EK 307: Electric Circuits

Fall 2017

Lecture 25

Dec 12, 2017

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Administrivia

- Homework 9 back, all other homeworks
- HW10/11 = HW10, not graded; do and we go over any questions at review
- Course evaluation
- Review/office hour – doodle poll

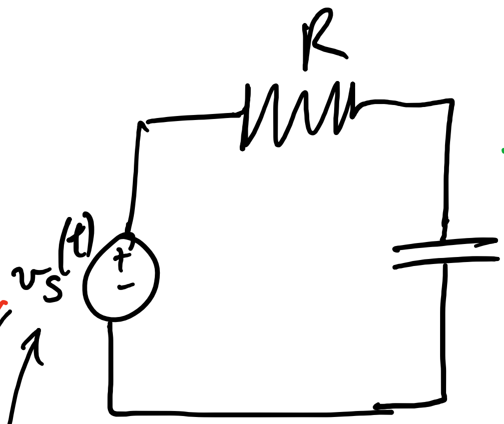
Administrivia

- Office hours between now and exam
  - Wed Dec 13 2:30-3:30pm PHO726
  - Thu Dec 14 2:30-3:30pm PHO726
  - Fri Dec 15 2:30-3:30pm PHO726
  - Mon Dec 18 1:30-3:30pm PHO726
  - Tue Dec 19 9:00-10:00am PHO726

Today

- Chapter 14 (14.1-14.4, 14.7)
  - Frequency response and filters

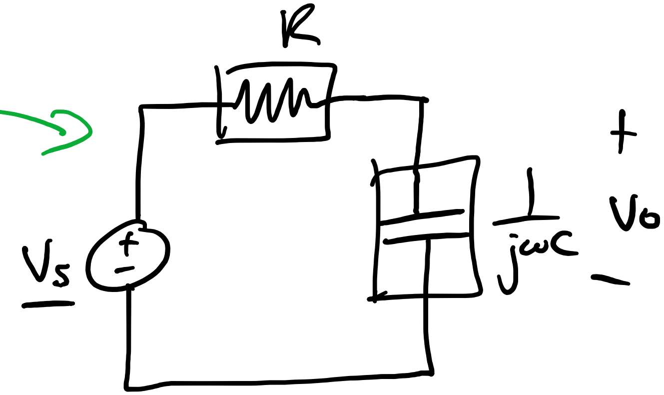
- Course wrap-up



$+$

$v_o(t) \leftarrow \underline{V_o}$

$-$



$v_s(t)$

$V_m \cos(\omega t + \phi)$

$\underline{V_s} = V_m e^{j\phi}$

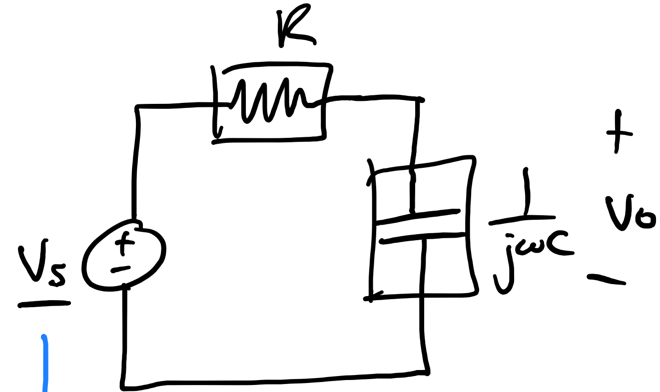
$$\boxed{\frac{1}{1 + j\omega RC}}$$

$|G| = \sqrt{|G} \quad \sqrt{\frac{1}{}}$

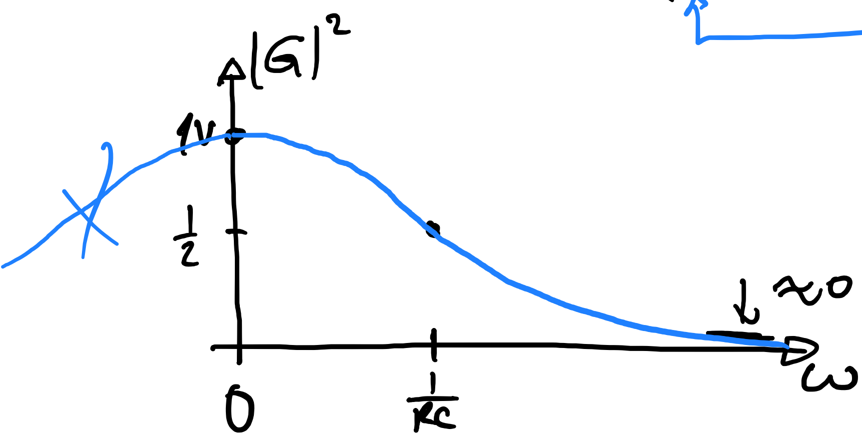
$$\boxed{|G| = \sqrt{\frac{1}{1^2 + (\omega RC)}}}$$

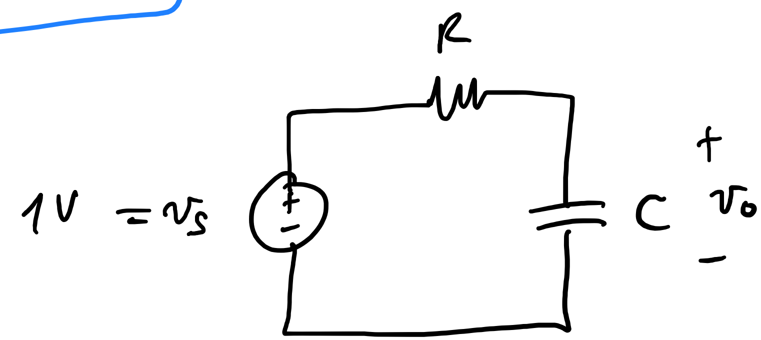
Power gain $= |G|^2 = \dfrac{1}{1 + (\omega RC)^2}$

Voltage gain: $|G| = \sqrt{\frac{1}{1^2+(\omega RC)^2}}$



Power gain $= |G|^2 = \frac{1}{1+(\omega RC)^2}$





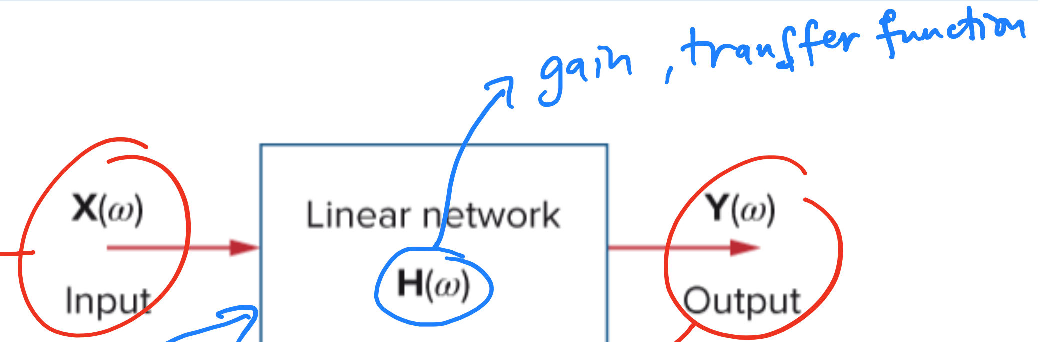
For $\omega = 0$: $|G|^2 = 1$

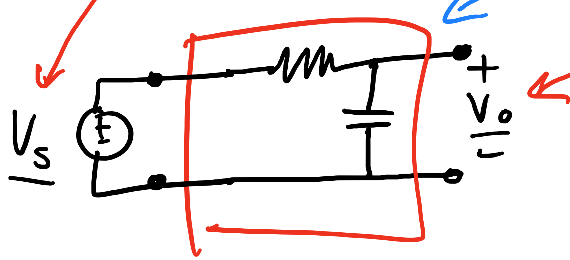
$\omega \Rightarrow \infty$: $|G|^2 = \frac{1}{\cancel{1}+(\omega RC)^2} \approx \frac{1}{(\omega RC)^2} \rightarrow 0$

$\omega = \frac{1}{RC}$: $|G|^2 = \frac{1}{2}$

Chapter 14: Frequency Response

The **frequency response** of a circuit is the variation in its behavior with change in signal frequency.





$$\mathbf{H}(\omega) = \frac{\mathbf{Y}(\omega)}{\mathbf{X}(\omega)}$$

Chapter 14: Frequency Response

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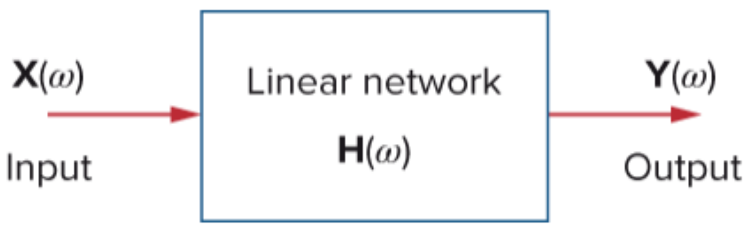


$$\mathbf{H}(\omega) = \text{Voltage gain} = \frac{\mathbf{V}_o(\omega)}{\mathbf{V}_i(\omega)}$$

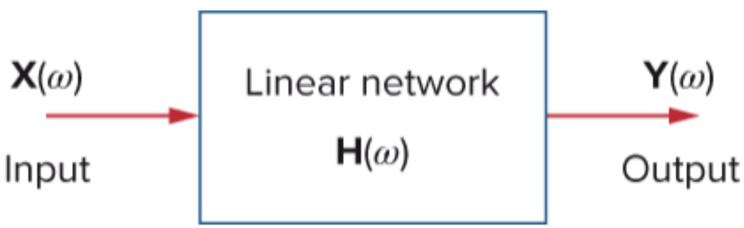
$$\mathbf{H}(\omega) = \text{Current gain} = \frac{\mathbf{I}_o(\omega)}{\mathbf{I}_i(\omega)}$$

$$\boxed{\mathbf{H}(\omega) = \frac{\mathbf{Y}(\omega)}{\mathbf{X}(\omega)}}$$

$$\mathbf{H}(\omega) = \text{Transfer impedance} = \frac{\mathbf{V}_o(\omega)}{\mathbf{I}_i(\omega)}$$

$$\mathbf{H}(\omega) = \text{Transfer admittance} = \frac{\mathbf{I}_o(\omega)}{\mathbf{V}_i(\omega)}$$

