$$3s^2 + 8s + 3 = 0$$

$$s = \frac{-8 \pm \sqrt{64-36}}{6}$$

$$= \cancel{\mathcal{E}} \; \frac{-8 \pm \sqrt{28}}{6}$$

$$= \frac{-8 \pm 2\sqrt{7}}{6}$$

$$= \frac{-4 \pm \sqrt{7}}{3}$$

→ Break away from the real axis enter the complex plane and then one branch moves to '∞' along 60° asymptotes second one move to '∞' along the 300° asymptotes. The branch which represents complex roots are known as complolex ~~poles.~~ root branches

$$s_1, s_2 = -0.451, -2.28$$

R.H critera.

s^3	1	3	
s^2	4	K	
s^1	$\frac{12-k}{4}$	0	$k = 12$
s^0	k		

$$4s^2 + K = 0$$

$$s = \pm j\sqrt{3}$$

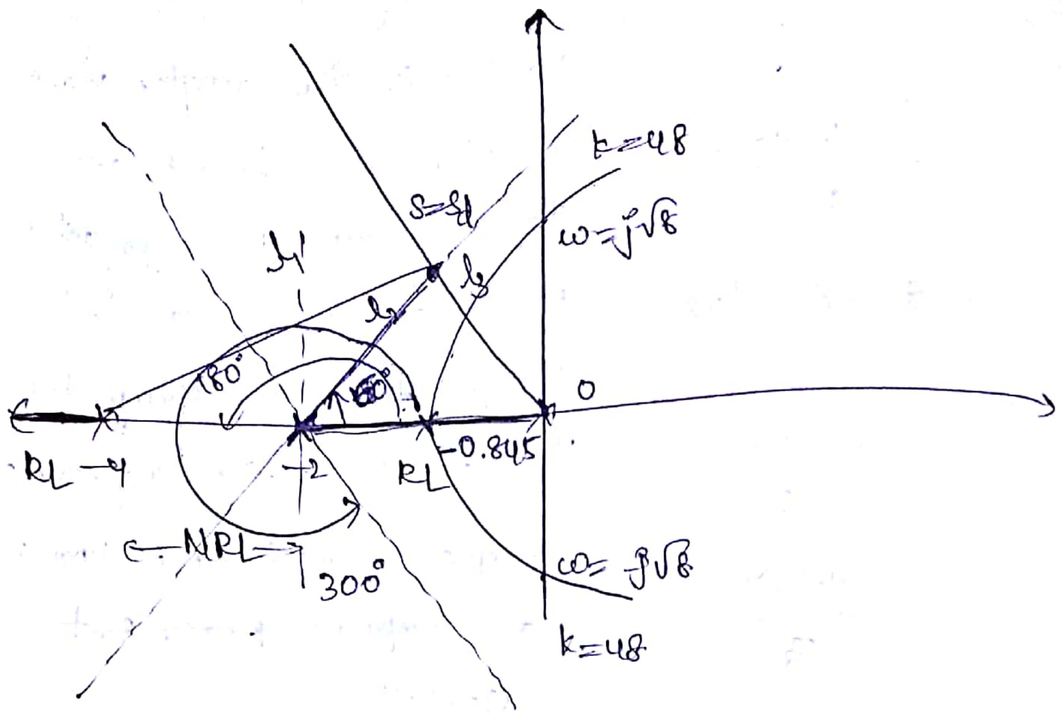
② Sketch ~~the~~ root locus of T.F $G(s)H(s) = \frac{k}{s(s+2)(s+4)}$

Find the value of k so that damping ratio of closed loop system is 0.5

Sol: 1) Identity the no. of poles

$$s = 0, -2, -4$$

8.



$$\text{Angle of asymptotes} = \frac{\pm(2q+1)}{n-m}\times \pm 180^\circ ,\ q = 0,1,2,\ n-m-1$$

$\cancel{= \pm 180}$

$q = 0 \Rightarrow \pm 60^\circ$

$q = 1 \Rightarrow \pm 180^\circ$

$q = 2 \Rightarrow \pm 300^\circ$

$$\text{centroid } (\sigma) = \frac{\Sigma \text{ R.P. poles} - \Sigma \text{ R.P zeros}}{\text{No. of poles} - \text{No. of zeros}}$$

$$= \frac{0-2-4-0}{3} = -2$$

BAP $\Rightarrow \frac{dk}{ds} = 0$

$$\frac{d}{ds}\left(1+G(s)H(s)\right) = 0$$

$$\frac{d}{ds}\left(1+\frac{k}{s(s+2)(s+4)}\right) = 0$$

$$\frac{d}{ds}\left(s(s^2+6s+8)+k\right) = 0$$

$$\frac{d}{ds}\left(s^3+6s^2+8s+k\right) = 0$$

$$3s^2+12s+8 = 0$$

$$s_1, s_2 = \frac{-12 \pm \sqrt{144-96}}{6}$$

$$\begin{array}{r} 24 \\ \times 4 \\ \hline 96 \end{array}$$

48
12

$$= \frac{-12 \pm 4\sqrt{3}}{6}$$

$$= -2 \pm \frac{2}{3}\sqrt{3}$$

$$= -0.845, -3.154$$

R.H criteria

$$s^3+6s^2+8s+k = 0$$

s^3	1	8
s^2	6	k
s^1	$\frac{48-k}{6}$	0
s^0	k	

$6s^2+k = 0$

$\Rightarrow \cancel{s^2}$

$k = 48$

$$\Rightarrow 6s^2 = -48$$

$$s^2 = -\cancel{48}^{8}/\cancel{6} = \pm j\sqrt{8}$$

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$$\theta = \cos^{-1}(\xi)$$

$$\theta = \cos^{-1}(0.5)$$

$$\theta = 60^{\circ}$$

$$K = \frac{l_1 \times l_2 \times l_3}{3}$$

③ $$G(s) = \frac{K}{S(s^2+4s+13)}$$

22/2/18

Q) Sketch the Bode plot for the following T.F. Determine Phase margin and gain margin.

$$G(s) = \frac{75(1+0.2s)}{s(s^2+16s+100)}$$

Sol:

~~$G(s) = \frac{75(1+0.2s)}{100s\left(1+\frac{16s}{100}+\right.}$~~

~~$G(s)$~~ $G(j\omega) = \dfrac{75(1+0.2j\omega)}{j\omega(-\omega^2+16j\omega+100)}$

$= \dfrac{75(1+0.2j\omega)}{100j\omega\left(1+j\frac{16}{100}\omega-\frac{\omega^2}{100}\right)}$

~~$2\xi\omega_n = $~~ $\frac{16}{100}$ $\quad \omega_n^2 = 100 \quad (\because s^2+2\xi\omega_n s+\omega_n^2)$

~~ω_n~~ $\quad \omega_{c_1} = \omega_{n_1} = 10$

$$\omega_{c_2} = \frac{1}{T_2} = \frac{1}{0.2} = 5$$

Term/factor	Corner freq	Slope (dB/dec)
0.75	—	0
$\frac{1}{j\omega}$	—	−20
$(1+0.2j\omega)$	$\omega_1 = \frac{1}{0.2} = 5$	+20
$\frac{1}{\left(1+j0.16\omega - \frac{\omega^2}{100}\right)}$	$\omega_{c_2} = \omega_n = 10$	−40

$$G(j\omega) = \frac{0.75\,(1+j0.2\omega)}{j\omega\left(1+j0.16\omega - \frac{\omega^2}{100}\right)}$$

~~M=~~

→ for $0 < \omega \leq 5$

$M = 20\log(0.75) - 20\log(\omega)$.

