

CAP14 – TABELAS E FIGURAS

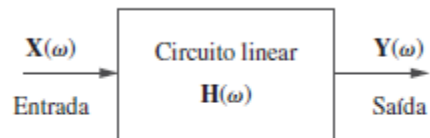


Figura 14.1 Representação em diagrama em bloco de um circuito linear.

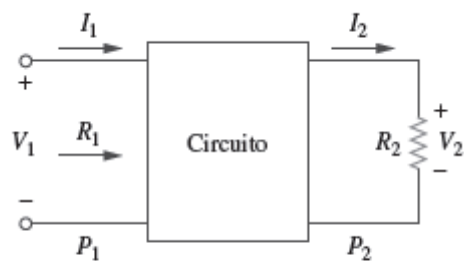


Figura 14.8 Relações tensão-corrente para um circuito de quatro terminais.

Tabela 14.2 • Ganho específico e seus valores em decibéis.*

Amplitude H	$20 \log_{10} H(\text{dB})$
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
1.000	60

* Alguns desses valores são aproximados.

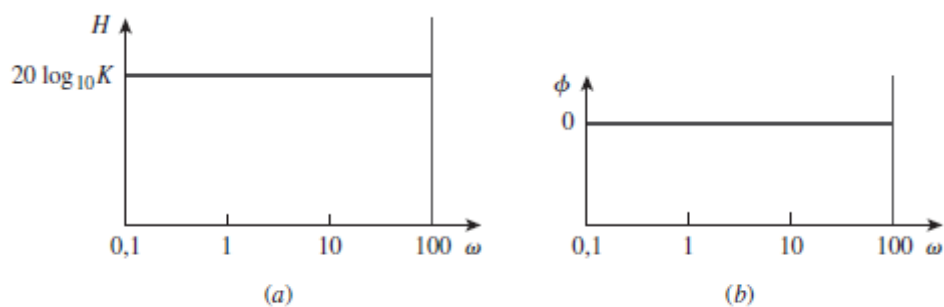
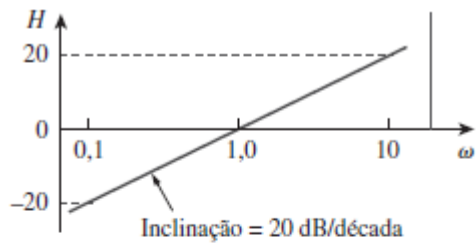
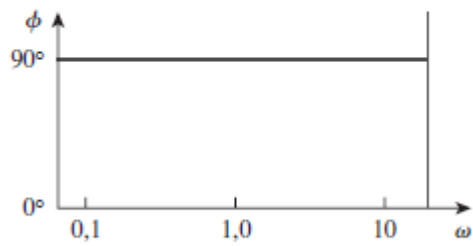


Figura 14.9 Gráficos de Bode para ganho K : (a) gráfico da amplitude; (b) gráfico da fase.



(a)



(b)

Figura 14.10 Gráfico de Bode para um zero ($j\omega$) na origem: (a) gráfico da amplitude; (b) gráfico da fase.

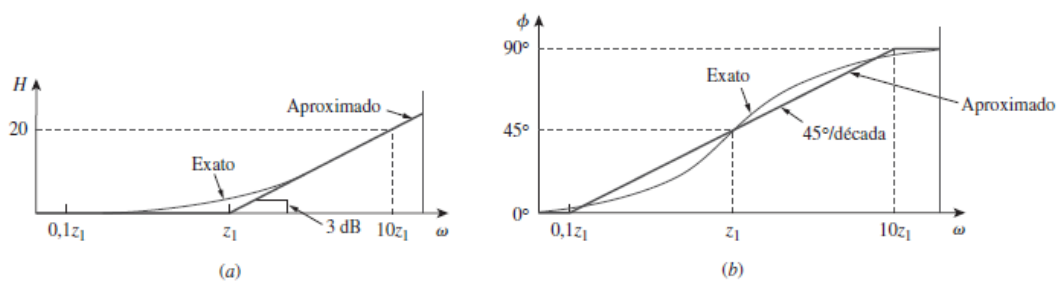


Figura 14.11 Gráfico de Bode para o zero $(1 + j\omega/z_1)$: (a) gráfico da amplitude; (b) gráfico da fase.