Chapter 14: Frequency Response



$\mathbf{H}(\omega) = H(\omega)\angle\phi.$

zeros of transfer fcn

$$\boxed{\mathbf{H}(\omega) = \frac{\mathbf{N}(\omega)}{\mathbf{D}(\omega)}}$$

poles of trans fcn

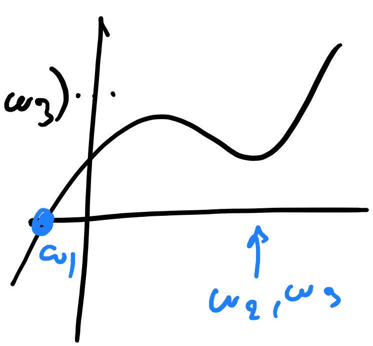
ω^N (for N cct elements)

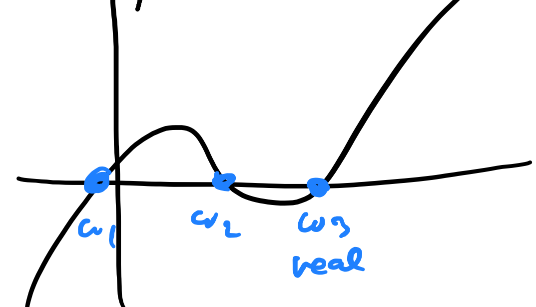
$N(\omega) = A + B\omega + C\omega^2 + D\omega^3 + \cdots$

$N(\omega) = K(\omega-\omega_1)(\omega-\omega_2)(\omega-\omega_3)\cdots$

$D(\omega) = M(\omega-\omega_{p1})(\omega-\omega_{p2})\cdots$

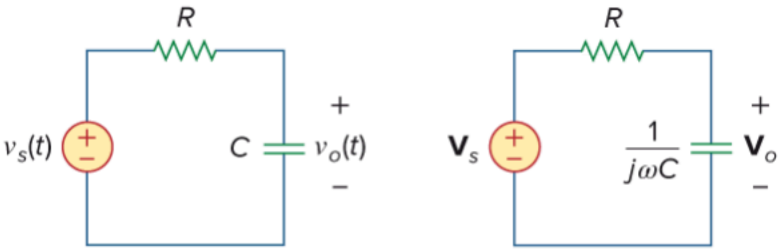
$N(\omega) = A + B\omega + C\omega^2 + D\omega^3$





Example 14.1

For the *RC* circuit in **Fig. 14.2(a)**, obtain the transfer function $\mathbf{V}_o/\mathbf{V}_s$ and its frequency response. Let $v_s = V_m \cos \omega t$.



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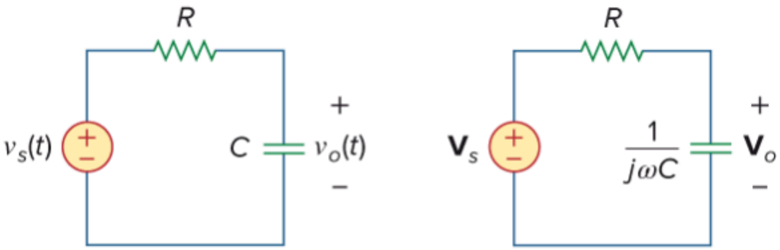
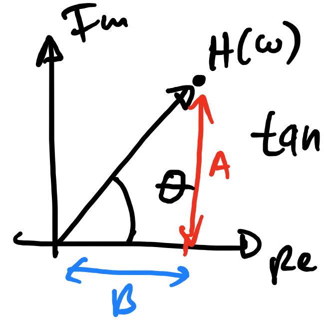
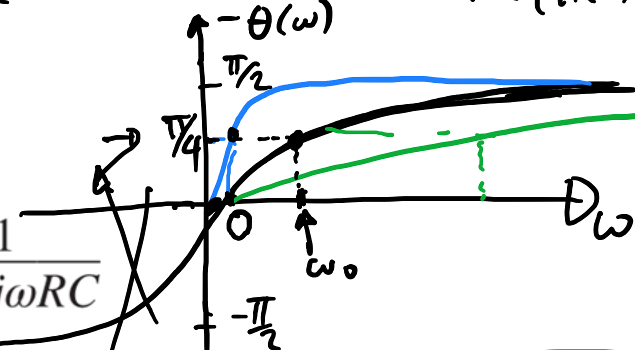




$$\tan\theta = \frac{Im(H(\omega))}{Re(H(\omega))} = \frac{A}{B}$$

Phase response:

$$\theta(\omega) = \tan^{-1}\frac{Im\{H(\omega)\}}{Re\{H(\omega)\}}$$



$$\mathbf{H}(\omega) = \frac{\mathbf{V}_o}{\mathbf{V}_s} = \frac{1/j\omega C}{R + 1/j\omega C} = \frac{1}{1 + j\omega RC}$$

$$H(\omega) = \frac{1 - j\omega RC}{1 + (\omega RC)^2} = \boxed{\frac{1}{1+(\omega RC)^2}} \boxed{- j\frac{\omega RC}{1+(\omega RC)^2}}$$

$$\sqrt{H(\omega)H^*(\omega)}$$

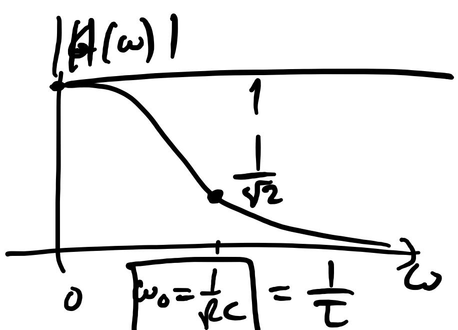
Magnitude response:

$$H = \frac{1}{\sqrt{1 + (\omega/\omega_0)^2}}, \qquad \phi = -\tan^{-1}\frac{\omega}{\omega_0}$$

$$\theta(\omega) = \tan^{-1}\frac{-\omega RC/\cancel{0}}{1/\cancel{0}}$$

$$= -\tan^{-1}\omega RC$$

$$\theta(\omega) = -\tan^{-1}\omega/\omega_0$$



Corner frequency $\omega_0 = \frac{1}{RC}$

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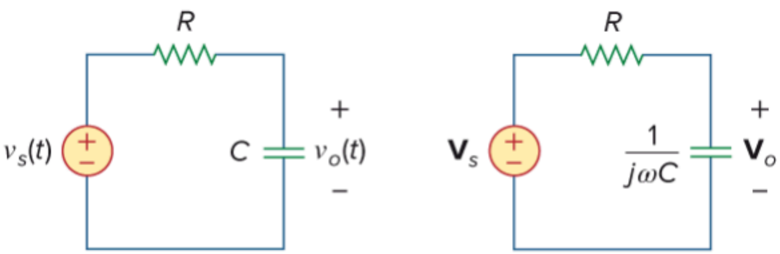
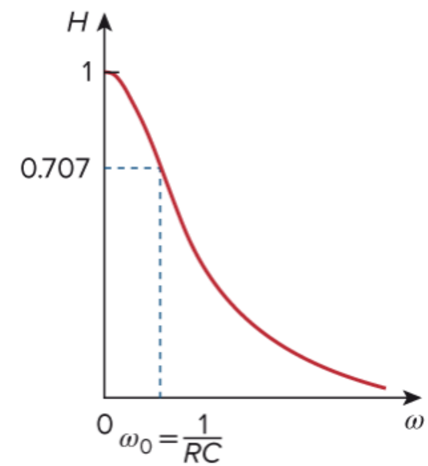
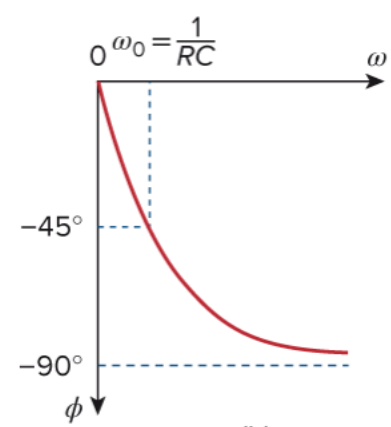




$$\mathbf{H}(\omega) = \frac{\mathbf{V}_o}{\mathbf{V}_s} = \frac{1/j\omega C}{R + 1/j\omega C} = \frac{1}{1 + j\omega RC}$$



$$H = \frac{1}{\sqrt{1 + (\omega/\omega_0)^2}}, \qquad \phi = -\tan^{-1}\frac{\omega}{\omega_0}$$

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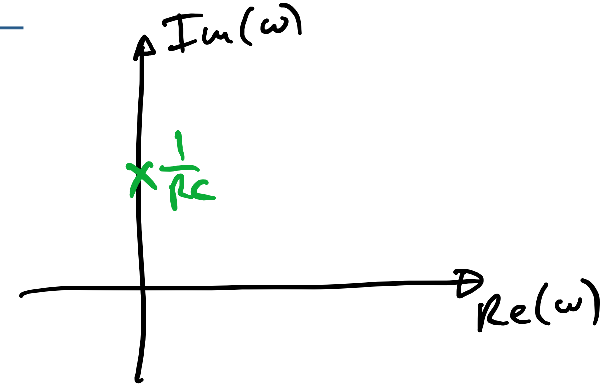