Slope = −20

~~$\omega = 0$ $\phi = -90^\circ$~~

$\omega = 0.1 \Rightarrow M = 17.5$ dB

$\omega = 5 \Rightarrow M = -16.47$ dB $\omega = 1 \Rightarrow M = -2.49$ dB

→ for $5 < \omega \leq 10$

$M = 20\log(0.75) + 20\log(\omega)(0.2) - 20\log(\omega)$

$\phi = \tan^{-1}(0.2\omega) - 90^\circ$ ~~= 11.8°~~

$\omega = 5$ Slope = 0

$\omega = 10 \Rightarrow M = -16.47$ dB

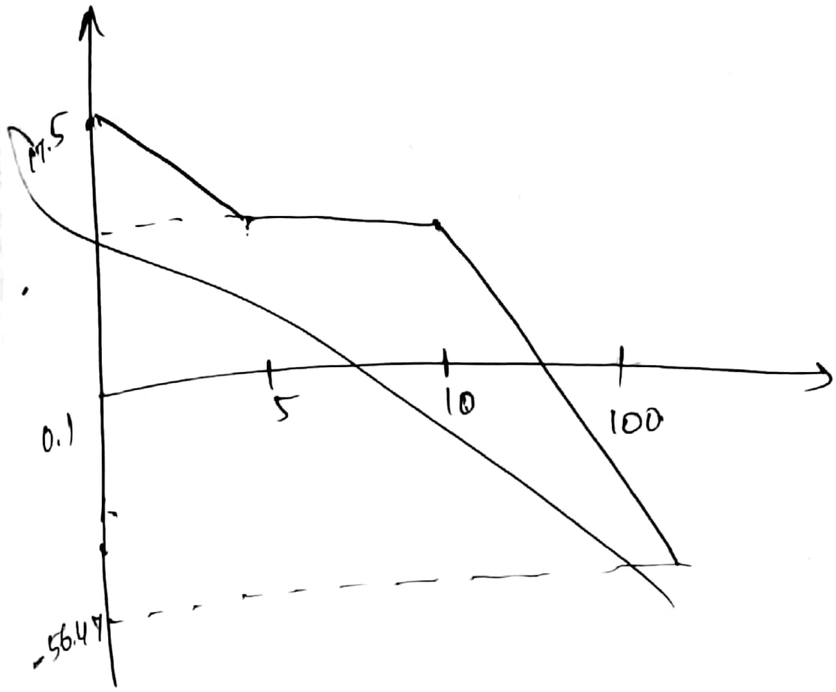
$\omega > 10$

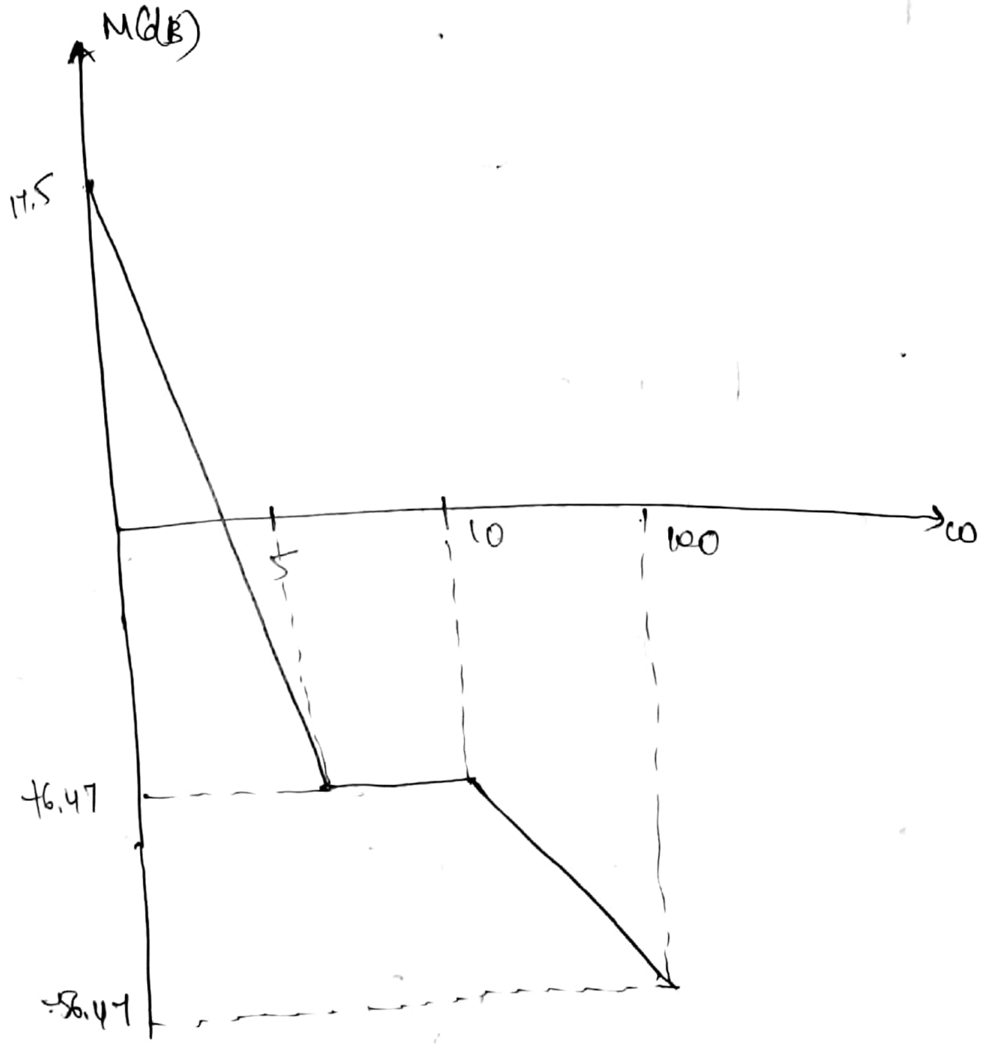
$M = 20\log(0.75) + 20\log(0.2\omega) - 20\log\omega$

