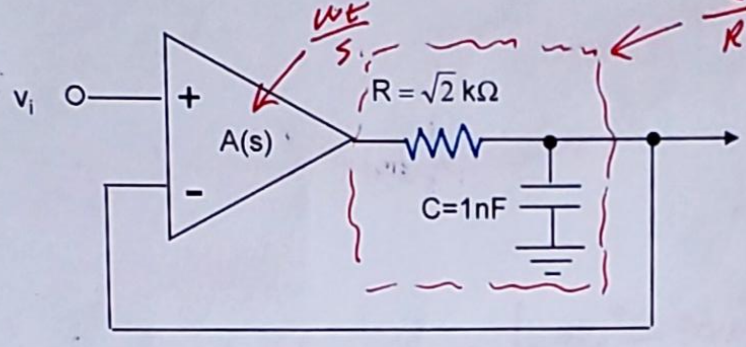
Problem 1 (50 points):

Consider the following closed-loop negative feedback opamp circuit. Assume the opamp has an open-loop transfer function, $A(s) \approx \omega_t/s = 10^6/s$.

$$\frac{\frac{1}{Cs}}{R+\frac{1}{Cs}} = \frac{1}{1+RCs}$$



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

b) Calculate the closed-loop transfer function, $A_f(s)=V_o/V_i(s)$.

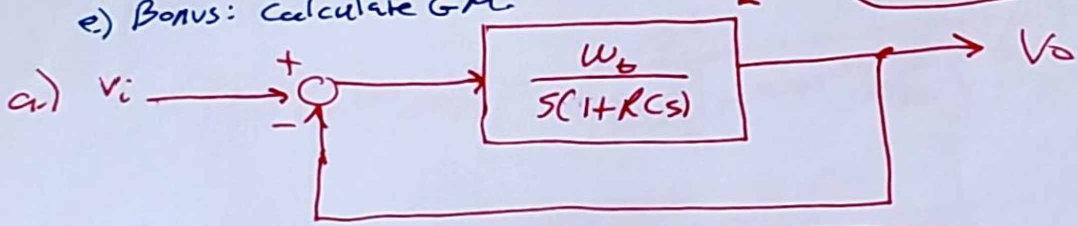
c) Calculate the Loop Gain, LG(s).

d) Calculate ω_1 and the PM.

e) Bonus: Calculate GM

$$\frac{10^6}{s(1+\sqrt{2}\times10^{-6}s)}$$

a)



b.) $$A_f(s) = \frac{\frac{\omega_t}{s(1+RCs)}}{1+\frac{\omega_t}{s(1+RCs)}} = \frac{1}{\sqrt{2}\times10^{-12}s^2 + 10^{-6}s + 1}$$

c.) $$LG(s) = \frac{\omega_t}{s(1+RCs)} = \frac{10^6}{s(1+\sqrt{2}\times10^{-6}s)}$$

d.) $$PM = 180° - |\angle LG(j\omega_1)|$$

$$\angle LG(j\omega_1) = -90° - \tan^{-1}(\sqrt{2}\times10^{-6}\omega_1)$$

$$|LG(j\omega_1)| = 1 = \frac{10^6}{\omega_1[1+2\times10^{-12}\omega_1^2]^{1/2}} \Rightarrow \omega_1 = \frac{\sqrt{2}}{2}\times10^6 \text{ rad/sec}$$

$$\Rightarrow \angle LG(j\omega_1) = -90° - \tan^{-1}(1) = -135° \Rightarrow PM = 45°$$

e.) Bonus : Calculate GM

$$GM = 20\log\left[\frac{1}{|\angle G(j\omega_{180})|}\right]$$

~~[illegible]~~

~~[illegible]~~

$$|\measuredangle \angle G(j\omega_{180})| = 180 = |-90^\circ - \tan^{-1}(\sqrt{2}\times10^{-6}\omega_{180})|$$

$$\tan^{-1}(\sqrt{2}\times10^{-6}\omega_{180}) = 180^\circ - 90^\circ = 90^\circ$$

