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Section : 05

~~Lecturer :~~

Question 1

a) zeroes : -3

poles : $-4, \; -2 \pm j1$

i) $\therefore G(s) = \dfrac{k(s+3)}{(s+4)(s+2-j1)(s+2+j1)}$

ii) $\sigma_a = \dfrac{(-4-2+j-2-j1)}{3-1} = \dfrac{-5}{2}$

$\cancel{\theta_a} =$

$\theta_a = \dfrac{(2k+1)\pi}{3-1}$

iii) $\theta_d = \sum \text{zero} - \sum \text{poles} = 180$

b) $OS = 10\%$

$\zeta = 0.59$

$w_n = 4.08$

i) $\sigma = \zeta w_n$

$= 0.59 \times 4.08$

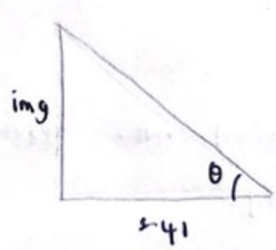
$= 2.41$

$\text{img} = \tan(53.84) \times 2.41$

$= 3.3$

$\theta = \cos^{-1} 0.59$

$= 53.84°$



$\therefore$ dominant closed-loop poles, $s =$

$-2.41 + j3.3$

ii) $s = -2.41 + j3.3$

$$k = \frac{|s+4| \cdot |s+2-j1| \cdot |s+2+j1|}{|s+3|}$$

$$= \frac{|(-2.41+j3.3)+4| \cdot |(-2.41+j3.3)+2-j1| \cdot |(-2.41+j3.3)+2+j1|}{|(-2.41+j3.3)+3|}$$

$\therefore K = 11$

iii) closed-loop transfer function:

$$T(s) = \frac{k(s+3)}{k(s+3) + (s+4)(s+2-j)(s+2+j)}$$

characteristic equation $= (s+4)(s^2+4s+5) + ks+3k \quad , k = 11$

$= s^3 + 4s^2 + 5s + 4s^2 + 16s + 20 + 11s + 33$

$= s^3 + \cancel{4}16s^2 + 32s + 53$

$s^3 + 16s^2 + 32s + 53 = 0$

$\therefore$ roots $= -13.98 \ , -1 \pm 1.67j$

$$\frac{13.98}{2.41} = 5.8\ 7\ 5$$

$\therefore$ Hence, the second order approximation validity is verified.

iv) $T_s = \frac{4}{|\sigma|} = \frac{4}{2.41} = 1.66\,s$

$T_p = \frac{\pi}{|img|} = \frac{\pi}{3.3} = 0.952\,s$

$k_p = \lim_{s\to 0} G(s) = \lim_{s \to 0} \frac{11(s+3)}{(s+4)(s+2-j1)(s+2+j)}$

$= \frac{11 \times 3}{4 \times (2-j) \times (2+j)}$

$= 1.65$

$e_{ss} = \frac{1}{1+k_p} = \frac{1}{2.65} = 0.377$

Question 2

a) $s = -0.88 + j1.72$

$OS = 20\%$

$T_s = \frac{4}{0.88} = 4.55\,s$

Requirement:

$OS = 20\%$

$T_{s\,new} = \frac{3}{5} T_{s\,old}$

$= \frac{3}{5} \times 4.55$

$= 2.73\,s$

∵ use PD Controller.

$G_{PD}(s) = k(s+z)$

Open loop transfer function:

$G(s) = \frac{k(s-1+i\sqrt{7})(s-1-i\sqrt{7})}{(s+3)(s+2-i)(s+2+i)}$

• New dominant poles, s :

$$T_s = \frac{4}{|\sigma|}$$

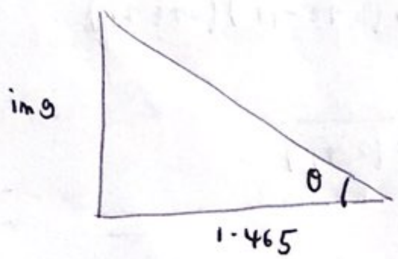
$$\sigma = \frac{4}{2.73} = 1.465$$

$$\zeta = \frac{-\ln(0.20)}{\sqrt{\pi^2 + \ln^2(0.2)}}$$

$$= 0.456$$

$$\theta = \cos^{-1} 0.456$$

$$= 62.87°$$

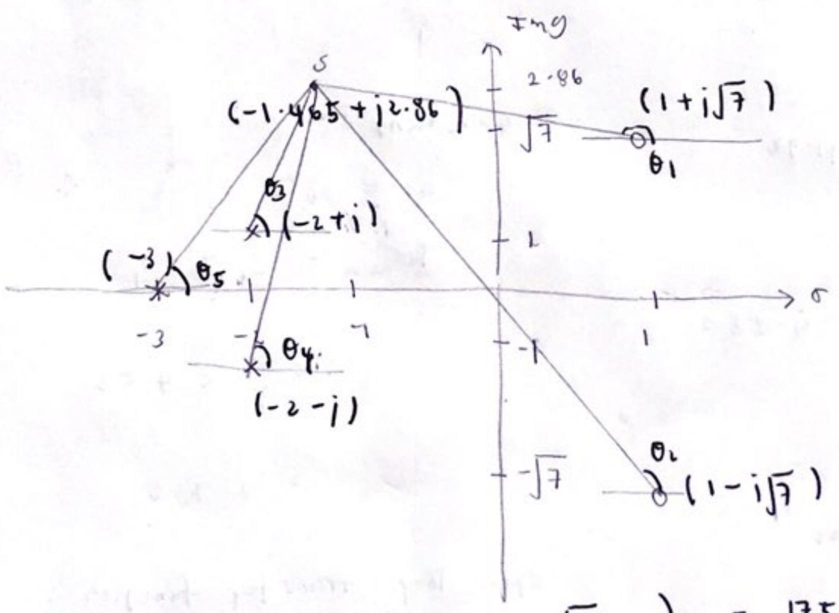


$$img = \tan(62.87) \times 1.465$$

$$= 2.86$$

$\therefore \quad s_{new} = -1.465 + j2.86$

• New zeroes, $(s+z)$:



$$\theta_1 = 180 - \left(\tan^{-1} \frac{2.86 - \sqrt{7}}{1 - (-1.465)}\right) = 175.03°$$

$$\theta_2 = 180 - \left(\tan^{-1} \frac{2.86 + \sqrt{7}}{1 - (-1.465)}\right) = 114.12°$$

$$\theta_3 = \tan^{-1}\left(\frac{2.86-1}{-1.465+2}\right) = 73.95$$

$$\theta_4 = \tan^{-1}\left(\frac{2.86+1}{-1.465+2}\right) = 82.11^{\circ}$$

$$\theta_5 = \tan^{-1}\left(\frac{2.86}{(3-1.465)}\right) = 49.24^{\circ}$$

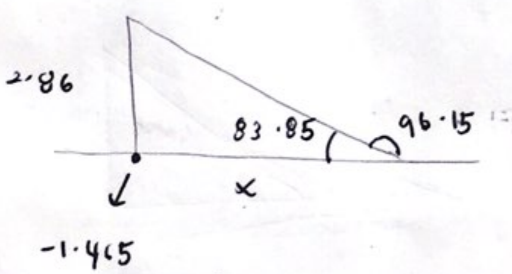
Angle criteria :