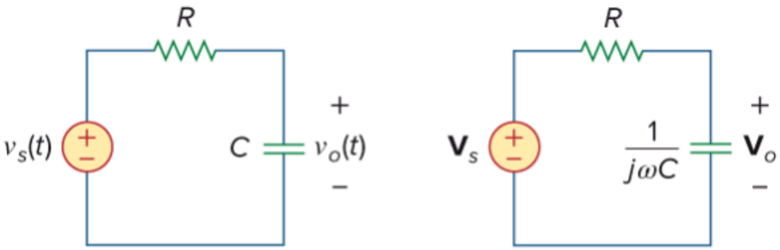

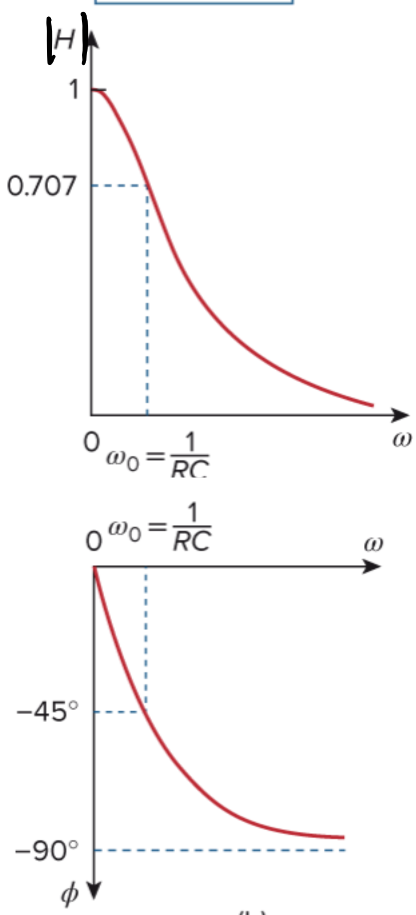

$$H(\omega) = \frac{1}{1+j\omega RC} = \frac{A\cancel{(\omega-\omega_{z1})}\cancel{(\omega-\omega_{z2})}\cdots}{(\omega-\omega_{p1})\cancel{(\omega-\omega_{p2})\cdots}}$$

$$= \frac{\frac{1}{jRC}}{\frac{1}{jRC}+\omega} = \frac{\frac{1}{jRC}}{\omega - \frac{-1}{jRC}}$$

$$= \frac{\boxed{\frac{1}{jRC}}}{\omega - \boxed{j\frac{1}{RC}}}$$

→ A

ω_0

→ $j\frac{1}{RC}$

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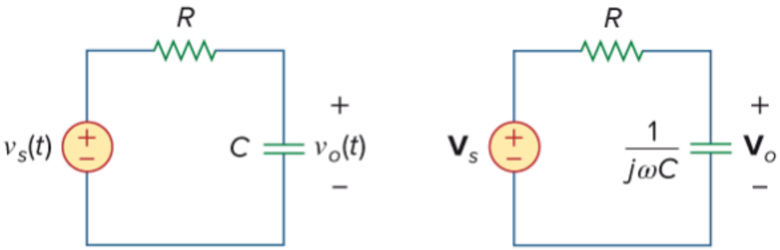
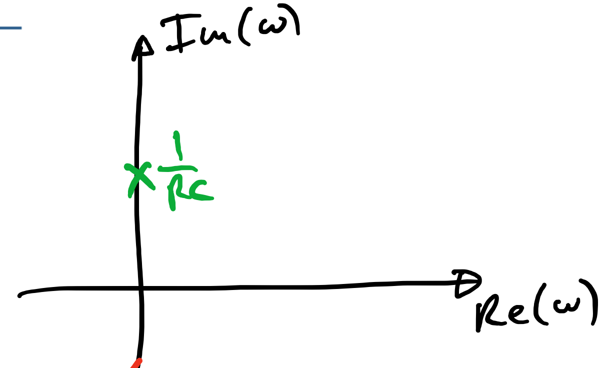


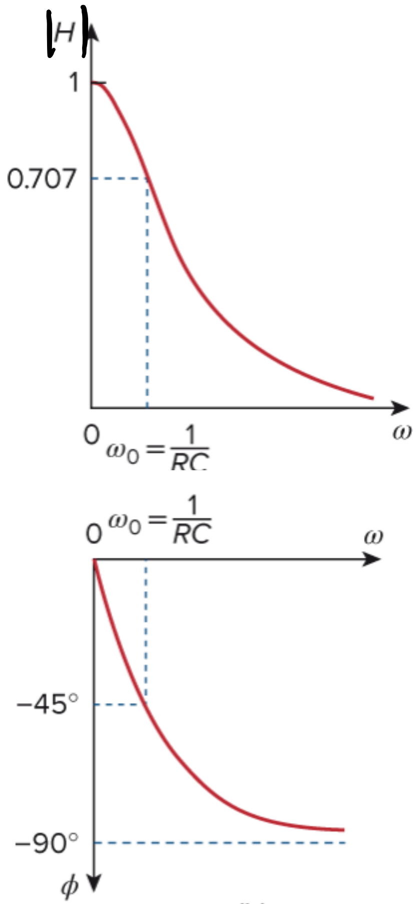


const

line

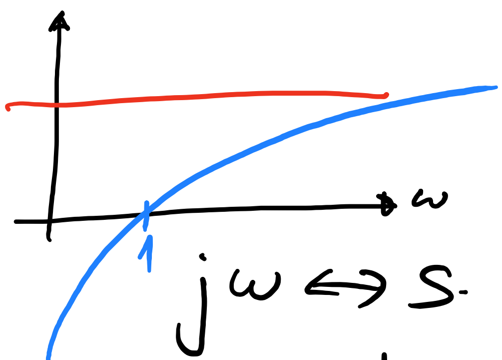
$$H(\omega) = \frac{1}{1+j\omega RC} = \frac{A\cancel{(\omega-\omega_{z1})}\cancel{(\omega-\omega_{z2})}\cdots}{(\omega-\omega_{p1})\cancel{(\omega-\omega_{p2})}\cdots} = \frac{A\cdot B\cdot C}{D\cdot E}$$

line



$$\ln H(\omega) = \ln\left(\frac{A\,B\,C}{D\,E}\right) = \ln A + \ln B + \ln C - \ln D - \ln E$$

$$= \boxed{\ln A} - \boxed{\ln(\omega-\omega_{p1})}$$

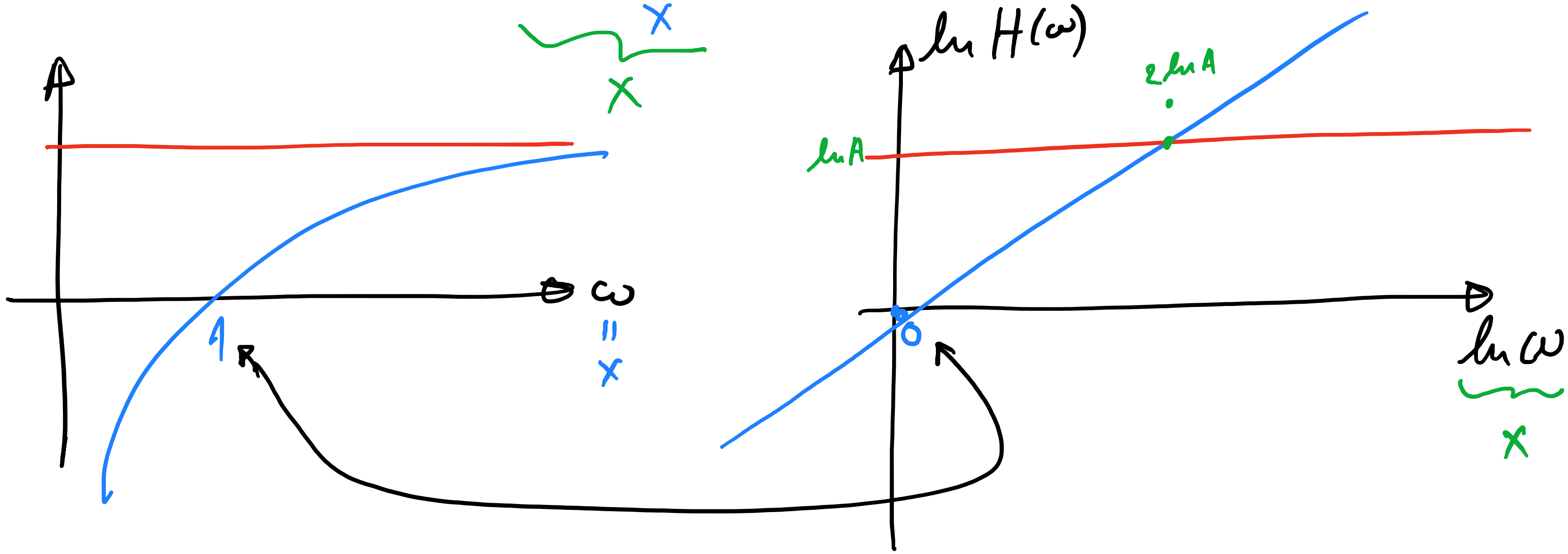


$$j\omega \Leftrightarrow s.$$

$$H(\omega) = \frac{1}{1+sRC} \longrightarrow s = \frac{-1}{RC}$$

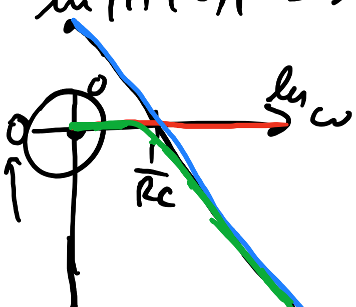
$$\ln H(\omega) = \boxed{\ln A} + \boxed{\underbrace{\ln(\omega)}_{X}}$$

$$\ln(\omega) = X$$



$$H(\omega) = \frac{1}{1 + j\omega RC}$$

$$\ln|H(\omega)| = \ln\frac{1}{\sqrt{1+(\omega RC)^2}} = \ln\left(\frac{1}{[1+(\omega RC)^2]}\right)^{\frac{1}{2}} = \frac{1}{2}\ln\frac{1}{1+(\omega RC)^2}$$



$$= \frac{1}{2}\left[\cancel{\ln 1}^{\,0} - \ln\left(1+(\omega RC)^2\right)\right] = -\frac{1}{2}\ln\left(1 + (\omega RC)^2\right)$$

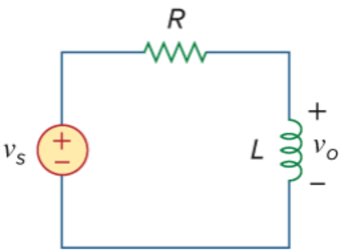
$$= -\frac{1}{2}\ln\left(1 + \left(e^{\ln\omega} RC\right)^2\right)$$

$$= -\frac{1}{2}\ln(\omega RC)^2 = -\ln \omega RC$$

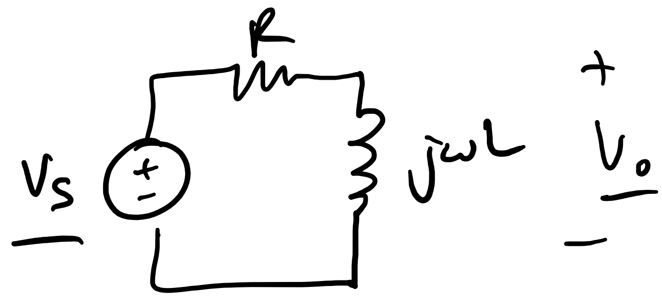
$$-\ln\omega + \ln RC$$

Practice Problem 14.1

Obtain the transfer function $\mathbf{V}_o/\mathbf{V}_s$ of the *RL* circuit in **Fig. 14.4**, assuming $v_s = V_m \cos \omega t$. Sketch its frequency response.



