Bode Plots

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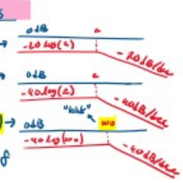
Pole Contributions

Poles:
- $(s+a)$ →



- $(s+a)^2$ →
- $(s^2+2\zeta\omega_0 s+\omega_0^2)$ →

- ω_0 = undamped f
- ζ = damped f
- "kink" = ω_0

ex. $H(s) = \dfrac{s^3+6s^2+13s+10}{s^4+11s^3+91s^2+601s+520}$ → zeros / → poles

→ Find zeros & poles: HP → cfactor( ) OR: for zeros → proot( )

$H(s) = \dfrac{(s+2)(s+2+j)(s+2-j)}{(s+1)(s+8)(s+1+8j)(s+1-8j)}$ → Find $s^2+2\zeta\omega_0 s+\omega_0^2$ → (For complex conj) → $(s+2)(s^2+2\cdot0.89\cdot2.24s+2.24^2)$

↳ $\omega_0=\sqrt{65}$, $\zeta=\frac{1}{\sqrt{65}}$

$= (s+1)(s+8)(s^2+2\cdot0.12\cdot8.06s+8.06^2)$

$\omega_0 = \sqrt{1^2+2^2} = \sqrt{5}$

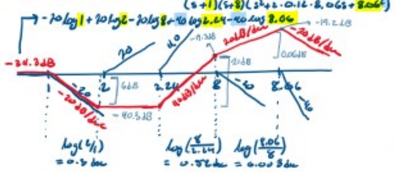
$\zeta = \cos\theta = \frac{-2}{\sqrt{5}}$

→ single poles: 1, 8, double pole: 8.06

→ single zero: 2, double zero: 2.24

Bode Plot: $H(s) = \dfrac{(s+2)(s^2+2\cdot0.89\cdot2.24s+2.24^2)}{(s+1)(s+8)(s^2+2\cdot0.12\cdot8.06s+8.06^2)}$

→ $-20\log 1+20\log 2-20\log 8+40\log 2.24-40\log 8.06$



1. Write zeros & poles in order
2. Slope contributions
   - ↳ simple: 20dB/dec, double: 40dB/dec
   - ↳ zero: (+), pole: (−)
4. Entry from the left?
   - ↳ zero or pole @ 0 rad/sec?
   - ↳ For s @ zero: ⌃
   - ↳ For s @ pole: ⌄
   - ↳ No pole: —
5. Calculate starting point
   - ↳ Add log of all poles & zeros
   - ↳
6. Trace plot
   - ↳ From start point, add/dec by slope contributions
7. Calculate Horizontal Amplitude in dB
   - ↳ $\underbrace{\log\left(\frac{p_2}{p_1}\right)}_{\text{Horizontal dec.}}\cdot\underbrace{\#\,dB/dec}_{\text{slope}}$ = drop in amplitude / increase
8. Calculate Amplitude at each pole/zero
   - ↳ From original value, subtract (for (−) slope) or add (for (+) slope) the drop/increase

Webwork BOD

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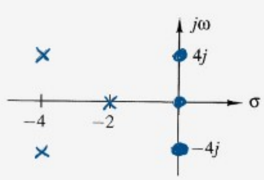
(25 points)
The transfer function $H(s)$ of a system has the three zeros and three poles shown in the figure. If $H(\infty) = 9$, find the transfer function, plot its Bode amplitude and phase plots and determine the values of those plots at the frequency $\omega = 2$ rad/s, and the absolute value of errors with respect to the exact values at that frequency.

Note: In this problem, you may only submit numerical answers. (i.e. If 4 is the correct answer, 4 will be marked as correct, but 2+2 will be marked as incorrect.)

3 poles and 3 zeros of the transfer function H(s)



(a) dB Bode plot at 2 rad/s : ____ dB

(a) dB |error| at 2 rad/s : ____ dB

(a) phase Bode plot at 2 rad/s : ____ deg

(a) phase |error| at 2 rad/s : ____ deg

Complex Roots

$s^2+2\cdot\zeta\omega_0+\omega_0^2$

$(s-4j)(s+4j)$: $\omega_0=\sqrt{0^2+4^2}=4$ $\zeta=\cos\theta=\frac{0}{4}=0$

$\therefore (s^2+2\cdot1\cdot4+4^2)$

$(s+4+4j)(s+4-4j)$ $\omega_0=\sqrt{4^2+4^2}=\sqrt{32}$ $\zeta=\cos\theta=\frac{4}{\sqrt{32}}=0.7071$

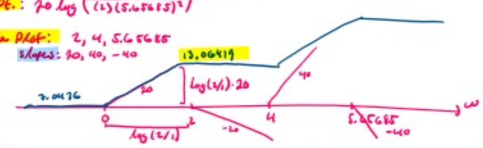
$\therefore (s^2+2\cdot0.7071\cdot\sqrt{32}+\sqrt{32}^2)$

$\therefore H(s) = \dfrac{9s(s-4j)(s+4j)}{(s+2)(s+4+4j)(s+4-4j)} = \dfrac{9s(s^2+2\cdot1\cdot4+4^2)}{(s+2)(s^2+2\cdot0.7071\cdot5.65685+5.65685^2)}$

↳ zeros: 0, 4 (double)
poles: 2, 5.65685 (double)

Starting Pt.: $20\log\left(\frac{4\cdot(1)\cdot(4)^2}{(2)(5.65685)^2}\right) = 7.0436$