$$\theta_1 + \theta_2 - \theta_3 - \theta_4 - \theta_5 + \theta_z = 180$$

$$175.03 + 114.12 - 73.95 - 82.11 - 49.24 + \theta_z = 180$$

$$83.85 + \theta_z = 180$$

$$\theta_z = 96.15^{\circ}$$



$$x = \frac{2.86}{\tan 83.85} = 0.308$$

$$\therefore z = 0.308 + (-1.465)$$

$$= -1.157$$

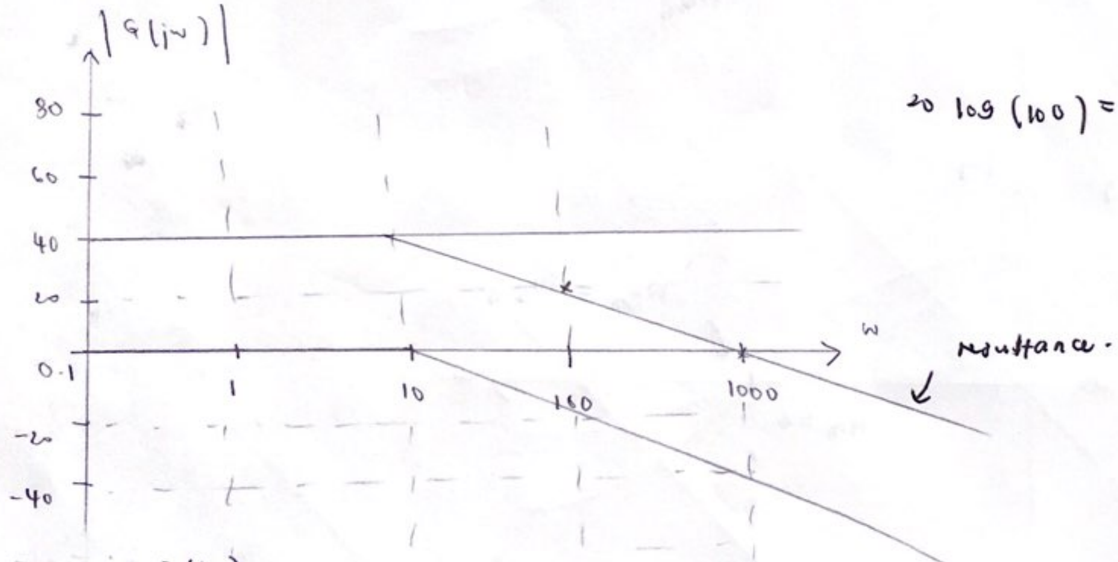
Question 3

a) i) $G(j\omega) = \dfrac{12}{j\omega(j\omega+6)} = \dfrac{12}{6\, j\omega\left(\frac{j\omega}{6}+1\right)}$

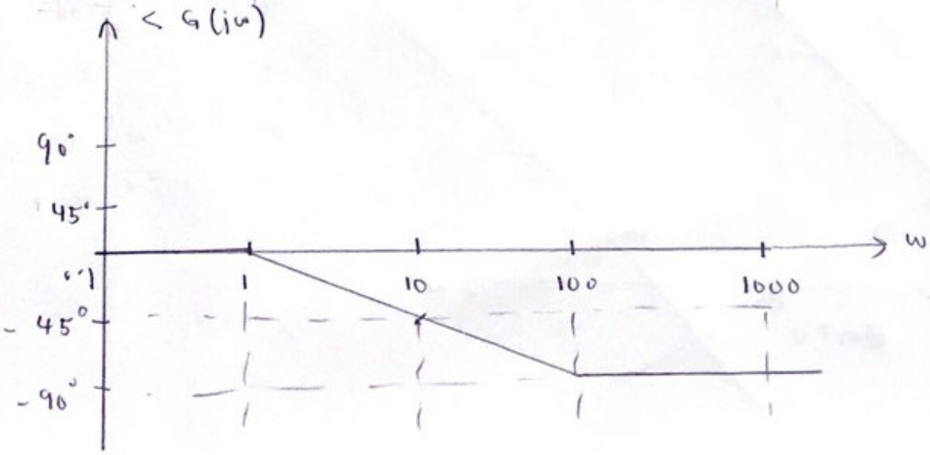
$$|G(j\omega)| = \frac{2}{j\omega\sqrt{\left(\frac{j\omega}{6}\right)^2+1}}$$