$\longrightarrow$



$$\underline{V_o} = \frac{j\omega L}{\underbrace{R + j\omega L}_{G}} \underline{V_s} = \frac{j\omega/\omega_z}{1 + j\omega/\omega_p} \to |H(\omega)|^2 = \frac{(\omega L)^2}{R^2 + (\omega L)^2}$$

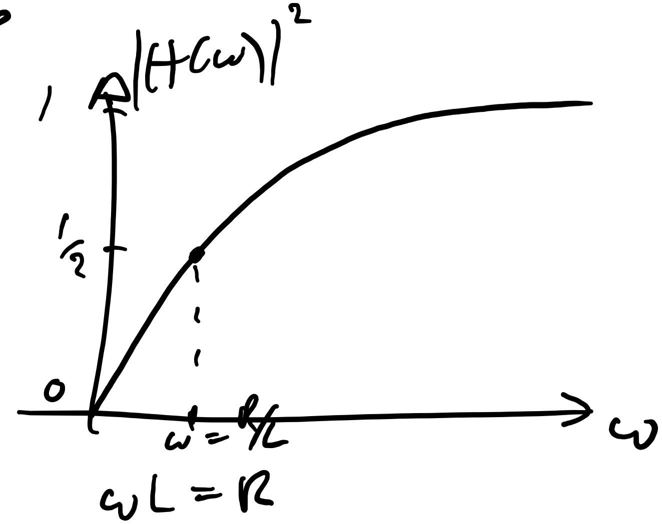
$\omega = 0 \to 0$

$\omega = \infty \to 1$

Zeros: $\omega_z = 0$

Poles: $j\omega = -\frac{R}{L}$

$\omega_p = \frac{R}{L} = \frac{1}{\tau}$



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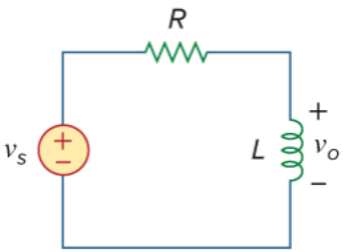
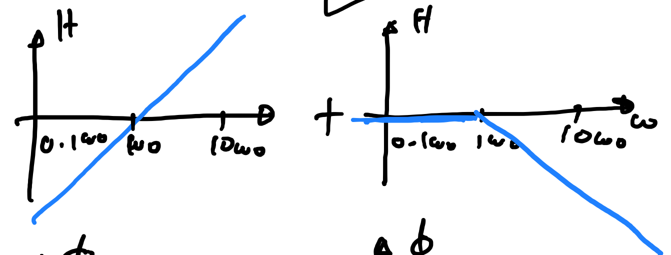


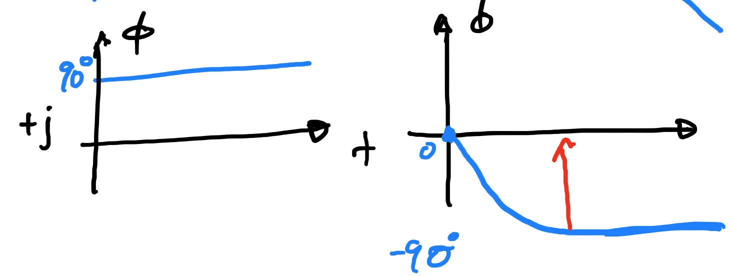
$$\frac{V_o}{V_s} = \frac{j\omega L}{R + j\omega L} = \frac{j\omega L/R}{1 + j\omega L/R} = \frac{j\omega/\omega_0}{1 + j\omega/\omega_0}$$

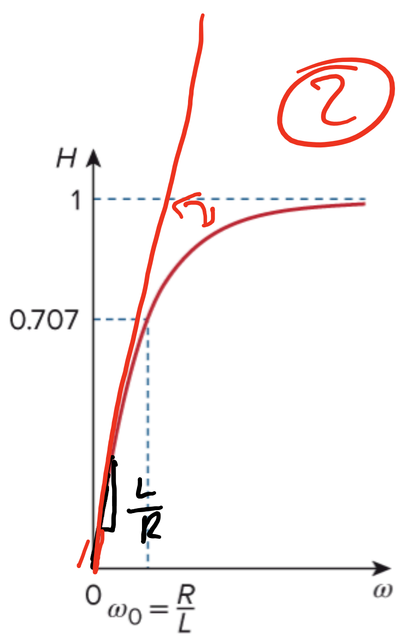
$$\boxed{\omega_0 = R/L}$$

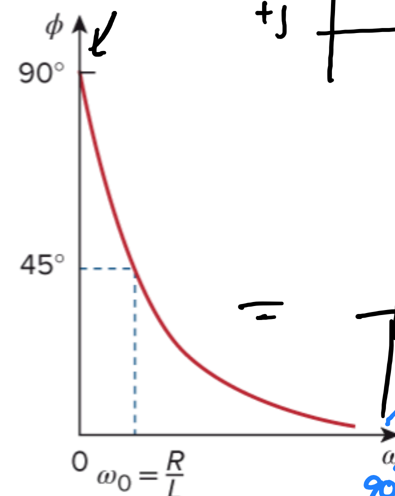
① $H_{dB} = 20\log_{10}\frac{V_o}{V_s} =$

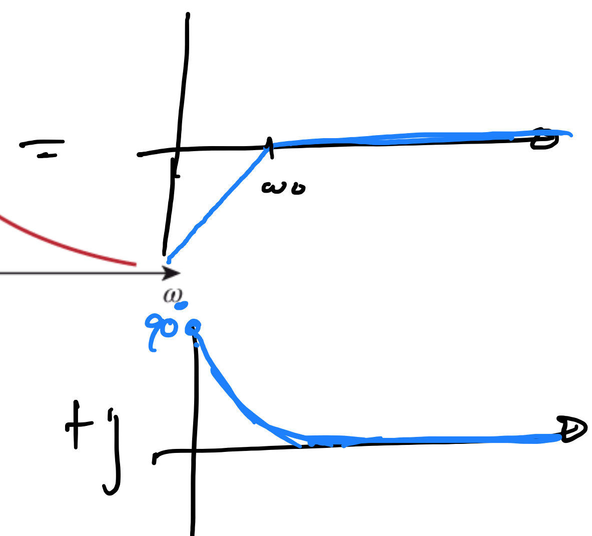


② $H \approx j\frac{\omega L}{R}$



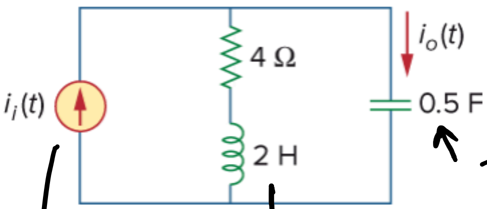






Example 14.2

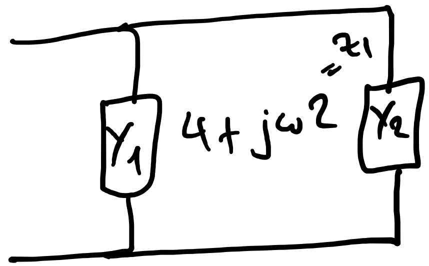
For the circuit in Fig. 14.6, calculate the gain $\mathbf{I}_o(\omega)/\mathbf{I}_i(\omega)$ and its poles and zeros.



I_o $\quad \frac{1}{j\omega 0.5}$

I_i $\quad j\omega 2$

$=$



$\frac{2}{j\omega} = Z_2$

$Y_1 = \frac{1}{Z_1}$

$Y_2 = \frac{1}{Z_2}$

$$I_o = \frac{j\omega/2}{j\omega/2 + \frac{1}{4+j\omega 2}} I_i = \frac{\quad}{Y_1+Y_2}$$

$$= \frac{j\frac{\omega}{2}(4+j\omega 2)}{j\frac{\omega}{2}(4+j\omega 2)+1} = \frac{\quad}{j\omega 2+(j\omega)^2+1}$$

$s \leftarrow j\omega$

$$= \frac{2s + s^2}{2s+s^2+1} = \frac{s(s+2)}{(s+1)^2}$$

zeros: $s=0,\ s=-2$

poles: $s=-1$

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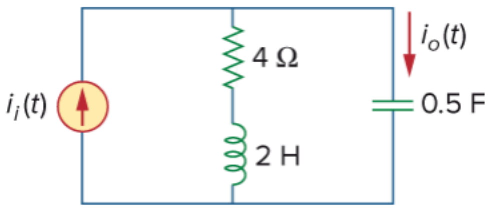


$$\mathbf{I}_o(\omega) = \frac{4 + j2\omega}{4 + j2\omega + 1/j0.5\omega}\mathbf{I}_i(\omega)$$

$$\frac{\mathbf{I}_o(\omega)}{\mathbf{I}_i(\omega)} = \frac{j0.5\omega(4 + j2\omega)}{1 + j2\omega + (j\omega)^2} = \frac{s(s+2)}{s^2 + 2s + 1}, \qquad s = j\omega$$

The zeros are at

$$s(s+2) = 0 \qquad \Rightarrow \qquad z_1 = 0,\ z_2 = -2$$

The poles are at

$$s^2 + 2s + 1 = (s+1)^2 = 0$$

Bode Plots

$$G_B = \text{Number of bels} = \log_{10}\frac{P_2}{P_1} = \log|G|^2$$

Gain in decibels (dB):
$$\boxed{G_{\text{dB}} = 10\log_{10}\frac{P_2}{P_1}} = 10\log_{10}\frac{V_2^2/\cancel{R}}{V_1^2/\cancel{R}} = 10\log_{10}\left(\frac{V_2}{V_1}\right)^2$$

$$G_{dB} = 20\log_{10}\frac{V_2}{V_1}$$

Bode Plots

$$G = \text{Number of bels} = \log_{10} \frac{P_2}{P_1}$$

$$\boxed{G_{\text{dB}} = 20 \log_{10} \frac{V_2}{V_1}}$$

Gain in decibels (dB):

$$\boxed{G_{\text{dB}} = 10 \log_{10} \frac{P_2}{P_1}}$$

$$G_{\text{dB}} = 20 \log_{10} \frac{I_2}{I_1}$$

Bode Plots

$$\mathbf{H} = H\underline{/\phi} = He^{j\phi}$$

$$\ln \mathbf{H} = \ln H + \ln e^{j\phi} = \ln H + j\phi$$

$$\boxed{H_{\mathrm{dB}} = 20 \log_{10} H}$$

Bode Plots

$$\mathbf{H} = H\underline{/\phi} = He^{j\phi}$$

$$\ln \mathbf{H} = \ln H + \ln e^{j\phi} = \ln H + j\phi$$

$$\boxed{H_{\text{dB}} = 20 \log_{10} H}$$

Specific gain and their decibel values.*

Magnitude H	$20 \log_{10} H$ (dB)
0.001	−60
0.01	−40
0.1	−20
0.5	−6
$1/\sqrt{2}$	−3
1	0
$\sqrt{2}$	3
2	6
10	20
20	26
100	40
1000	60