$-40 \log\left(\frac{\omega}{10}\right)$ slope $= 20-20-40 = -40$

$\phi = 11.3$

$\omega = 100 \Rightarrow M = -56.47$





$$20\log(0.75) - 20\log\omega = 0$$

$$20\log(0.75) = 20\log(\omega)$$

$$-2.498 = 20\log(\omega)$$

$$\omega = 10^{\frac{-2.498}{20}}$$

$$\omega_{gc} = 0.75 \text{ rad/s.}$$

$$PM = 180 + \phi_{gc}$$

$$\phi_{gc} = \angle G(s)H(s)\Big|_{\omega=0.75}$$

$$\cancel{G(j\omega)}$$

$$G(j\omega) = \frac{0.75\left(1+j(0.2)(0.75)\right)}{j\omega\left(1+j0.16\times(0.75) - \frac{(0.75)^2}{100}\right)}$$

$$\cancel{= -90^\circ + \tan^{-1}(0.2\times0.75) - \tan^{-1}}$$

$$\phi = -90^\circ + \tan^{-1}(0.2\omega) - \tan^{-1}\left[\frac{0.16\omega}{1-0.01\omega^2}\right] \quad \omega \le$$

$$= -90^\circ + \tan^{-1}(0.2\omega) - \left[\tan^{-1}\left[\frac{0.16\omega}{1-0.01\omega^2}\right] + 180\right] \quad \omega \ge$$

$$\phi = -180^\circ = -90 + 180 + \tan^{-1}(0.2\omega) - \tan^{-1}\left(\frac{0.16\omega}{1-0.01\omega^2}\right)$$

$$-270^\circ = \tan^{-1}(0.2\omega) - \tan^{-1}\left(\frac{0.16\omega}{1-0.01\omega^2}\right)$$

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ω	ϕ
0.5	-88°
1	-88°
10	-111.6
20	-148°
50	-168°
100	-194

$\omega_{pc} = \infty$

$GM = \frac{1}{\frac{\phi}{\infty}} = \infty$ $\quad GM = \left| \frac{1}{G(s)} \right|_{\omega = \omega_{pc}}$

At $\omega = 0.75$,

$\phi = -90^\circ + \tan^{-1}(0.2\omega) - \tan^{-1}\left[\frac{0.18\omega}{1-0.01\omega^2}\right]$

$\phi = -89.97$

$PM = 180 + \phi_{gc} = 180^\circ - 89.97$

$= 90.02$

② $G(s) = \frac{Ks^2}{(1+0.2s)(1+0.02s)}$, ~~Ske~~ Sketch the bode plot & find K ~~ω~~ $\omega_{gc} = 5$ rad/s

$\omega_{gc} =$ K 5 r/s

Sol: let ~~ω =~~ $k=1$

$\cancel{G(s) = \frac{K s^2}{1+0.2\omega}}$

EXAMPLE 4.11

Consider a unity feedback system having an open loop transfer function $G(s) = \dfrac{K}{s(1+0.2s)\,(1+0.05s)}$. Sketch the polar plot and determine the value of K so that (i) Gain margin is 18 db (ii) Phase margin is 60°.

SOLUTION

Given that, $G(s) = \dfrac{K}{s\,(1+0.2s)\,(1+0.05s)}$. The polar plot is sketched by taking K = 1.

$\therefore$ Put K = 1 and $s = j\omega$ in G(s). $\therefore\; G(j\omega) = \dfrac{1}{j\omega\,(1+j0.2\omega)\,(1+j0.05\omega)}$

The corner frequencies are ω_{c1} = 1/0.2 = 5 rad/sec and ω_{c2} =1/0.05 = 20 rad/sec. The magnitude and phase angle of G(jω) are calculated for various frequencies and tabulated in table-1. Using polar to rectangular conversion the polar coordinates listed in table-1 are converted to rectangular coordinates and tabulated in table-2. The polar plot using polar coordinates is sketched on a polar graph sheet as shown in fig 4.11.1. Polar plot using rectangular coordinates is sketched on an ordinary graph sheet as shown in fig 4.11.2.

$$G(j\omega) = \frac{1}{j\omega\,(1+j0.2\omega)\,(1+j0.05\omega)}$$

$$= \frac{1}{\omega\angle 90^\circ\;\sqrt{1+(0.2\omega)^2}\;\angle\tan^{-1}0.2\omega\;\sqrt{1+(0.05\omega)^2}\;\angle\tan^{-1}0.05\omega}$$

$$= \frac{1}{\omega\;\sqrt{1+(0.2\omega)^2}\;\sqrt{1+(0.05\omega)^2}}\angle(-90^\circ - \tan^{-1}0.2\omega - \tan^{-1}0.05\omega)$$

$$\therefore |G(j\omega)| = \frac{1}{\omega\;\sqrt{1+(0.2\omega)^2}\;\sqrt{1+(0.05\omega)^2}} \quad\text{and}\quad \angle G(j\omega) = -90^\circ - \tan^{-1}0.2\omega - \tan^{-1}0.05\omega$$

TABLE-1 : Magnitude and phase of G(jω) at various frequencies

ω rad/sec	0.6	0.8	1	2	3	4
|G(jω)|	1.65	1.23	1.0	0.5	0.3	0.2
∠G(jω) deg	−98	−101	−104	−117.5	−129.4	−140

ω rad/sec	5	6	7	9	10	11	14
|G(jω)|	0.14	0.1	0.07	0.05	0.04	0.03	0.02
∠G(jω) deg	−149	−157	−164	−176	−180	−184	−195

TABLE-2 : Real and imaginary part of G(jω) at various frequencies

ω rad/sec	0.6	0.8	1	2	3	4
$G_R(j\omega)$	−0.23	−0.23	−0.24	−0.23	−0.19	−0.15
$G_I(j\omega)$	−1.63	−1.21	−0.97	−0.44	−0.23	−0.13

ω rad/sec	5	6	7	9	10	11	14
$G_R(j\omega)$	−0.120	−0.092	−0.067	−0.050	−0.04	−0.030	−0.019
$G_I(j\omega)$	−0.072	−0.039	−0.019	−0.0034	0	0.002	0.005

In the polar plot shown in fig 4.11.1 and 4.11.2 there are two plots, marked as curve-I and curve-II. These two loci are sketched with different scales to clearly determine the gain margin and phase margin.

From the polar plot, with K = 1,

Gain margin, $K_g = 1/0.04 = 25$.