Amplitude Plot: 2, 4, 5.65685
slopes: 20, 40, −40

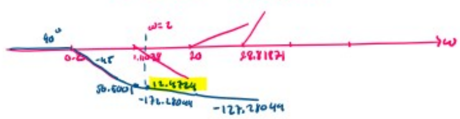


dB Error: $s=2j$
→ solve $20\log(H(s)) = 7.487841$
dB Error = |plot value − exact value|
= 13.0643 − 7.487841
= 5.57645

Phase Plot: For complex roots: $\omega_0/10^{\zeta}$, $\omega_0\cdot10^{\zeta}$
0.2, 0.4, 1.11033, 20, 28.81871, 40
slopes: −45, $90/\zeta$, $-90/\zeta$, 45, $90/\zeta$, $-90/\zeta$
∞ −127.28044 127.28044 −∞

→ zeros: ⌃
poles: ⌄

phase Error: $s=2j$
→ solve $\arg(H(s))$
phase Error = |plot value − exact value|
= 12.4724 − 15.25512
= 2.78291



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(25 points)
Complete the table below for the transfer function with $\omega_1 = 3krad/s$, $\omega_2 = 150krad/s$ and $\omega_3 = 905krad/s$:

$$H(s) = \frac{0.4(s+\omega_2)}{(s+\omega_1)(s+\omega_3)}$$

Note1: For the phase value, assume a continuous phase characteristic for the Bode plot that includes 0 degrees.

Note2: In this problem, you may only submit numerical answers. (i.e. If 4 is the correct answer, 4 will be marked as correct, but 2+2 will be marked as incorrect.)

Frequency	Magnitude (dB)		Phase (degrees)	
	Approx	Exact	Approx	Exact
$0.1\omega_1$				
ω_1				
$(\omega_1\omega_2)^{1/2}$				
ω_2				

50.5007 12.4724 -176.28044 -127.28044

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Frequency	Magnitude (dB)		Phase (degrees)	
	Approx	Exact	Approx	Exact
$0.1\omega_1$				
ω_1				
$(\omega_1\omega_2)^{1/2}$				
ω_2				
$(\omega_2\omega_3)^{1/2}$				
ω_3				
$10\omega_3$				

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(25 points)
Complete the table of Bode plot approximation values below for the given transfer function with $\omega_1 = 45krad/s$, $\omega_2 = 601krad/s$, $\omega_3 = 5571krad/s$ and $\zeta = 0.4$. At frequencies where a slope changes discontinuously, enter the slope for $H(j\omega_-)$ (i.e., on the bode plot, just left of where the discontinuity occurs).

– treat like LHS for A
– treat like $\frac{s^2}{s+\omega_3}$ for φ

$$H(s) = \frac{70s(s-\omega_3)}{(s+\omega_1)(s^2+2\zeta\omega_2 s+\omega_2^2)}$$ → RHS zero

Note1: For the phase value, assume a continuous phase characteristic for the Bode plot that includes 0 degrees. In this problem, this means that some values entered will not be the principal argument (a sketch of the characteristic will allow you to rapidly determine these values).

Note2: In this problem, you may only submit numerical answers. (i.e. If 4 is the correct answer, 4 will be marked as correct, but 2+2 will be marked as incorrect.)

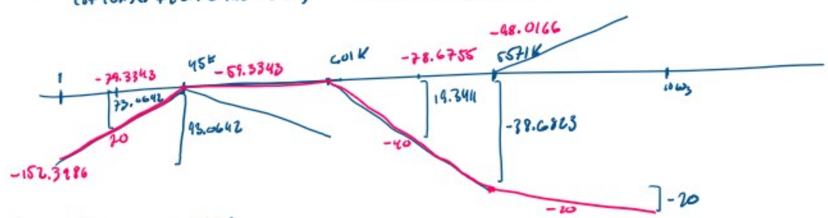
Frequency	Magnitude Char Approx		Phase Char Approx	
	Value (dB)	Slope (dB/dec)	Value (Â°)	Slope (Â°/dec)
$0.1\omega_1$	-79.33	20	270	0
ω_1	-59.53	20	225	-45
$(\omega_1\omega_2)^{1/2}$	-59.33	0	199.67	-45
ω_2	-59.33	0		-270
$(\omega_2\omega_3)^{1/2}$	-78.67	-40		-45
ω_3	-98.02	-40		-45
$10\omega_3$	-118.02	-20		-45

Amplitude

$$H(s) = \frac{70s(s-5571K)}{(s+45K)(s^2+2\cdot 0.4\cdot 601Ks+601K^2)}$$

→ 0, 5571K
→ 45K, 601K (double)

$$20\log\left(\frac{(5571K)70}{(45K)(601K)^2}\right) = -152.3986$$



$(\omega_1\omega_2)^{1/2} = 164453.6409$
$(\omega_2\omega_3)^{1/2} = 1829700.8088$

Phase

$(s-\omega_3) \rightarrow \frac{s^2}{s+\omega_3}$ $\therefore H(s) = \frac{70s^3}{(s+5571K)(s+45K)(s^2+2\cdot 0.4\cdot 601K+601K^2)}$ → 557.1K, 55710K, 4.5K, 450K,

↳ For complex: $601K \times 10^{-0.4} = 239262.4095$ $601K \times 10^{0.4} = 1509643.7453$

$\frac{90}{0.4} = 225°$