Bode Plots: Adding on Log Scale

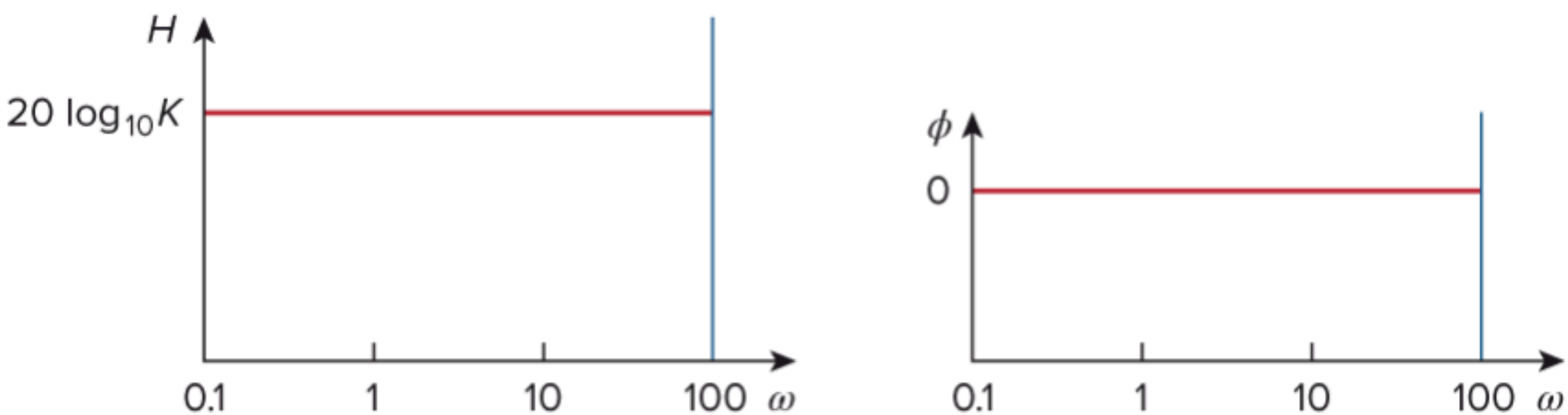
$$\mathbf{H}(\omega) = \frac{K(j\omega)^{\pm 1}(1 + j\omega/z_1)[1 + j2\zeta_1\omega/\omega_k + (j\omega/\omega_k)^2]\cdots}{(1 + j\omega/p_1)[1 + j2\zeta_2\omega/\omega_n + (j\omega/\omega_n)^2]\cdots} \quad \textbf{(14.15)}$$

$$= \frac{K s \,(1 + s/z_1)\,[1 + \zeta_1 s/\omega_k + (s/\omega_k)^2]}{}$$

1. A gain K
2. A pole $(j\omega)^{-1}$ or zero $(j\omega)$ at the origin
3. A simple pole $1/(1 + j\omega/p_1)$ or zero $(1 + j\omega/z_1)$
4. A quadratic pole $1/[1 + j2\zeta_2\omega/\omega_n + (j\omega/\omega_n)^2]$ or zero $[1 + j2\zeta_1\omega/\omega_k + (j\omega/\omega_k)^2]$

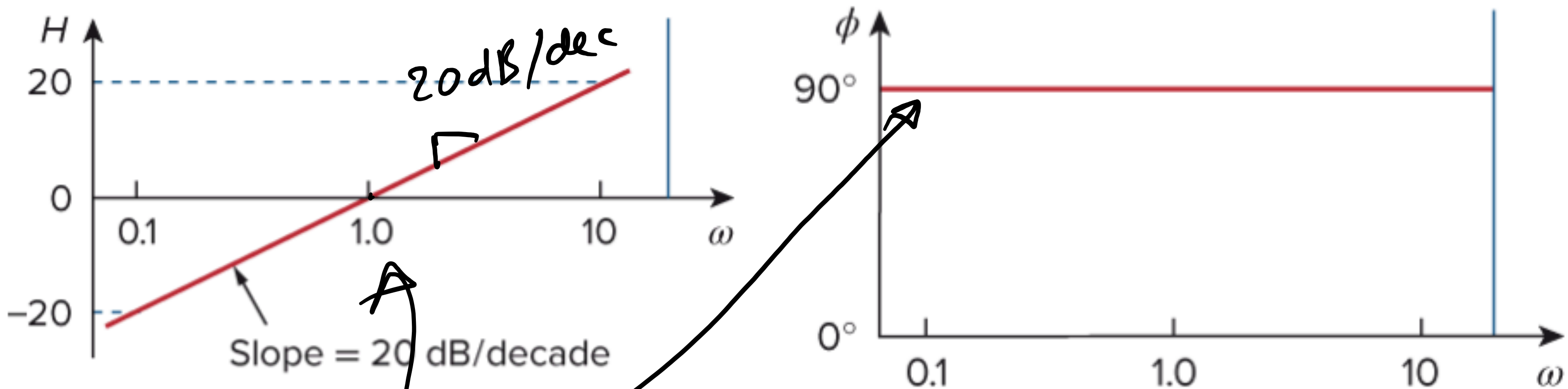
Bode Plots: A constant term

Constant term: For the gain K, the magnitude is $20 \log_{10} K$ and the phase is $0°$; both are constant with frequency. Thus, the magnitude and phase plots of the gain are shown in **Fig. 14.9**. If K is negative, the magnitude remains $20 \log_{10} |K|$ but the phase is $\pm 180°$.



Bode Plots: Linear terms

Pole/zero at the origin: For the zero ($j\omega$) at the origin, the magnitude is 20 $\log_{10}\omega$ and the phase is 90°. These are plotted in **Fig. 14.10**, where we notice that the slope of the magnitude plot is 20 dB/decade, while the phase is constant with frequency.



$$H(\omega) = A\, j\omega$$

$$20\log_{10} H(\omega) = 20\log_{10} A + 20\log_{10}(j\omega)$$

Bode Plots: Linear terms away from zero frequency

$A(\omega - \omega_1)$

$\downarrow$

$\left(\frac{j\omega}{j\omega_1} - 1\right)$

$H(\omega) = \frac{A\boxed{\left(1+\frac{j\omega}{z_1}\right)}\left(1+\frac{j\omega}{z_2}\right)\cdots}{\quad}$

$$H_{\text{dB}} = 20\log_{10}\underbrace{\left|1+\frac{j\omega}{z_1}\right|}_{H} \quad \Rightarrow \quad 20\log_{10}1 = 0$$

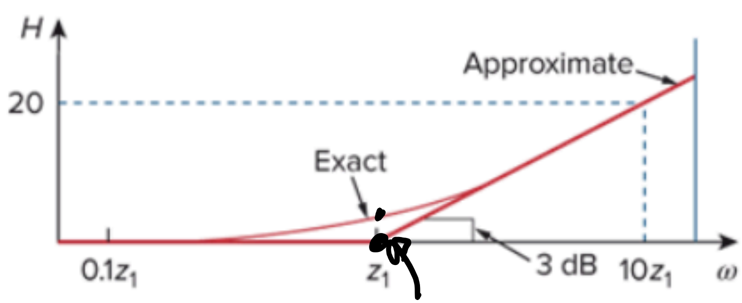
as $\omega \to 0$

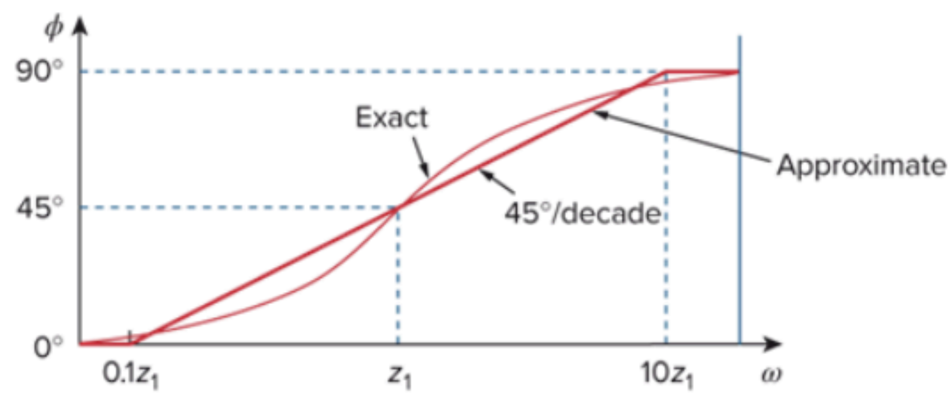
$$H_{\text{dB}} = 20\log_{10}\left|\overset{\approx 0}{\cancel{1}}+\frac{j\omega}{z_1}\right| \quad \Rightarrow \quad 20\log_{10}\frac{\omega}{z_1}$$

as $\omega \to \infty$

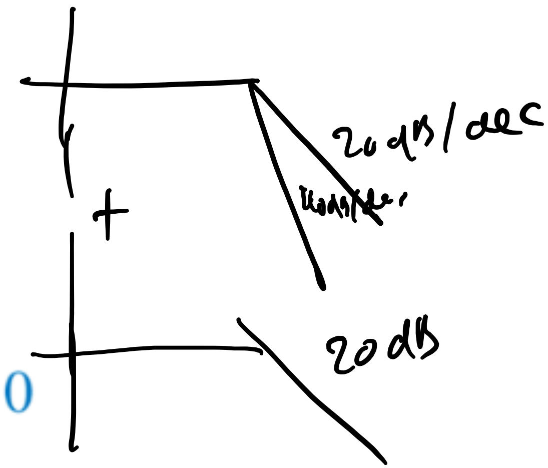
$\omega = z_1 \Rightarrow \quad \left|1+j\frac{\omega}{z_1}\right| = |1+j1| = \sqrt{2} = H$

$$20\log_{10}|(1+j1)| = 20\log_{10}\sqrt{2} \simeq 3\text{ dB}.$$





Bode Plots: Quadratic Term



Quadratic pole/zero: The magnitude of the quadratic pole $1/[1 + j2\zeta_2\omega/\omega_n + (j\omega/\omega_n)^2]$ is $-20\log_{10}|1 + j2\zeta_2\omega/\omega_n + (j\omega/\omega_n)^2|$ and the phase is $-\tan^{-1}(2\zeta_2\omega/\omega_n)/(1 - \omega^2/\omega_n^2)$. But