Gain margin in db = 20 log 25 = 28 db.

Phase margin, $\gamma = 76°$.

Case (i)

With K = 1, let G(jω) cut the −180° axis at point B and gain corresponding to that point be G_B. From the polar plot $G_B = 0.04$. The gain margin of 28 db with K = 1 has to be reduced to 18 db and so K has to be increased to a value greater than one.

Let G_A be the gain at −180° for a gain margin of 18 db.

$$\text{Now, } 20\log\frac{1}{G_A} = 18 \quad\Rightarrow\quad \log\frac{1}{G_A} = \frac{18}{20} \quad\Rightarrow\quad \frac{1}{G_A} = 10^{18/20}$$

$$\therefore G_A = \frac{1}{10^{18/20}} = 0.125$$

$$\text{The value of K is given by, } K = \frac{G_A}{G_B} = \frac{0.125}{0.04} = 3.125$$

Case (ii)

With K = 1, the gain margin is 76°. This has to be reduced to 60°. Hence gain has to be increased.

Let ϕ_{gc2} be the phase of G(jω) for a phase margin of 60°

$$\therefore 60° = 180° + \phi_{gc2}$$

$$\phi_{gc2} = 60° - 180° = -120°$$

In the polar plot the −120° line cut the locus of G(jω) at point C and cut the unity circle at point D.

Let, G_C = Magnitude of G(jω) at point C.

G_D = Magnitude of G(jω) at point D.

From the polar plot, $G_C = 0.425$ and $G_D = 1$.

$$\text{Now, } K = \frac{G_D}{G_C} = \frac{1}{0.425} = 2.353$$

RESULT

(i) When K = 1, Gain margin, $K_g = 25$

Gain margin in db = 28db

(ii) When K = 1, Phase margin, $\gamma = 76°$

(iii) For a gain margin of 18 db, K = 3.125

(iv) For a phase margin of 60°, K = 2.353

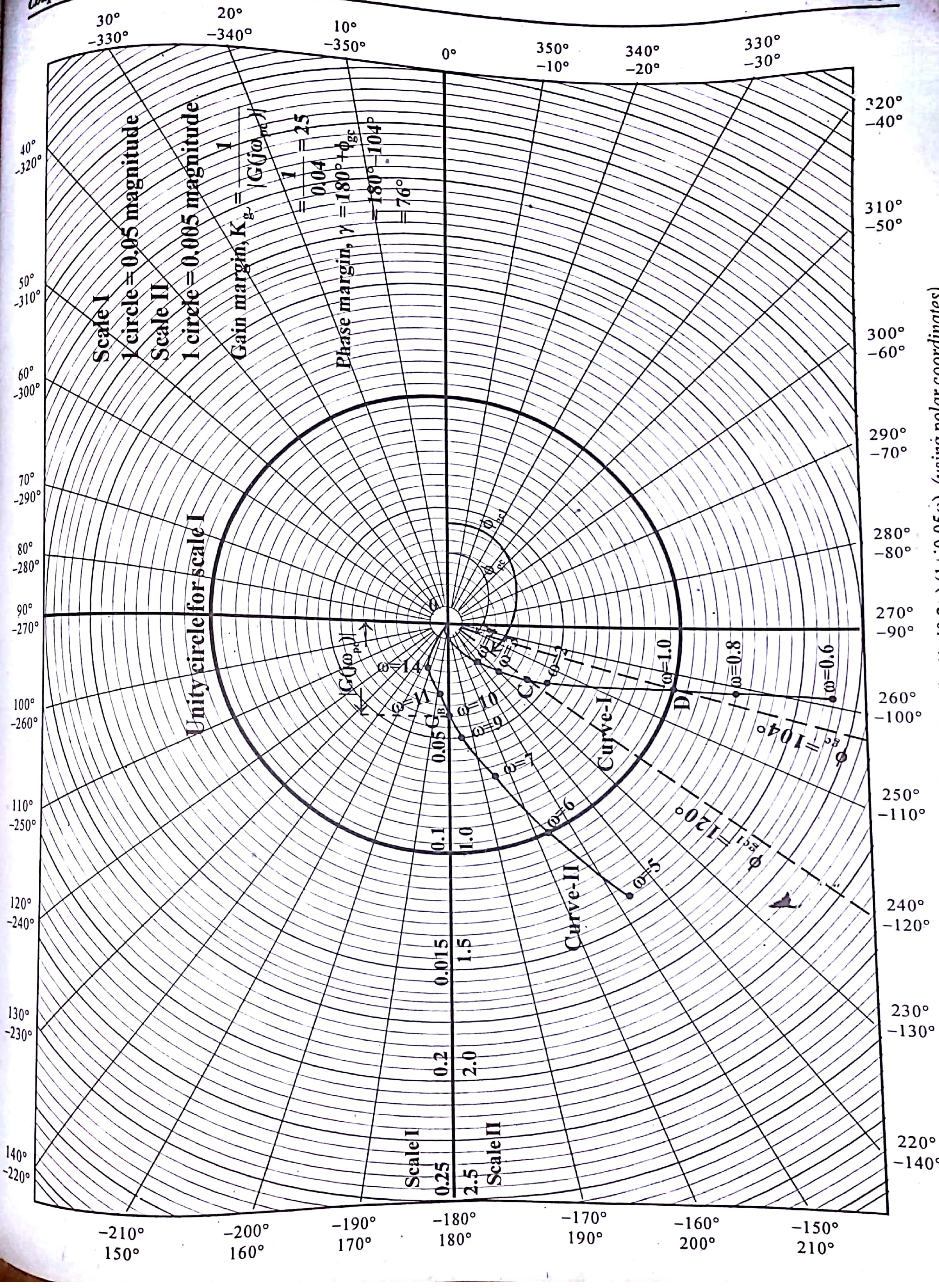

Fig 4.11.1: Polar plot of $G(j\omega) = 1/j\omega\,(1+j0.2\omega)\,(1+j0.05\omega)$, *(using polar coordinates)*