$$\sqrt{2}\times10^{-6}\omega_{180} = \tan 90^\circ = \infty$$

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

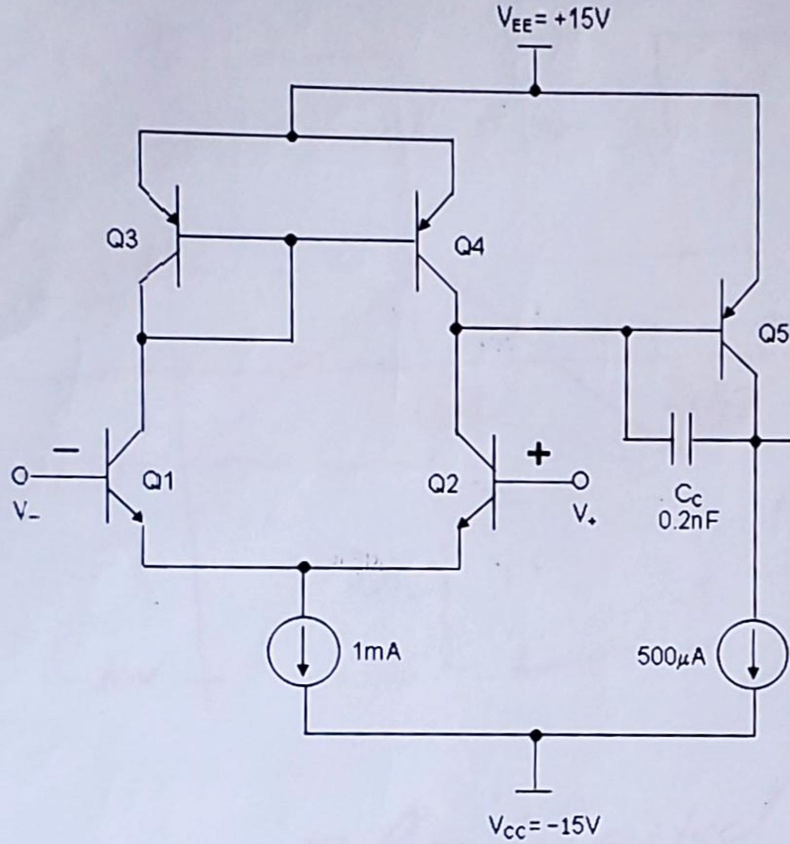
$$|\angle G(j\omega_{180})| = \frac{10^6}{\omega_{180}\left[1+2\times10^{-12}\omega_{180}^2\right]^{1/2}}$$

$$= 0$$

$$\therefore\ GM = 20\log\left[\frac{1}{0}\right] = \infty\ dB$$

Problem 2 (50 points)

Consider the following open-loop opamp circuit. Assume the unity-gain output buffer is ideal. Assume V_T=25mV, β_n=β_p=100 and V_{An}=V_{Ap}=500V. You may make reasonable approximations, as usual.



$g_{m2} = .02$ A/V
$r_{o2} = r_{o4} = 1$ MΩ
$g_{m5} = .02$ A/V
$r_{o5} = 1$ MΩ
$r_{\pi 5} = \frac{\beta_5}{g_{m5}} = 5$ kΩ

a) Calculate A_0 of the opamp. $\Rightarrow A_0 = g_{m2}[r_{o2} \| r_{o4} \| r_{\pi 5}]\, g_{m5} r_{o5} = 2\times10^6$ V/V

b) Calculate ω_H of the opamp. $\Rightarrow \omega_H = \frac{1}{(g_{m5} r_{o5})[r_{o2} \| r_{o4} \| r_{\pi 5}] C_c} = 50$ rad/sec

c) Calculate ω_t of the opamp. $\Rightarrow \omega_t = A_0 \omega_H = g_{m2}/C_c = 10^8$ rad/sec

d) Calculate the SR of the opamp. $\Rightarrow SR = \frac{I_{01}}{C_c} = 5$ V/µs

e) Now, connect the opamp in its unity-gain configuration. Determine the closed-loop transfer function, $A_f(s)$. (Please assume $A(s) \approx \omega_t/s$). $A_f(s) = \frac{1}{1+s/\omega_t} = \frac{1}{1+s/10^8}$

f) For the circuit in Part e), if $v_i(t)$ is a square wave of amplitude ±10V and frequency 500kHz, qualitatively sketch and annotate the output voltage, $v_o(t)$. (Hint: $v_o(t)$ will be Slew Rate limited and have no dc offset).