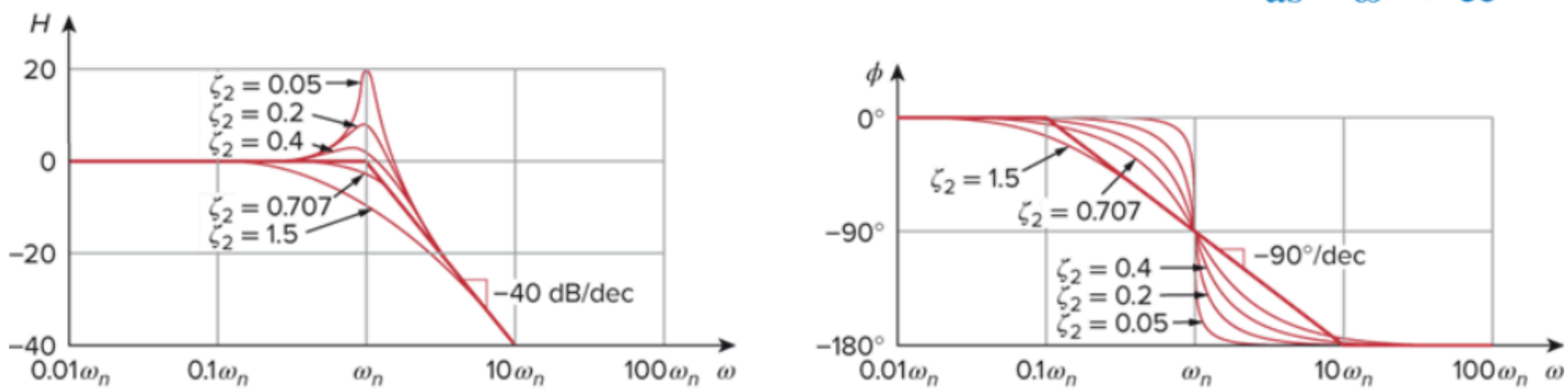
$$H(\omega) = \frac{(j\omega)(j\omega)}{\;}$$

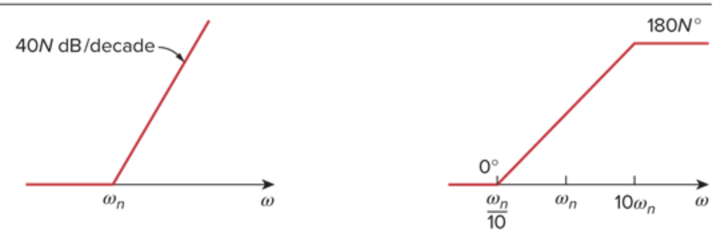
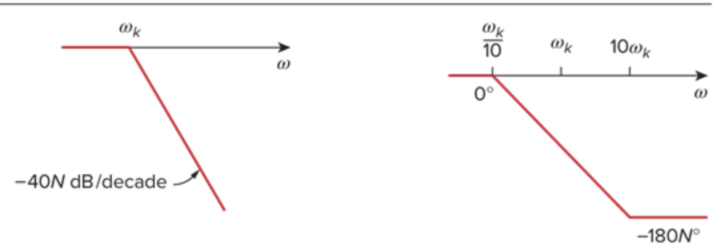
$$H_{\mathrm{dB}} = -20\log_{10}\left|1 + \frac{j2\zeta_2\omega}{\omega_n} + \left(\frac{j\omega}{\omega_n}\right)^2\right| \quad \Rightarrow \quad 0$$

as $\omega \to 0$

$$H_{\mathrm{dB}} = -20\log_{10}\left|1 + \frac{j2\zeta_2\omega}{\omega_n} + \left(\frac{j\omega}{\omega_n}\right)^2\right| \quad \Rightarrow \quad -40\log_{10}\frac{\omega}{\omega_n}$$

as $\omega \to \infty$



Factor	Magnitude	Phase
K		
$(j\omega)^N$		
$\dfrac{1}{(j\omega)^N}$		
$\left(1+\dfrac{j\omega}{z}\right)^N$		
$\dfrac{1}{(1+j\omega/p)^N}$		
$\left[1+\dfrac{2j\omega\zeta}{\omega_n}+\left(\dfrac{j\omega}{\omega_n}\right)^2\right]^N$		
$\dfrac{1}{[1+2j\omega\zeta/\omega_k+(j\omega/\omega_k)^2]^N}$		

Practice Problem 14.3

Draw the Bode plots for the transfer function

$$\mathbf{H}(\omega) = \frac{5(j\omega + 2)}{j\omega(j\omega + 10)}$$

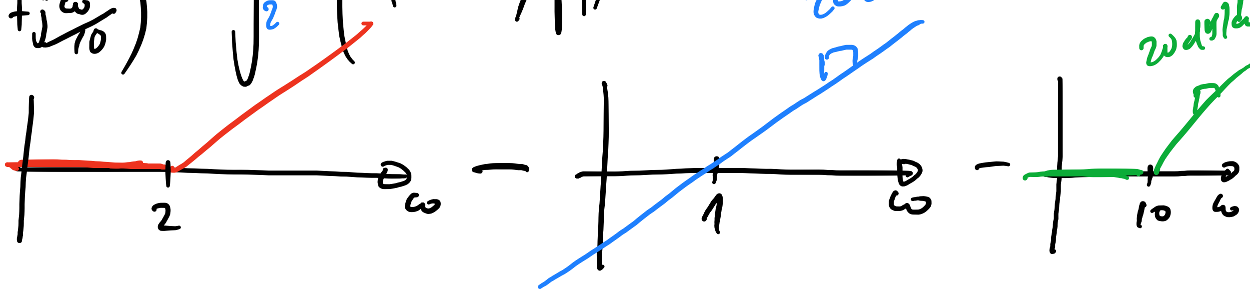
$$= \frac{\cancel{10}\left(1 + \frac{j\omega}{2}\right)}{j\omega\left(1 + \frac{j\omega}{10}\right)\cancel{10}}$$

$$= \frac{10\left(1 + \frac{j\omega}{2}\right)}{j\omega\left(1 + \frac{j\omega}{10}\right)}$$

$$\overline{A\left(1 + j\omega/z_1\right)} \rightarrow \omega_{z_1} \Leftrightarrow z_1$$

$$j\omega\left(1 + j\omega/p_1\right) \rightarrow \omega_{p_1} \Leftrightarrow p_1$$

$$H_{dB} = 20\log_{10}|H| = 10 +$$



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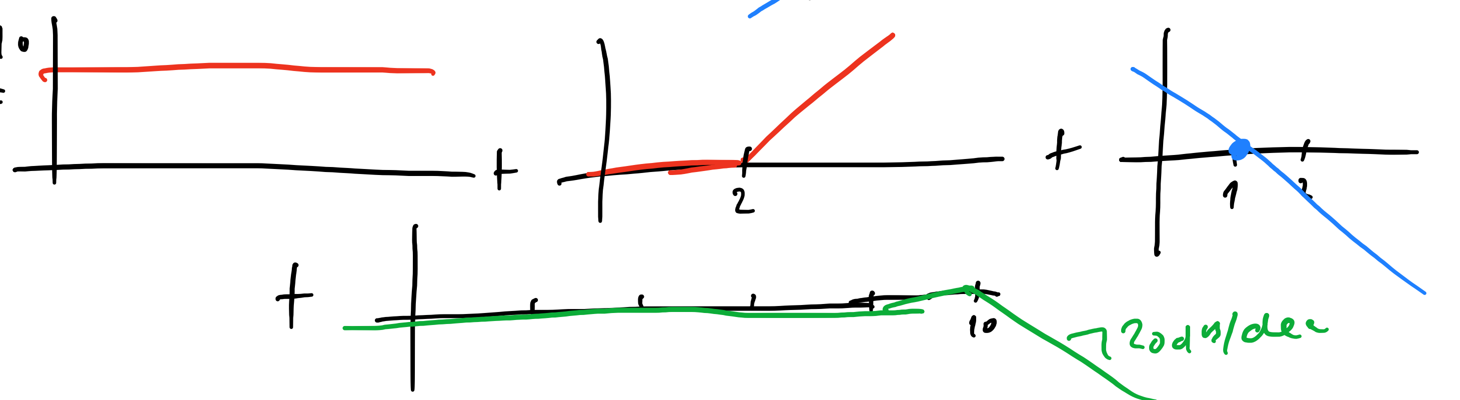
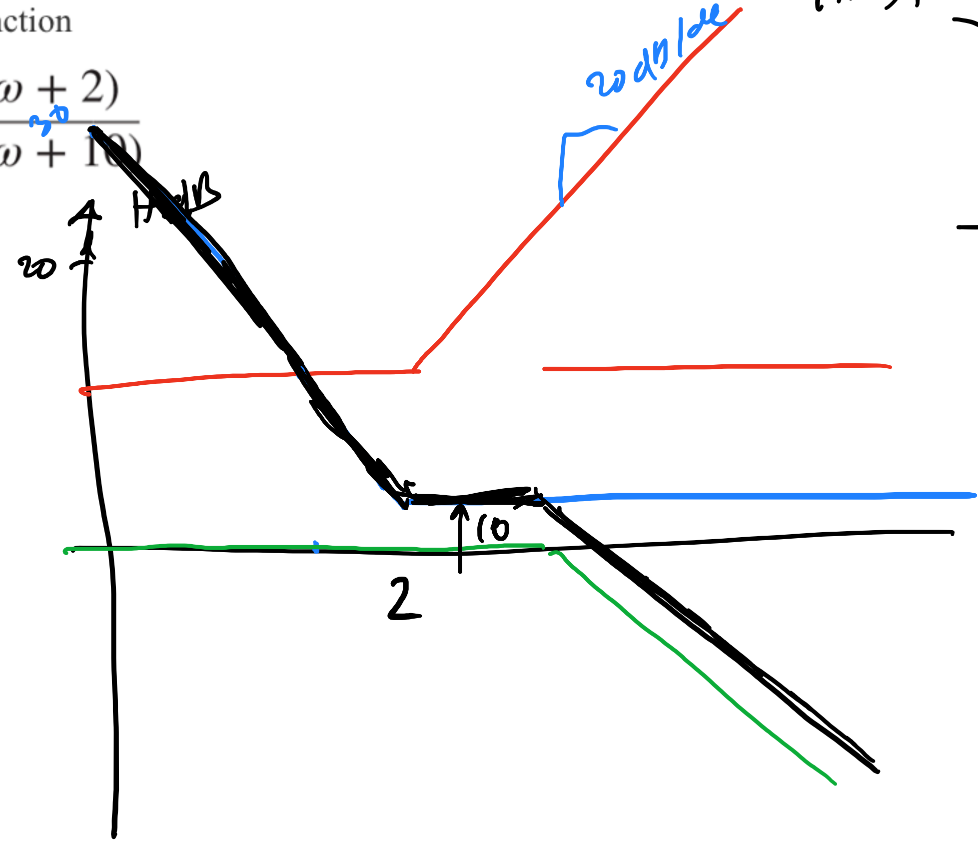