ii) $$|G(20)| = \frac{2}{20\sqrt{\left(\frac{20}{6}\right)^2+1}} = 0.0287$$

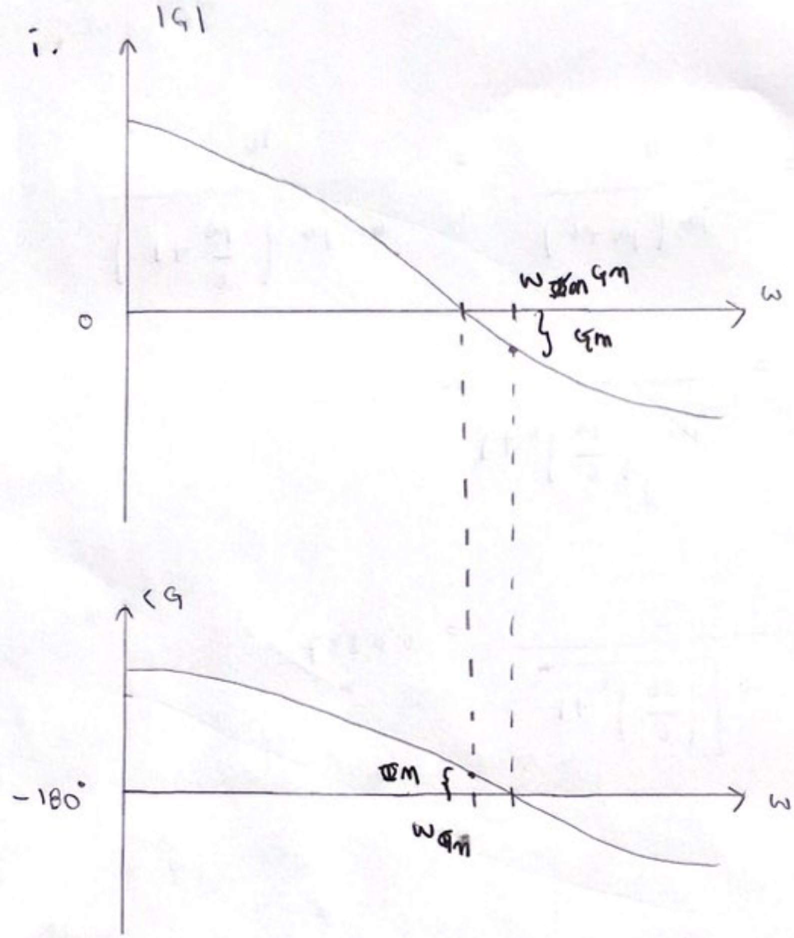
b)