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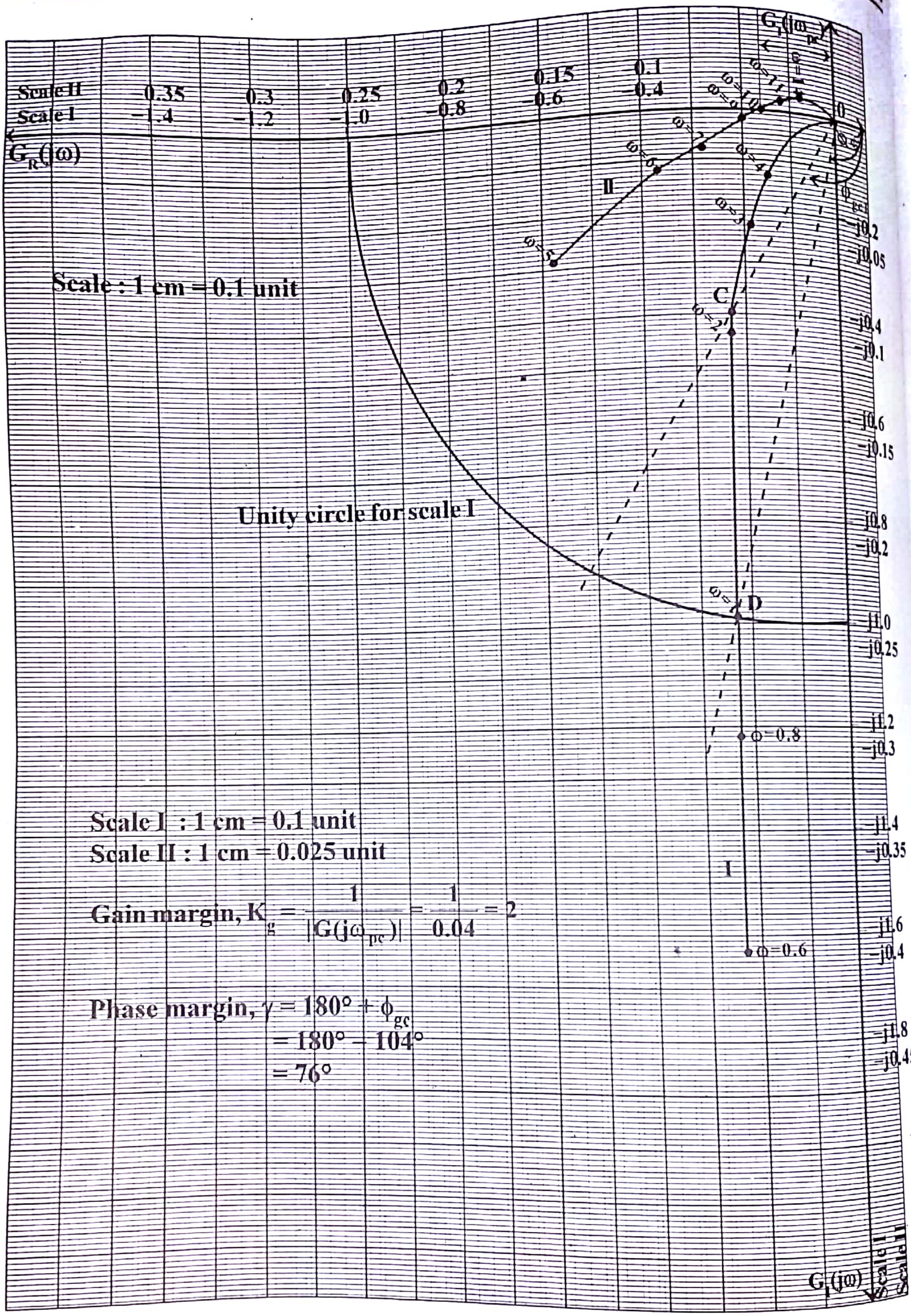


Fig 4.11.2: Polar plot of $G(j\omega) = 1/j\omega\,(1+j0.2\omega)\,(1+j0.05\omega)$, *(using rectangular coordinates)*

types can be used, the compensation may be cascaded series combination

~~GM > 0, & P~~

GM & PM > 0 ⇒ stable

= 0 → Marginally stable

< 0 ⇒ unstable

Types of

~~A~~ compensator is an electrical n/w which has ~~finite~~ poles and ~~finite~~ zeros to the system.

There are 3 types of compensator.

1) Lead compensator
2) Lag "
3) Lead-lag "

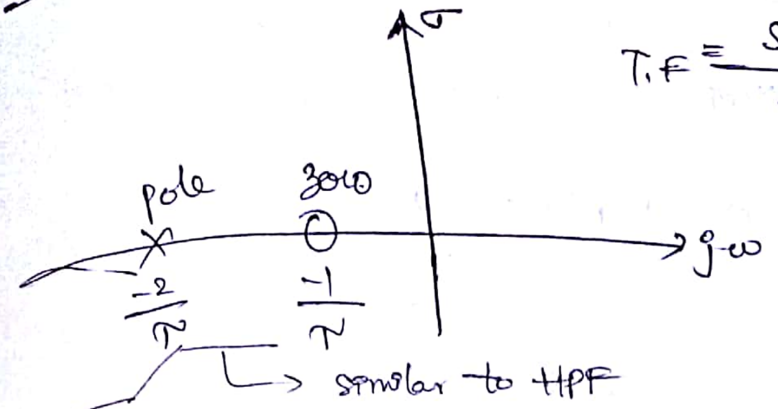
Lead compensator:

When sinusoidal i/p is applied to a n/w, to produce a sinusoidal steady state o/p having phase lead w.r.t i/p, then the compensator is called lead compensator.

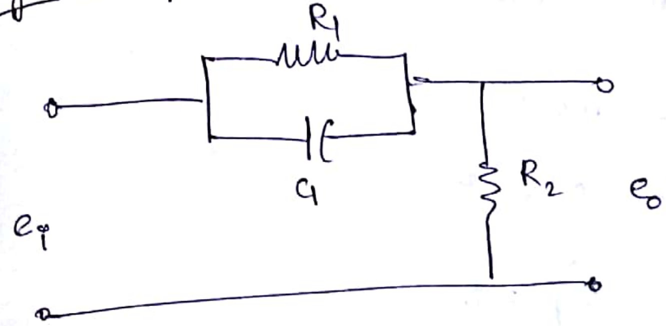
Lead compensator improves the transient response and increases margin of stability of a system and also ~~improves~~ increase the system error constant through a limited range.