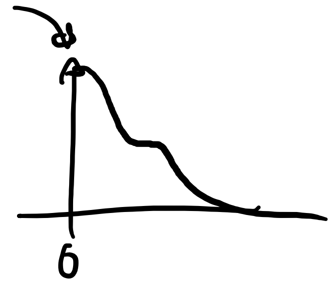
Practice Problem 14.3

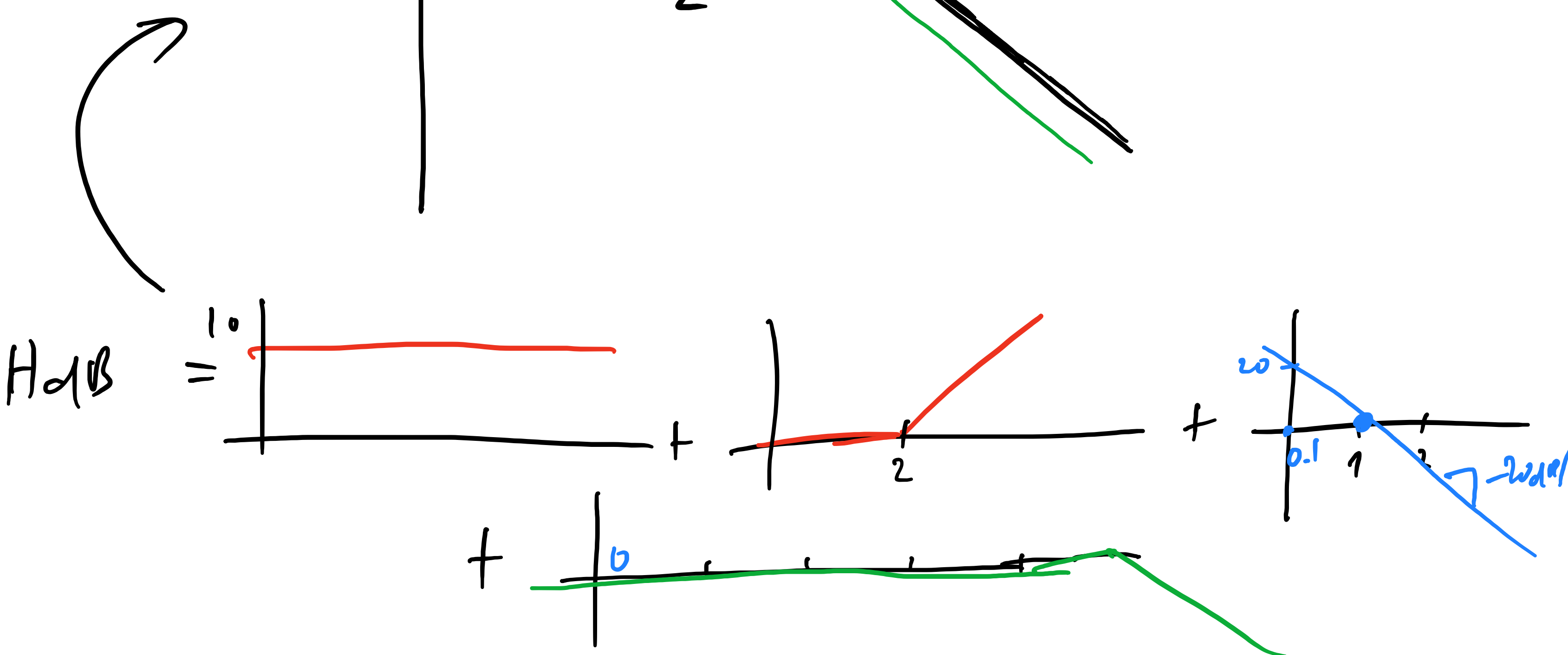
Draw the Bode plots for the transfer function

$$\mathbf{H}(\omega) = \frac{5(j\omega + 2)}{j\omega(j\omega + 10)}$$

$$|H(\omega)|^2 = 10^{HdB/20}$$



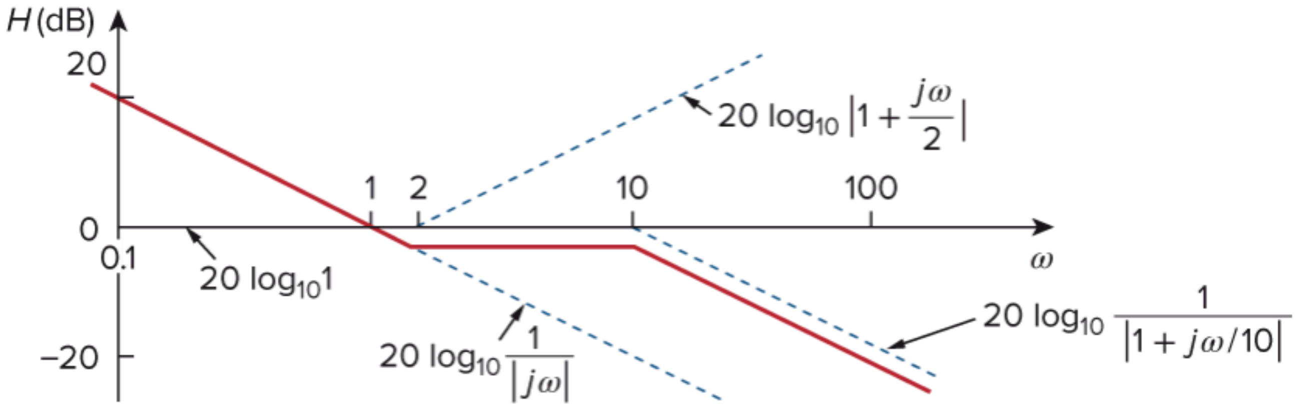




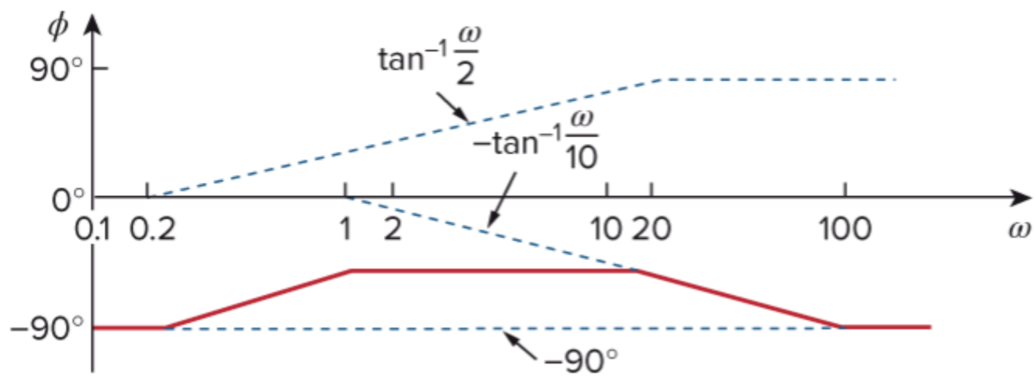
Practice Problem 14.3

Draw the Bode plots for the transfer function

$$\mathbf{H}(\omega) = \frac{5(j\omega + 2)}{j\omega(j\omega + 10)}$$

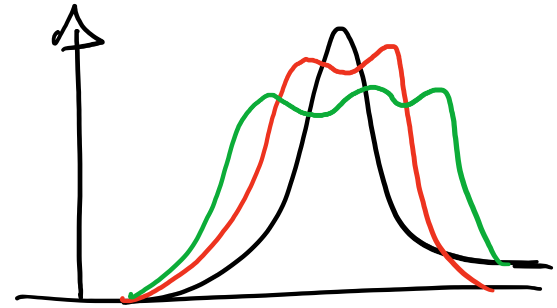


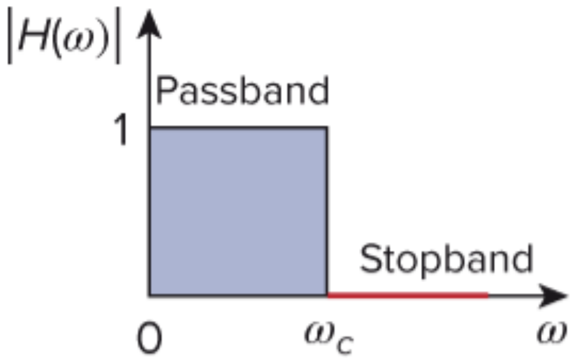
(a)



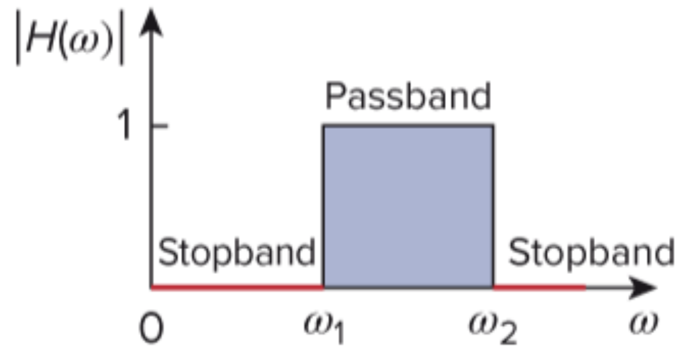
(b)