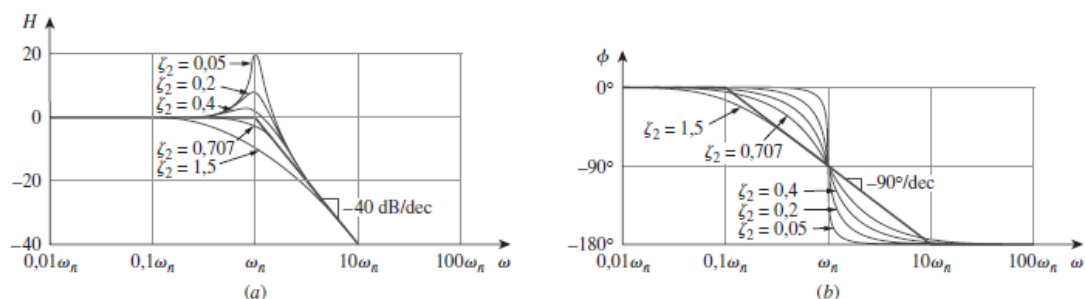


Figura 14.12 Gráficos de Bode do polo quadrático $[1 + j2\zeta\omega/\omega_n - \omega^2/\omega_n^2]^{-1}$: (a) gráfico da amplitude; (b) gráfico da fase.

Tabela 14.3 • Resumo dos gráficos de linha reta de Bode para amplitude e fase.

Fator	Amplitude	Fase
K	$20 \log_{10} K$	0°
$(j\omega)^N$	$20N \text{ dB/década}$	$90N^\circ$
$\frac{1}{(j\omega)^N}$	$-20N \text{ dB/década}$	$-90N^\circ$
$\left(1 + \frac{j\omega}{z}\right)^N$	$20N \text{ dB/década}$	0° a $90N^\circ$

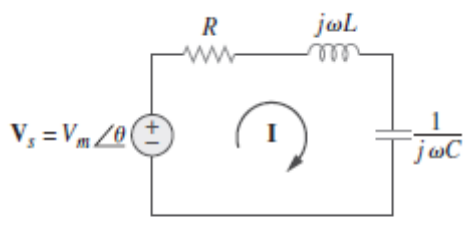
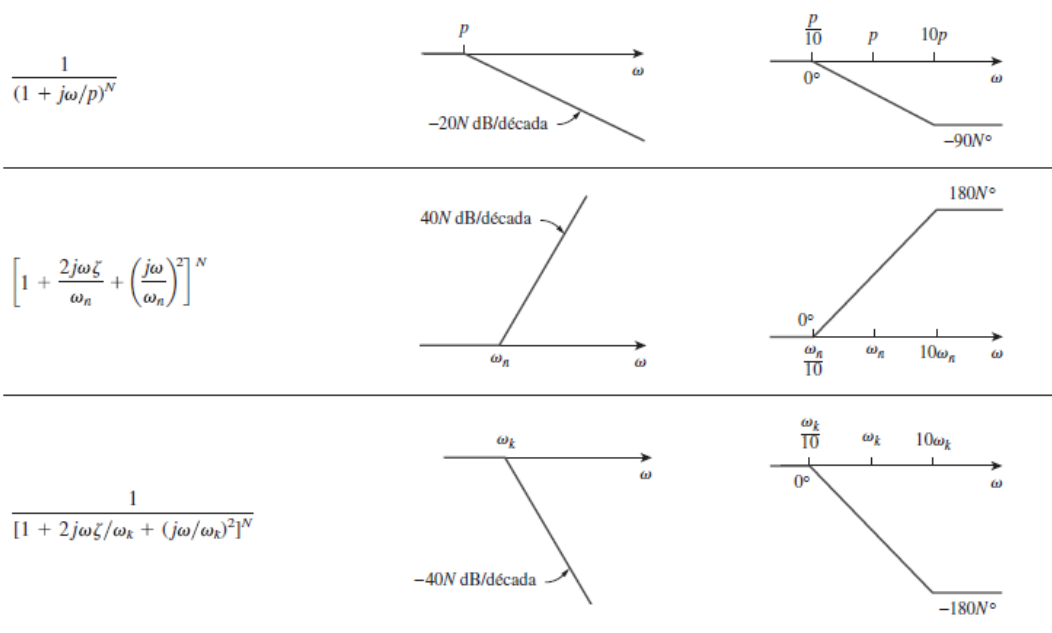


Figura 14.21 Circuito ressonante em série.