Pole zero diagram of lead compensator:

$$T.F = \frac{s+Z_c}{s+P_c}, \quad \frac{Z_c}{P_c} > 1$$



Lag compensator:



$$\frac{e_o(s)}{e_i(s)} = \frac{R_2}{R_2 + R_1 // \frac{1}{sC}}$$

$$= \frac{R_2}{R_2 + \frac{R_1 \times \frac{1}{sC}}{R_1 + \frac{1}{sC}}}$$

$$= \frac{R_2(sCR_1+1)}{R_2(sCR_1+1)+R_1}$$

$$= \frac{R_2(1+sCR_1)}{R_1+R_2+sCR_1R_2}$$

$$= \frac{R_2}{R_1+R_2} + \frac{1+sCR_1}{1+sC\left(\frac{R_1R_2}{R_1+R_2}\right)}$$

Let $T = R_1C \rightarrow$ time constant

$\alpha = \frac{R_2}{R_1+R_2}$ = lead constant

$$T.F = \alpha\left[\frac{1+sT}{1+\alpha sT}\right]$$

$$T.F(j\omega) = \alpha\left[\frac{1+j\omega T}{1+\alpha j\omega T}\right]$$

$$= \frac{\alpha\sqrt{1+(\omega T)^2}}{\sqrt{1+(\alpha\omega T)^2}}$$

$$\phi = \tan^{-1}(\omega T) - \tan^{-1}(\alpha\omega T)$$

$$\frac{d\phi}{d\omega} = 0$$

Maximum phase lead occurs.

$$\phi = \frac{\omega T - \alpha\omega T}{1+\omega^2\alpha T^2}$$

$$\frac{d}{d\omega}\left(\frac{\omega T - \alpha\omega T}{1+\omega^2\alpha T^2}\right) = 0$$

$$\frac{d\phi}{d\omega} = \frac{(1+\omega^2\alpha T^2)(1-\alpha)T - \omega T(1-\alpha)2\omega\alpha T^2}{(1+\omega^2\alpha T^2)^2} = 0$$

$$(1+\omega^2\alpha T^2) - \omega\cdot 2\omega\alpha T^2 = 0$$

$$1 - 2\omega^2\alpha T^2 + \omega^2\alpha T^2 = 0$$

$$1 - \omega^2\alpha T^2 = 0$$

$$1 = \omega^2\alpha T^2$$

$$\cancel{T = \frac{1}{\sqrt{\omega}}}$$

$$\omega_m = \frac{1}{\sqrt{\alpha T^2}} = \frac{1}{T\sqrt{\alpha}}$$

$$\omega_{c_1} = \frac{1}{T}$$

$$\omega_{c_2} = \frac{1}{\sqrt{\alpha}\, T}$$

$$\omega_{c_2} = \frac{1}{\alpha T}$$

$$\omega_m^2 = \omega_{c_1} - \omega_{c_2}$$

$$\omega_m = \frac{1}{\sqrt{T \alpha T}} = \frac{1}{T\sqrt{\alpha}}$$

$$\tan \phi_m = \frac{\omega_m T (1-\alpha)}{1 + \omega_m^2 \alpha T^2}$$

$$\tan \phi_m = \frac{\frac{1}{T\sqrt{\alpha}} T (1-\alpha)}{1 + \frac{1}{T^2 \alpha} \alpha T^2}$$

$$\tan \phi = \frac{1-\alpha}{2\sqrt{\alpha}}$$

$$\sin \phi_m = \frac{1-\alpha}{1+\alpha}$$

$$\sin \phi_m (1+\alpha) = 1-\alpha$$

$$\sin(\phi_m) + \sin(\phi_m) . \alpha = 1 - \alpha$$

$$\sin \phi_m - 1 = -\alpha - \alpha . \sin \phi_m$$

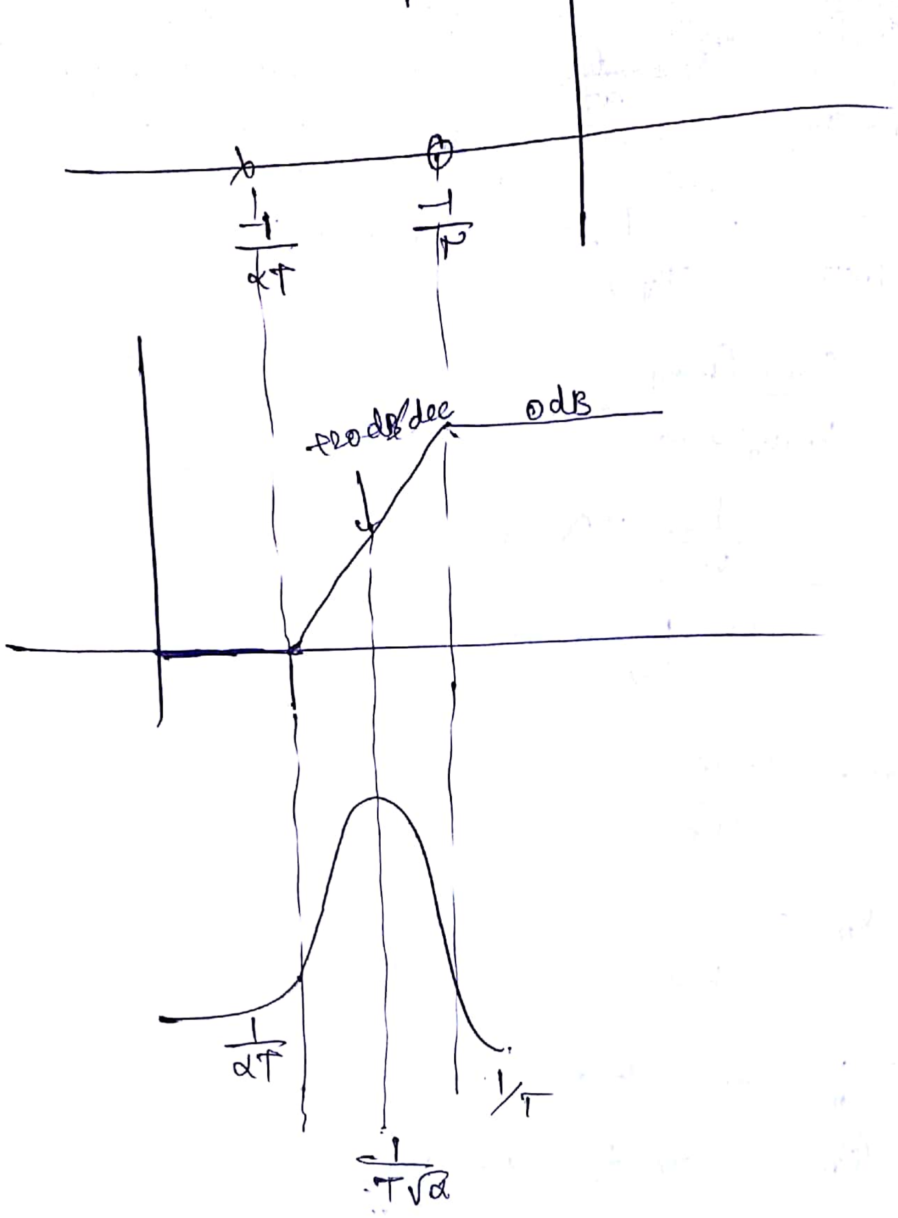
$$\sin \phi_m - 1 = -\alpha (1 + \sin \phi_m)$$

$$1 - \sin \phi_m = \alpha (1 + \sin \phi_m)$$

$$|\alpha| = \left| \frac{1 - \sin(\phi_m)}{1 + \sin(\phi_m)} \right|$$

$T = RC$

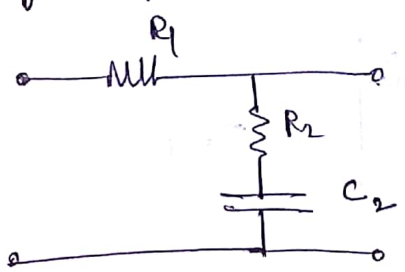
Lead compensator



→ 'α' value should not be less than 0.07

optimal value of $\alpha = 0.05$

Lag compensator



COMPLETE NYQUIST PLOT

The entire Nyquist plot in G(s)H(s)-plane can be obtained by combining the mappings of individual sections, as shown in fig 5.17.10.