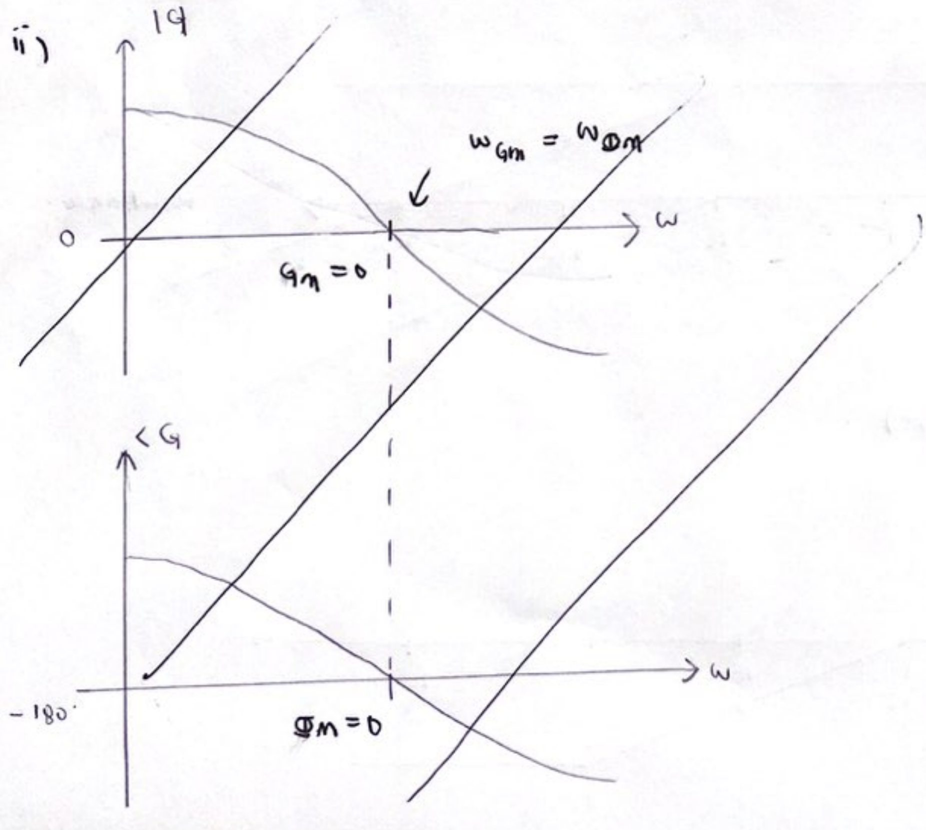
$20 \log(100) = 40$

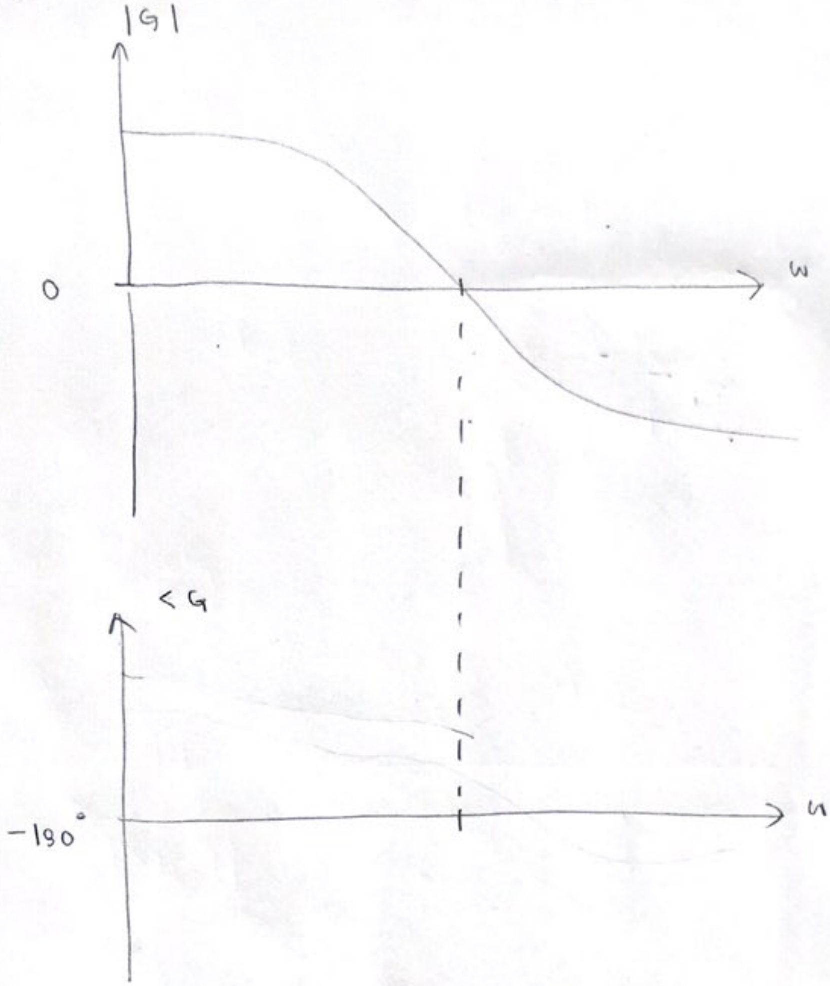


c) i.



ii)

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