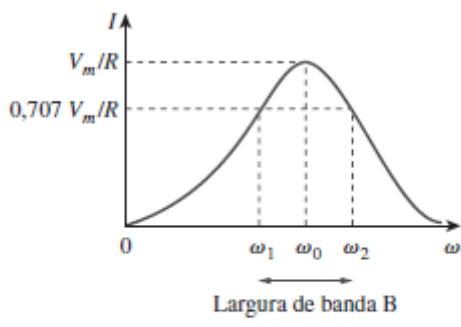


Figura 14.22 A amplitude da corrente *versus* a frequência para o circuito ressonante em série da Figura 14.21.

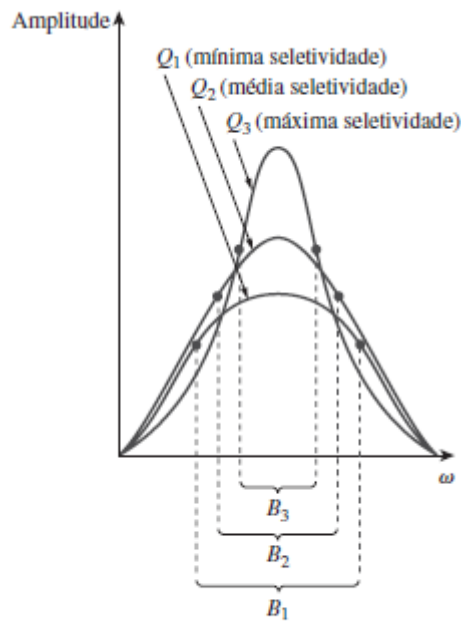


Figura 14.23 Quanto maior o Q do circuito, menor a largura de banda.

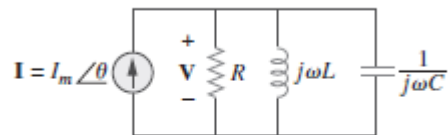


Figura 14.25 Circuito de ressonância em paralelo.

Tabela 14.4 • Resumo das características dos circuitos *RLC* ressonantes.

Característica	Circuito em série	Circuito em paralelo
Frequência de ressonância, ω_0	$\frac{1}{\sqrt{LC}}$	$\frac{1}{\sqrt{LC}}$
Fator de qualidade, Q	$\frac{\omega_0 L}{R}$ ou $\frac{1}{\omega_0 RC}$	$\frac{R}{\omega_0 L}$ ou $\omega_0 RC$
Largura de banda, B	$\frac{\omega_0}{Q}$	$\frac{\omega_0}{Q}$
Frequência de meia potência, ω_1, ω_2	$\omega_0 \sqrt{1 + \left(\frac{1}{2Q}\right)^2} \pm \frac{\omega_0}{2Q}$	$\omega_0 \sqrt{1 + \left(\frac{1}{2Q}\right)^2} \pm \frac{\omega_0}{2Q}$
Para $Q \geq 10$, ω_1, ω_2	$\omega_0 \pm \frac{B}{2}$	$\omega_0 \pm \frac{B}{2}$