STABILITY ANALYSIS

The Nyquist contour in G(s)H(s)-plane does not encircle the point (–1+j0) but the open loop transfer function has one pole on the right half s-plane. Therefore the system is unstable.

RESULT

Both open loop and closed loop systems are unstable.

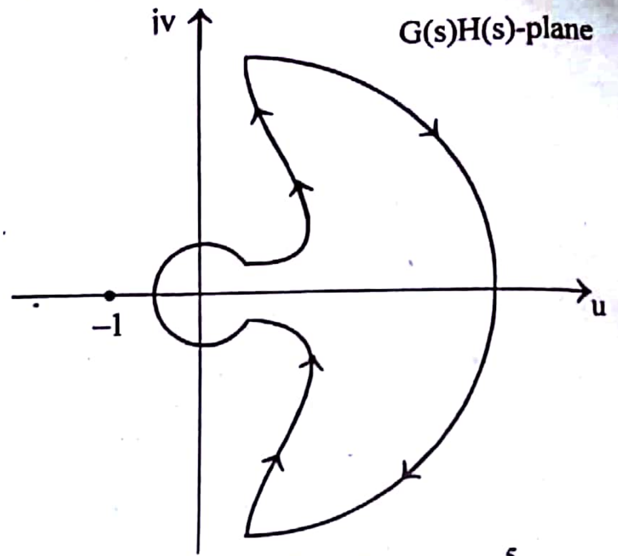


Fig 5.17.10 : Nyquist plot of $G(s) = \dfrac{5}{s(1-s)}$.

EXAMPLE 5.18

By Nyquist stability criterion determine the stability of closed loop system, whose open loop transfer function is given by, $G(s)H(s) = \dfrac{(s+2)}{(s+1)(s-1)}$. Comment on the stability of open-loop and closed loop system.

SOLUTION

Given that, $G(s)H(s) = \dfrac{(s+2)}{(s+1)(s-1)}$

The open loop transfer function does not have a pole at origin. Hence choose the Nyquist contour on s-plane enclosing the entire right half plane as shown in fig 5.18.1.

The Nyquist contour has three sections C_1, C_2 and C_3. The mapping of each section is performed separately and the overall Nyquist plot is obtained by combining the individual sections.

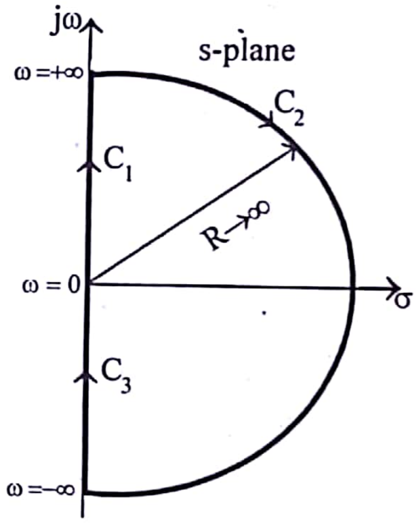


Fig 5.18.1 : Nyquist contour in s-plane.

MAPPING OF SECTION C_1

In section C_1, ω varies from 0 to +∞. The mapping of section C_1 is given by the locus of $G(j\omega)H(j\omega)$ as ω is varied from 0 to ∞. This locus is the polar plot of $G(j\omega)\,H(j\omega)$.

$$G(s)H(s) = \frac{s+2}{(s+1)(s-1)} = \frac{2(1+0.5s)}{(1+s)(-1+s)}$$

Let $s = j\omega$.

> *Note : $(-1+j\omega)$ represent a point in second quadrant*

$$\therefore G(j\omega)H(j\omega) = \frac{2(1+j0.5\omega)}{(1+j\omega)(-1+j\omega)} = \frac{2\sqrt{1+0.25\omega^2}\ \angle\tan^{-1}0.5\omega}{\sqrt{1+\omega^2}\ \angle\tan^{-1}\omega\ \sqrt{1+\omega^2}\ \angle(180°-\tan^{-1}\omega)}$$

$$= \frac{2\sqrt{1+0.25\omega^2}}{1+\omega^2}\angle(-180+\tan^{-1}0.5\omega)$$

–1)

$$\therefore\ |G(j\omega)H(j\omega)| = \frac{2\sqrt{1+0.25\omega^2}}{1+\omega^2}$$

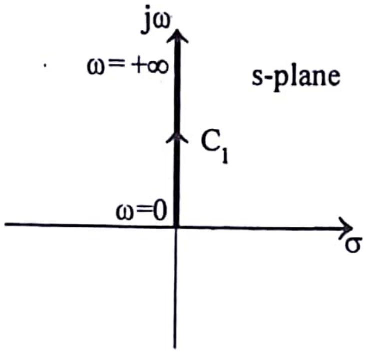
$$\angle G(j\omega)H(j\omega) = -180° + \tan^{-1}0.5\omega$$

The exact shape of $G(j\omega)H(j\omega)$ locus is determined by calculating the magnitude and phase of $G(j\omega)H(j\omega)$ for various values of ω.

ω rad/sec	0	0.4	1.0	2.0	10.0	∞
$\lvert G(j\omega)H(j\omega)\rvert$	2	1.76	1.12	0.57	0.1	0
$\angle G(j\omega)H(j\omega)$ deg	−180	−168	−153	−135	−101	−90

From the above analysis, we can conclude that $G(j\omega)H(j\omega)$ locus starts at $-180°$ axis at a magnitude of -2 for $\omega = 0$ and meets the origin along $-90°$ axis when $\omega = +\infty$.

The section C_1 in s-plane and its corresponding mapping in G(s)H(s)-plane are shown in fig 5.18.2 and 5.18.3.