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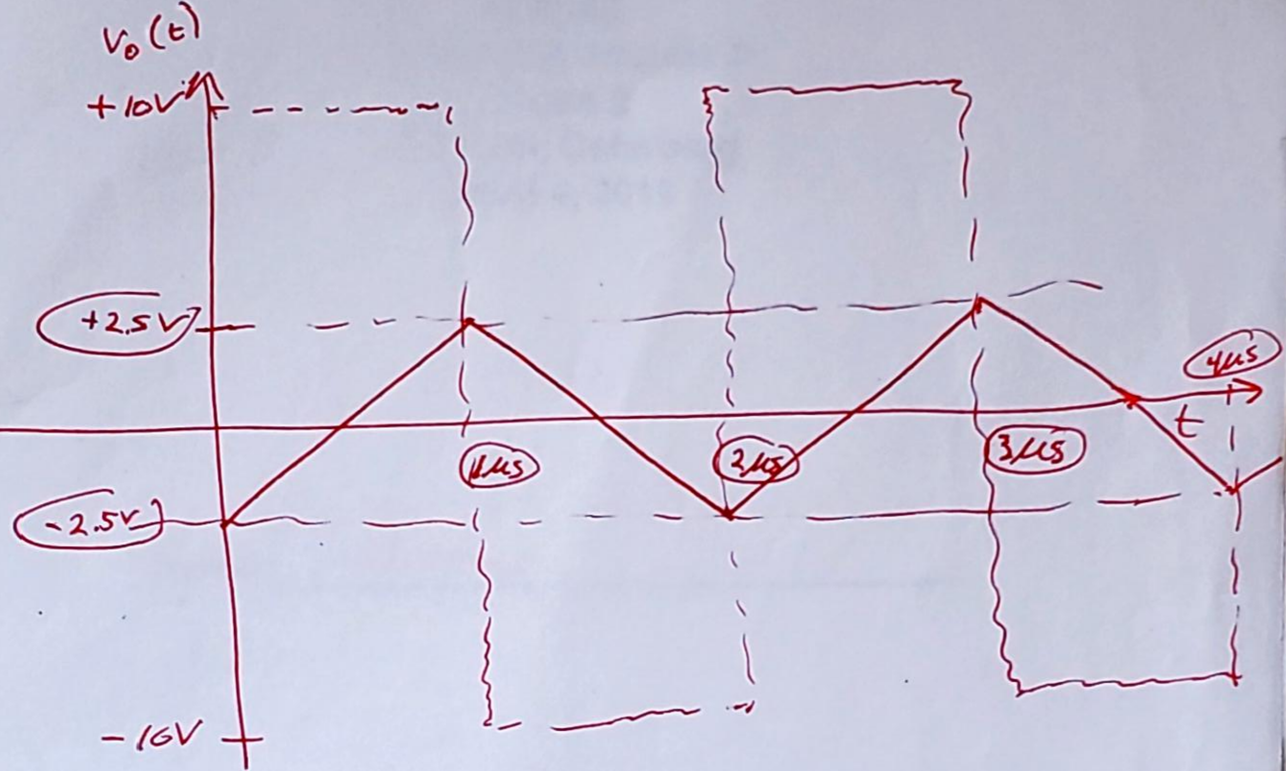
f.)



SR-Limited

$$SR = \left.\frac{dV_o}{dt}\right|_{max} = 5\ V/\mu s$$