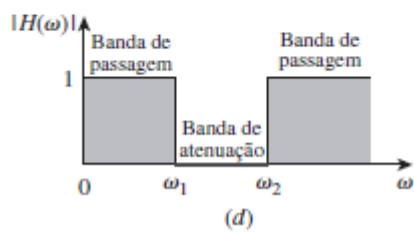
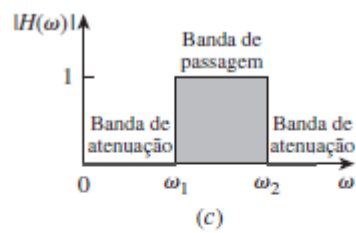
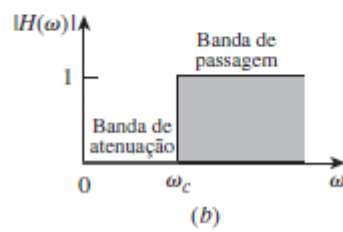
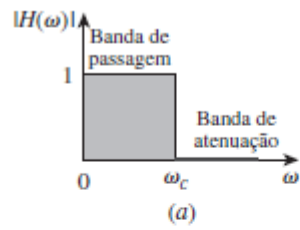


Figura 14.30 Resposta de frequência ideal de quatro tipos de filtros: (a) passa-baixas; (b) passa-altas; (c) passa-faixa; (d) rejeita-faixa.

Tabela 14.5 • Síntese das características dos filtros ideais.			
Tipo de Filtro	$H(0)$	$H(\infty)$	$H(\omega_c)$ ou $H(\omega_0)$
Passa-baixas	1	0	$1/\sqrt{2}$
Passa-altas	0	1	$1/\sqrt{2}$
Passa-faixa	0	0	1
Rejeita-faixa	1	1	0

ω_c é a frequência de corte para os filtros passa-baixas e passa-altas; ω_0 é a frequência central para os filtros passa-faixa e rejeita-faixa.

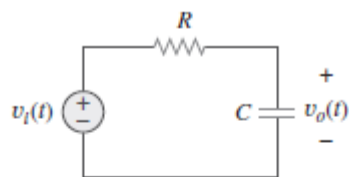


Figura 14.31 Filtro passa-baixas.

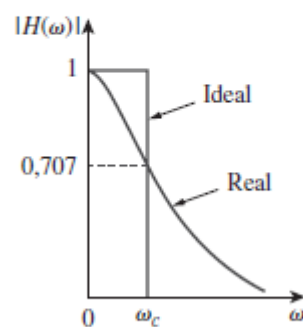


Figura 14.32 Respostas de frequência ideal e real de um filtro passa-baixas.

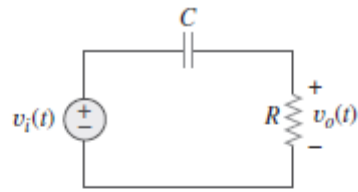


Figura 14.33 Filtro passa-altas.

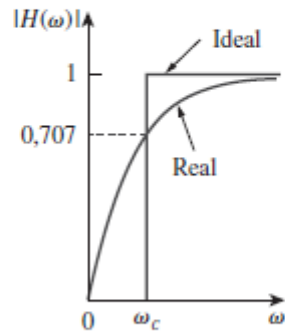


Figura 14.34 Respostas de frequência ideal e real de um filtro passa-altas.

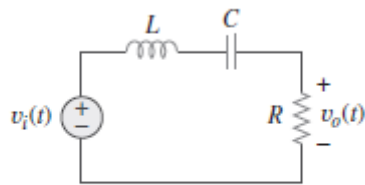


Figura 14.35 Filtro passa-faixa.

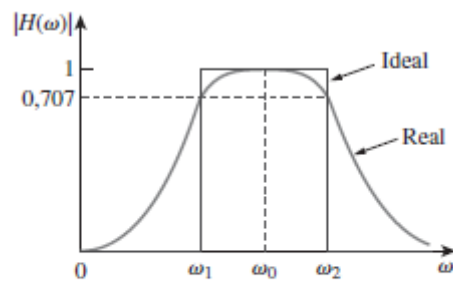


Figura 14.36 Respostas de frequência ideal e real de um filtro passa-faixa.

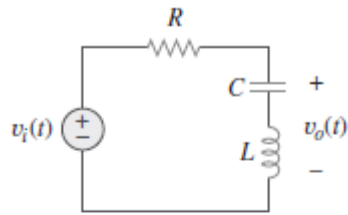


Figura 14.37 Filtro rejeita-faixa.