$\Rightarrow$

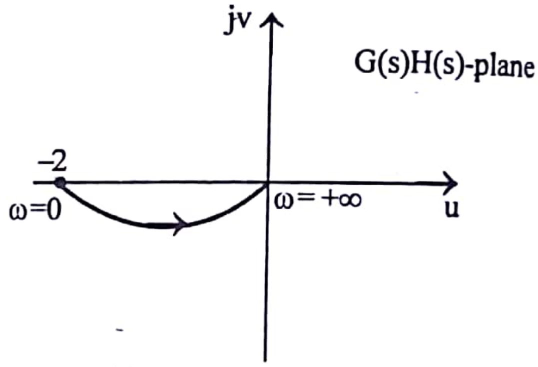


Fig 5.18.2 : Section C_1 in s-plane.

Fig 5.18.3 : Mapping of section C_1 in G(s)H(s)-plane.

MAPPING OF SECTION C_2

The mapping of section C_2 from s-plane to G(s)H(s)-plane is obtained by letting $s = \underset{R\to\infty}{\mathrm{Lt}}\ R\,e^{j\theta}$ in G(s)H(s) and varying θ from $+\pi/2$ to $-\pi/2$. Since $s \to R\,e^{j\theta}$ and $R \to \infty$, G(s) H(s) can be approximated as shown below, [i.e., $(1+sT) \approx sT$].

$$G(s)H(s) = \frac{2(1+0.5s)}{(1+s)\,(-1+s)} \approx \frac{2\times 0.5s}{s\times s} = \frac{1}{s}$$

Let, $s = \underset{R\to\infty}{\mathrm{Lt}}\ R\,e^{j\theta}$.

$$\therefore G(s)H(s)\Bigg|_{s=\underset{R\to\infty}{\mathrm{Lt}}\ R\,e^{j\theta}} = \frac{1}{\underset{R\to\infty}{\mathrm{Lt}}\ R\,e^{j\theta}} = 0e^{-j\theta}$$

$$\text{When } \theta = \frac{\pi}{2}, \qquad G(s)H(s) = 0e^{-j\frac{\pi}{2}} \qquad \text{.....(1)}$$

$$\text{When } \theta = -\frac{\pi}{2}, \qquad G(s)H(s) = 0e^{j\frac{\pi}{2}} \qquad \text{.....(2)}$$

From the equations (1) and (2) we can say that section C_2 in s-plane (fig 5.18.4) is mapped as circular arc of zero radius around origin in G(s)H(s)-plane with argument varying from $-\pi/2$ to $+\pi/2$ as shown in fig 5.18.5.

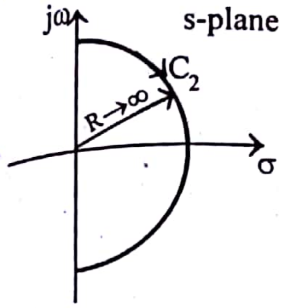


Fig 5.18.4 : Section C_2 in s-plane.

⇒

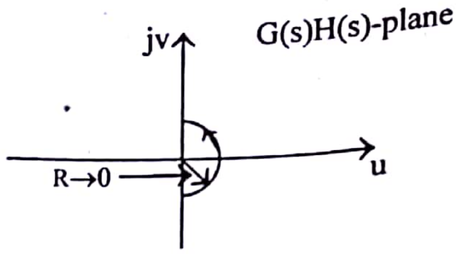


Fig 5.18.5 : Mapping of section C_2 in G(s)H(s)-plane.

MAPPING OF SECTION C_3

In section C_3, ω varies from $-\infty$ to 0. The mapping of section C_3 is given by the locus of G(jω)H(jω) as ω is varied from $-\infty$ to 0. This locus is the inverse polar plot of G(jω)H(jω).

The inverse polar plot is given by the mirror image of polar plot with respect to real axis. The section C_3 in s-plane and its corresponding contour in G(s)H(s) plane are shown in fig 5.18.6 and fig 5.18.7.

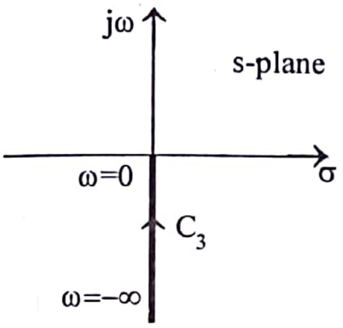


Fig 5.18.6 : Section C_3 in s-plane.

⇒

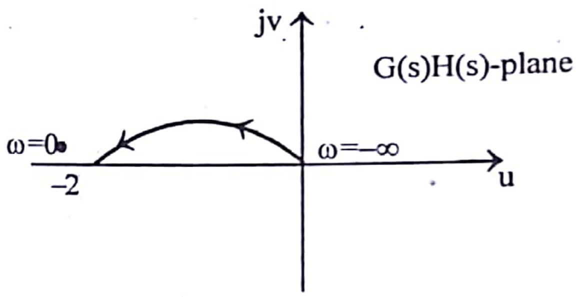


Fig 5.18.7 : Mapping of section C_3 in G(s)H(s)-plane.

COMPLETE NYQUIST PLOT

The entire Nyquist plot in G(s)H(s)-plane can be obtained by combining the mappings of individual sections, as shown in fig 5.18.8.

STABILITY ANALYSIS

On travelling through Nyquist contour it is observed that $-1+j0$ point is encircled in anticlockwise direction one time. Also the open loop transfer function has one pole at right half s-plane. Since the number of anticlockwise encirclement is equal to number of open loop poles on right half s-plane, the closed loop system is stable.

RESULT

1. Open loop system is unstable
2. Closed loop system is stable.

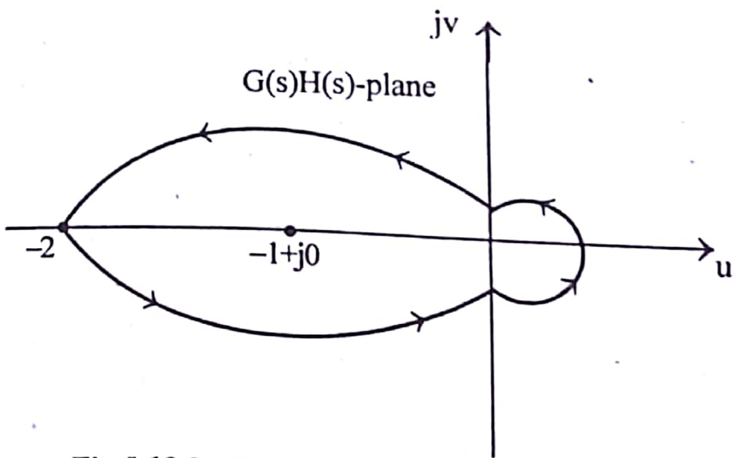


Fig 5.18.8 : Nyquist plot of $G(s)\,H(s) = \dfrac{(s+2)}{(s+1)\,(s-1)}$.