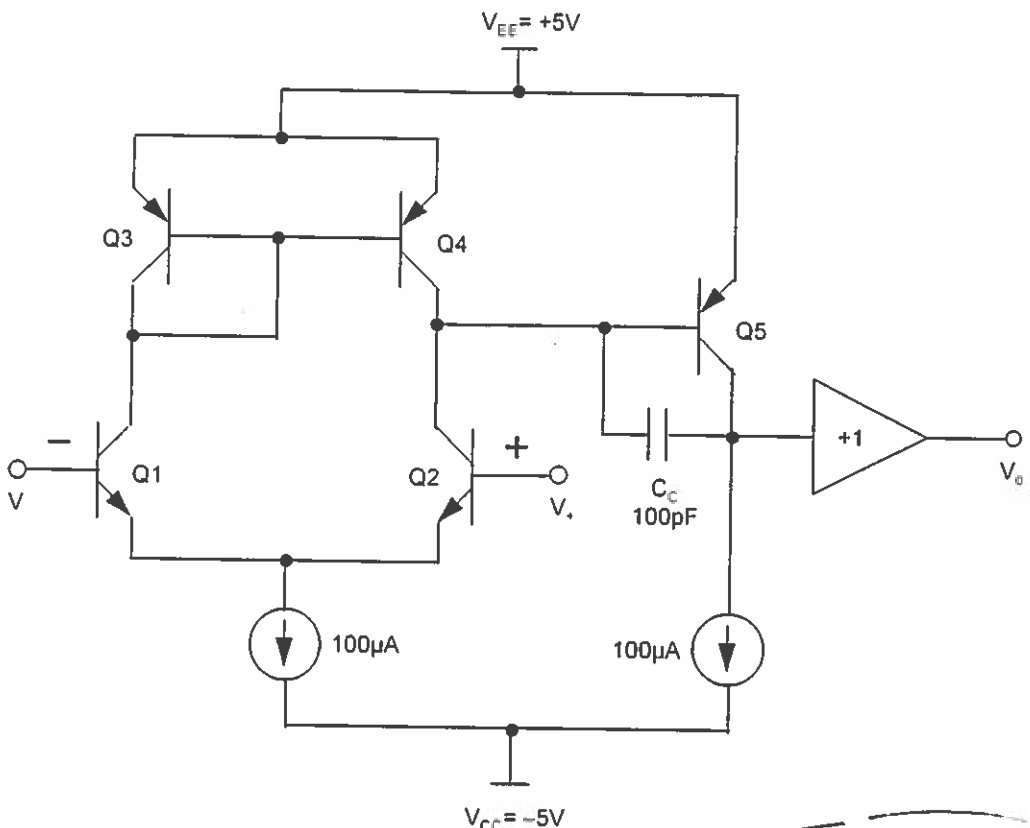
$$|\measuredangle LG(j\omega_{180})| = 180 = \left|-90^\circ - \tan^{-1}\frac{\omega_{180}}{10\sqrt{3}}\right|$$

$$\Rightarrow 90^\circ = \tan^{-1}\frac{\omega_{180}}{10\sqrt{3}}$$

$$\Rightarrow \omega_{180} = \infty$$

Problem 2 (50 points)

Consider the following open-loop opamp circuit. Assume the unity-gain output buffer is **ideal**. Assume V_T=25mV, $\beta_n=\beta_p$=100, and $V_{An}=V_{Ap}$=100V. You may make reasonable approximations in your calculations.



a) Calculate ω_t of the opamp. $\omega_t = \frac{g_{m2}}{C_c} =$ 20M Rad/sec

b) Calculate SR of the opamp. $SR = I_{o1}/C_c =$ 1V/μs

c) Now connect the opamp in its closed-loop, unity-gain configuration. Determine the closed-loop transfer function, $A_f(s)$. (You may assume that $A(s) = \omega_t/s$).

$$A_f(s) = \frac{1}{1+s/\omega_t} = \frac{1}{1+s/20\times10^6}$$

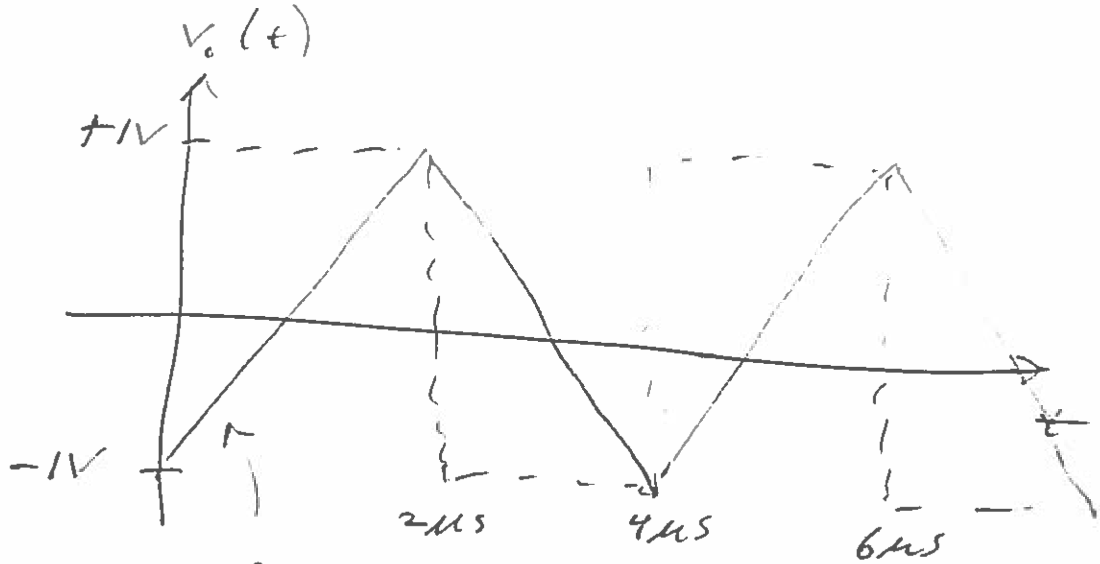
d) With the opamp still in its closed-loop, unity-gain configuration, if $v_i(t)$ is a square wave of amplitude ±1V and frequency 250kHz, sketch and label the output voltage, $v_o(t)$. Next page

e) **Optional extra credit (10 points, no partial credit):**

Calculate A_o and ω_H of the opamp.

$$A_o = g_{m2}\underbrace{[r_{o2}||r_{o4}||r_{\pi5}]}_{r_{\pi5}=25K} g_{m5} r_{o5} =$$ 200 KV/V

$$\omega_H = \frac{\omega_t}{A_o} =$$ 100 rad/sec



$SR = 1V/\mu s$