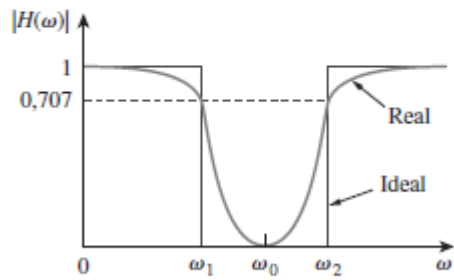


Figura 14.38 Respostas de frequência ideal e real de um filtro rejeita-faixa.

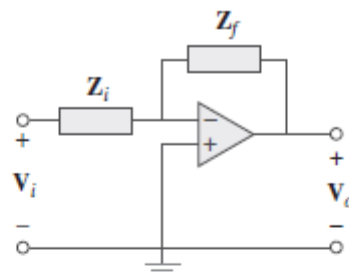


Figura 14.41 Filtro ativo de primeira ordem genérico.

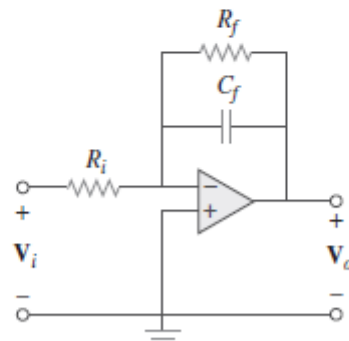


Figura 14.42 Filtro passa-baixas de primeira ordem ativo.

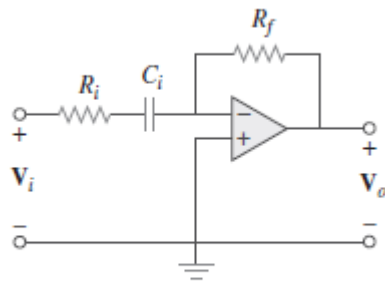


Figura 14.43 Filtro passa-altas de primeira ordem ativo.

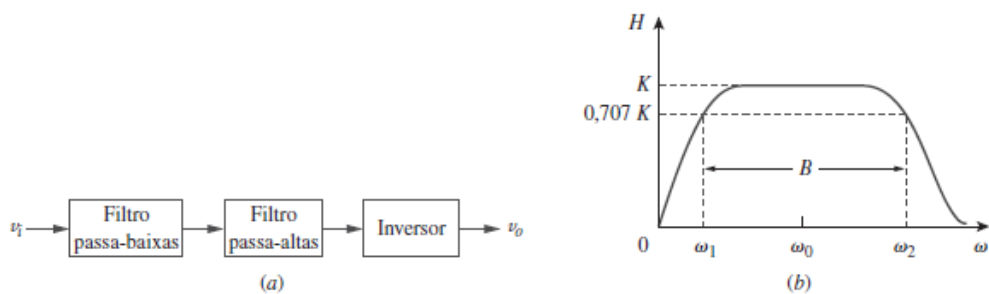


Figura 14.44 Filtro passa-faixa ativo: (a) diagrama em bloco; (b) resposta de frequência.

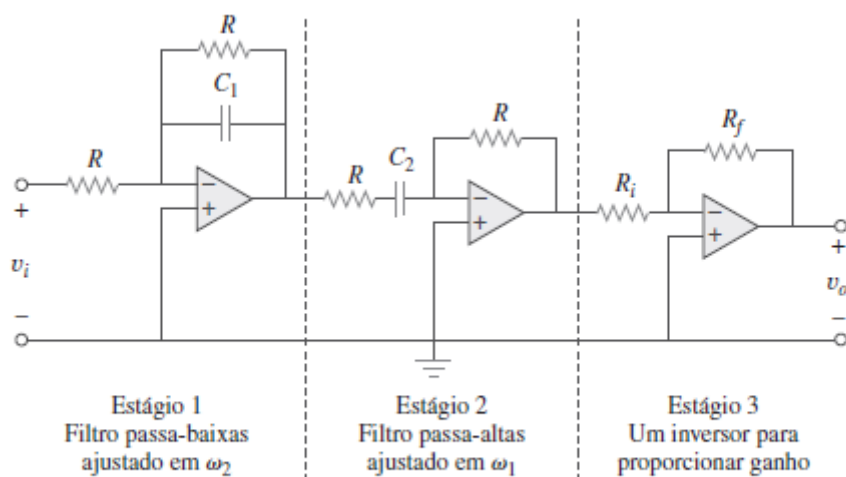


Figura 14.45 Filtro passa-faixa ativo.