Filters

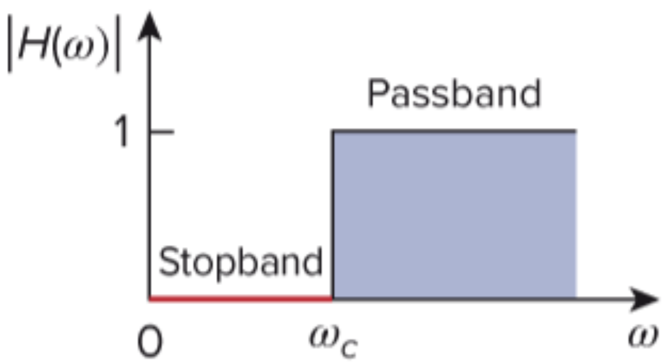




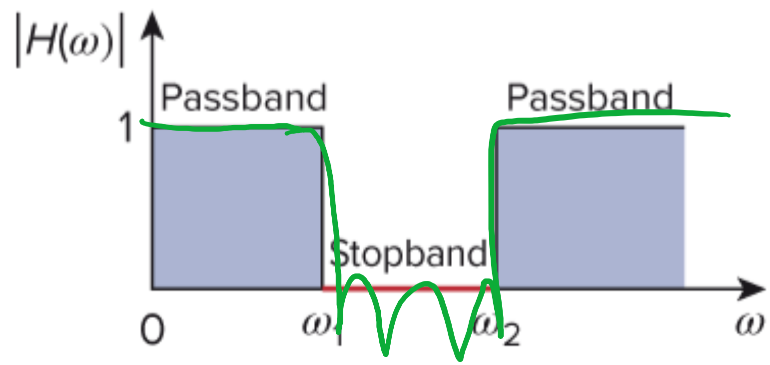
(a)



(c)



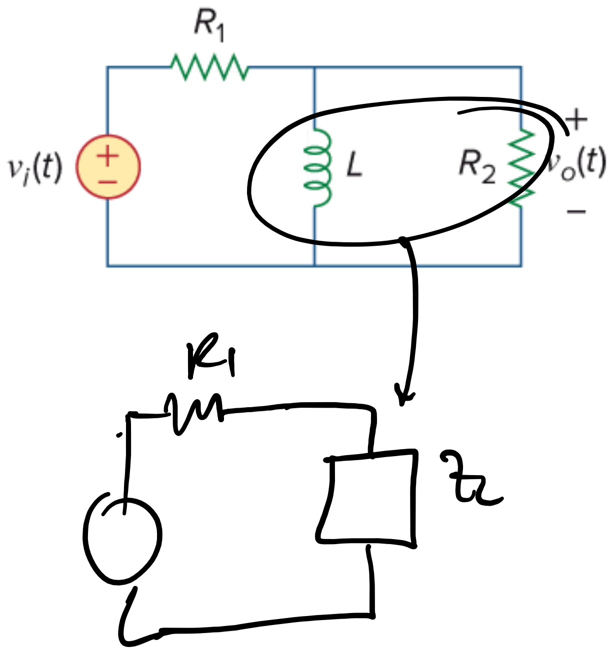
(b)



(d)

Practice Problem 14.10

For the circuit in **Fig. 14.40**, obtain the transfer function $\mathbf{V}_o(\omega)/\mathbf{V}_i(\omega)$. Identify the type of filter the circuit represents and determine the corner frequency. Take $R_1 = 100\ \Omega = R_2$, $L = 2$ mH.



$$\frac{V_o}{V_i} = \frac{\left(\frac{1}{R_2} + \frac{1}{j\omega L}\right)^{-1}}{R_1 + \left(\frac{1}{R_2} + \frac{1}{j\omega L}\right)^{-1}} = \frac{\left(\frac{j\omega L + R_2}{j\omega L R_2}\right)^{-1}}{R_1 + \left(\frac{j\omega L + R_2}{j\omega L R_2}\right)^{-1}}$$

$$= \frac{\frac{j\omega L R_2}{\cancel{j\omega L + R_2}}}{\frac{R_1(j\omega L + R_2)}{\cancel{j\omega L + R_2}} + \frac{j\omega L R_2}{\cancel{j\omega L + R_2}}}$$

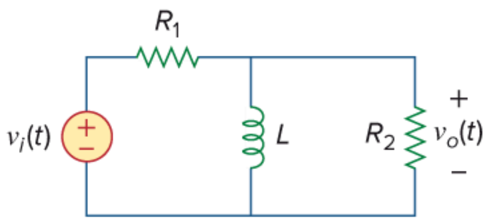
$$= \frac{j\omega L R_2}{j\omega L R_1 + R_1 R_2 + j\omega L R_2}$$

$$= \frac{j\omega L R_2}{R_1 R_2 + j\omega L (R_1 + R_2)} = \frac{j\omega L R_2 / R_1 R_2}{1 + j\omega \frac{L(R_1 + R_2)}{R_1 R_2}}$$

$$\omega_{p1} = \frac{R_1 R_2}{L(R_1 + R_2)}$$

Practice Problem 14.10

For the circuit in Fig. 14.40, obtain the transfer function $\mathbf{V}_o(\omega)/\mathbf{V}_i(\omega)$. Identify the type of filter the circuit represents and determine the corner frequency. Take $R_1 = 100\ \Omega = R_2$, $L = 2$ mH.



Answer: $\dfrac{R_2}{R_1 + R_2}\left(\dfrac{j\omega}{j\omega + \omega_c}\right)$, high-pass filter

$$\omega_c = \frac{R_1 R_2}{(R_1 + R_2)L} = 25 \text{ krad/s.}$$

Review of Course Topics

- Units
- Circuit elements (R,L,C)
- Circuit Laws (KCL, KVL, P = VI)
- Solving circuits (node voltage, mesh current)
- Op-amps: ideal and non-ideal
- Types of circuits to solve:
  - DC
  - Step response (over, under, critically damped): diff eq.
  - Sinusoidal steady state (phasors)
- Complex #s, impedance, power in phasor domain
- Frequency response

Final exam topics

Lecture Schedule

Section A1 – Prof. Miloš Popović, Section A2 – Prof. Mark Horenstein, Section A3 – Prof. Min-Chang Lee

Lec	Date		Topic	Reading: Chapter
	Sec. A1	Sec. A2,A3		
1	9/5	9/6	System of Units; Charge, Current and Voltage; Power and Energy; Circuit Elements; Ohm's law	Chapter 1, 2.1–2.2
2	9/8	9/11	KVL, KCL, Resistors in Series and voltage division, Resistors in parallel and current division	2.3–2.6,
3	9/12	9/13	Node-Voltage Method, Solving circuits with linear algebra	3.1–3.3
4	9/14	9/18	Mesh-current method, Application: Transistors, LED	3.4–3.7, 3.9-3.10
5	9/19	9/20	Circuit theorems: Linearity, superposition, source transformation	4.1–4.4
6	9/21	9/25	Thevenin & Norton theorems	4.5–4.7
7	9/26	9/27	Maximum Power Transfer, Examples: Source modeling, Bridge circuits, Interface circuits	4.8, 4.10–4.11
8	9/28	10/2	Introduction to operational amplifiers, Inverting and non-inverting amplifiers	5.1–5.5
9	10/3	10/4	Op-amp circuit analysis, Examples: Voltage follower, Summing and Differencing Amplifiers,	5.6–5.7
10	10/6	10/10	Cascaded OP AMP circuits	5.7-5.8
11	10/12	10/11	Op-amp circuit design, Applications: D/A conversion, Instrumentation amplifier.	5.10-5.11
12	10/17	10/16	**MIDTERM EXAM 1 (Sections 1 & 2)** Introduction to Capacitors, Inductors Applications: Integrator, Differentiator	Chapter 6
13	10/19	10/18	First order circuits: Source free RL and RC circuits	7.1–7.3
14	10/24	10/23	Singularity functions, RL and RC step response	7.4–7.6
15	10/26	10/25	First order op-amp circuits	7.7, 7.9–7.10
16	10/31	10/30	Intro to second order circuits Series/Parallel RLC circuits, damping	8.1–8.4

Final exam topics

Lecture Schedule

Section A1 – Prof. Miloš Popović, Section A2 – Prof. Mark Horenstein, Section A3 – Prof. Min-Chang Lee

Lec	Date		Topic	Reading: Chapter
	Sec. A1	Sec. A2,A3		
18	11/7	11/6	Sinusoidal steady state and phasors Phasor relations for circuit elements	9.1–9.4
19	11/9	11/8	Impedance and Admittance	9.5–9.8
20	11/14	11/13	**MIDTERM EXAM 2 (Sections 1 & 2)** Circuit analysis techniques with phasors: Thevenin and Norton.	10.1–10.6
21	11/16	11/15	OP AMP AC Circuits, maximum average power transfer	10.7, 11.3
22	11/21	11/20	Intro to filter circuits: Low-pass filters, High-pass filters, Decibel and Bode plots	14.1–14.3, 14.7
~~23~~	~~11/28~~	~~11/27~~	~~Band-pass filters,~~ ~~RLC frequency response, Resonance~~	~~14.4, 14.7~~
~~24~~	~~11/30~~	~~11/29~~	~~Active Filters~~	~~14.8~~
~~25~~	~~12/5~~	~~12/4~~	~~Filter design, Applications~~	~~14.12, Notes~~
~~26~~	~~12/7~~	~~12/6~~	~~Mutual inductance and transformers~~	~~13.1–13.5~~
~~27~~	~~12/12~~	~~12/11~~	~~Mutual inductance and transformers, Applications~~	~~notes~~
28	TBA	TBA	Review for final exam	
	TBA	TBA	**FINAL EXAM**	

Prep for final

– practice exam

- HW10 (not due); will review in review session
- Review session → doodle poll.
- Office hours between now and exam
  - Wed Dec 13 2:30-3:30pm PHO726
  - Thu Dec 14 2:30-3:30pm PHO726
  - Fri Dec 15 2:30-3:30pm PHO726
  - Mon Dec 18 1:30-3:30pm PHO726
  - Tue Dec 19 9:00-10:00am PHO726

- Exam: emphasis on last 1/3.