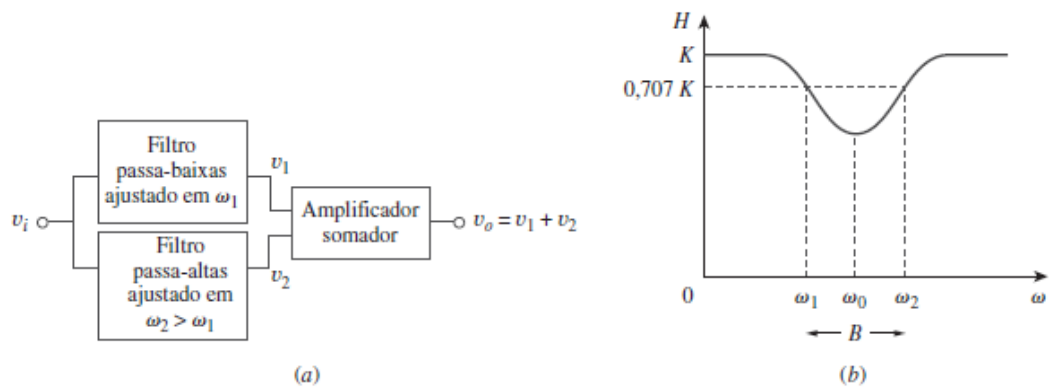


Figura 14.46 Filtro rejeita-faixa ativo: (a) diagrama em bloco; (b) resposta de frequência.

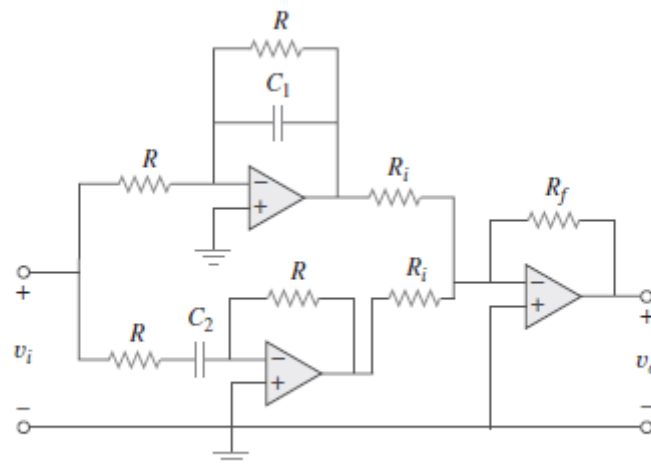


Figura 14.47 Filtro rejeita-faixa ativo.

RESOLUÇÃO DE EXERCÍCIOS

- 14.3 Para o circuito mostrado na Figura 14.70, $R_1 = 2 \Omega$, $R_2 = 5 \Omega$, $C_1 = 0,1 \text{ F}$ e $C_2 = 0,2 \text{ F}$, determine a função de transferência $\mathbf{H}(s) = V_o(s)/V_i(s)$.

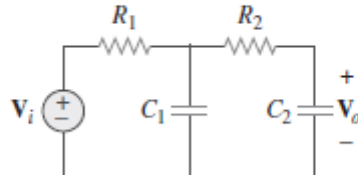
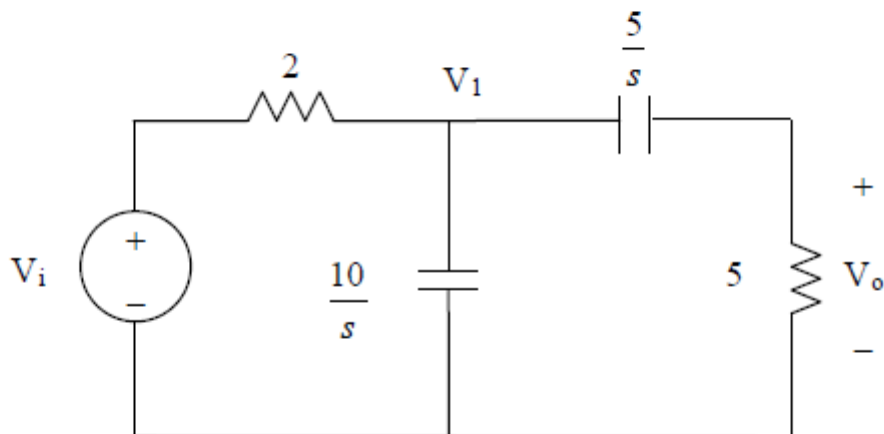


Figura 14.70 Esquema para o Problema 14.3.

$$0.2F \longrightarrow \frac{1}{j\omega C} = \frac{1}{s(0.2)} = \frac{5}{s}$$

$$0.1F \longrightarrow \frac{1}{s(0.1)} = \frac{10}{s}$$

The circuit becomes that shown below.



$$\text{Let } Z = \frac{10}{s} // \left(5 + \frac{5}{s}\right) = \frac{\frac{10}{s} \left(5 + \frac{5}{s}\right)}{5 + \frac{15}{s}} = \frac{\frac{10}{s} 5 \left(\frac{1+s}{s}\right)}{\frac{5}{s} (3+s)} = \frac{10(s+1)}{s(s+3)}$$

$$V_1 = \frac{Z}{Z+2} V_i$$

$$V_o = \frac{5}{5+5/s} V_1 = \frac{s}{s+1} V_1 = \frac{s}{s+1} \cdot \frac{Z}{Z+2} V_i$$

$$H(s) = \frac{V_o}{V_i} = \frac{s}{s+1} \cdot \frac{\frac{10(s+1)}{s(s+3)}}{2 + \frac{10(s+1)}{s(s+3)}} = \frac{10s}{2s(s+3) + 10(s+1)} = \frac{5s}{s^2 + 8s + 5}$$

$$\mathbf{H(s) = 5s/(s^2+8s+5)}$$

14.6 Considere o circuito mostrado na Figura 14.73 e determine $H(s) = I_o(s)/I_s(s)$.

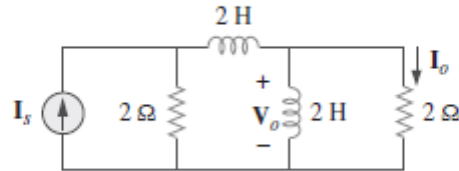
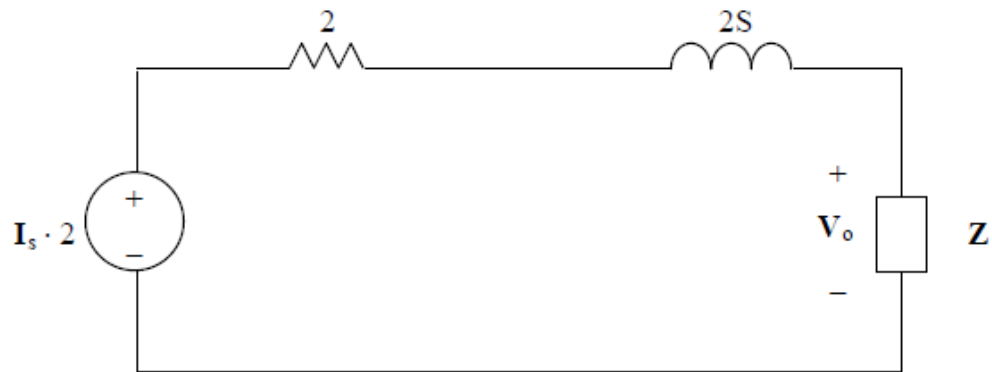


Figura 14.73 Esquema para o Problema 14.6.

The 2 H inductors become $j\omega 2$ or $2s$.

Let $Z = 2s \parallel 2 = [(2s)(2)/(2s+2)] = 2s/(s+1)$

We convert the current source to a voltage source as shown below.



$$V_o = [(Z)/(Z+2s+2)](2I_s) = \frac{\frac{2s}{s+1}}{\frac{2s+2s^2+2s+2s+2}{s+1}} (2I_s) = \frac{2s}{s^2+3s+1} I_s \quad \text{or}$$

$$H(s) = I_o/I_s = [2s/(s^2+3s+1)].$$

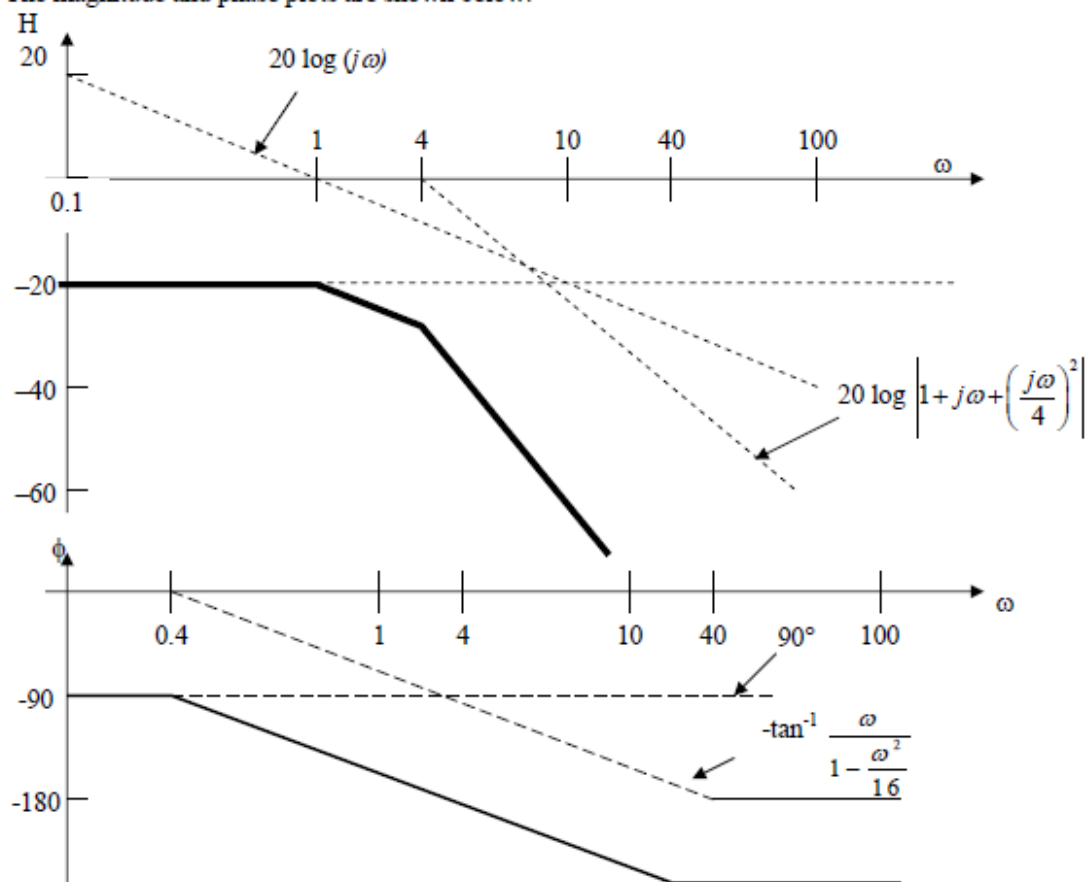
14.16 Trace os gráficos de Bode de amplitude e de fase para

$$H(s) = \frac{1,6}{s(s^2 + s + 16)}, \quad s = j\omega$$

$$H(\omega) = \frac{\frac{1,6}{16}}{j\omega \left[1 + j\omega + \left(\frac{j\omega}{4}\right)^2 \right]} = \frac{0,1}{j\omega \left[1 + j\omega + \left(\frac{j\omega}{4}\right)^2 \right]}$$

$$H_{db} = 20\log_{10}|0,1| - 20\log_{10}|j\omega| - 20\log_{10}|1 + j\omega + (j\omega/4)^2|$$

The magnitude and phase plots are shown below.



14.19 Esboce os gráficos de Bode assintóticos da amplitude e da fase para

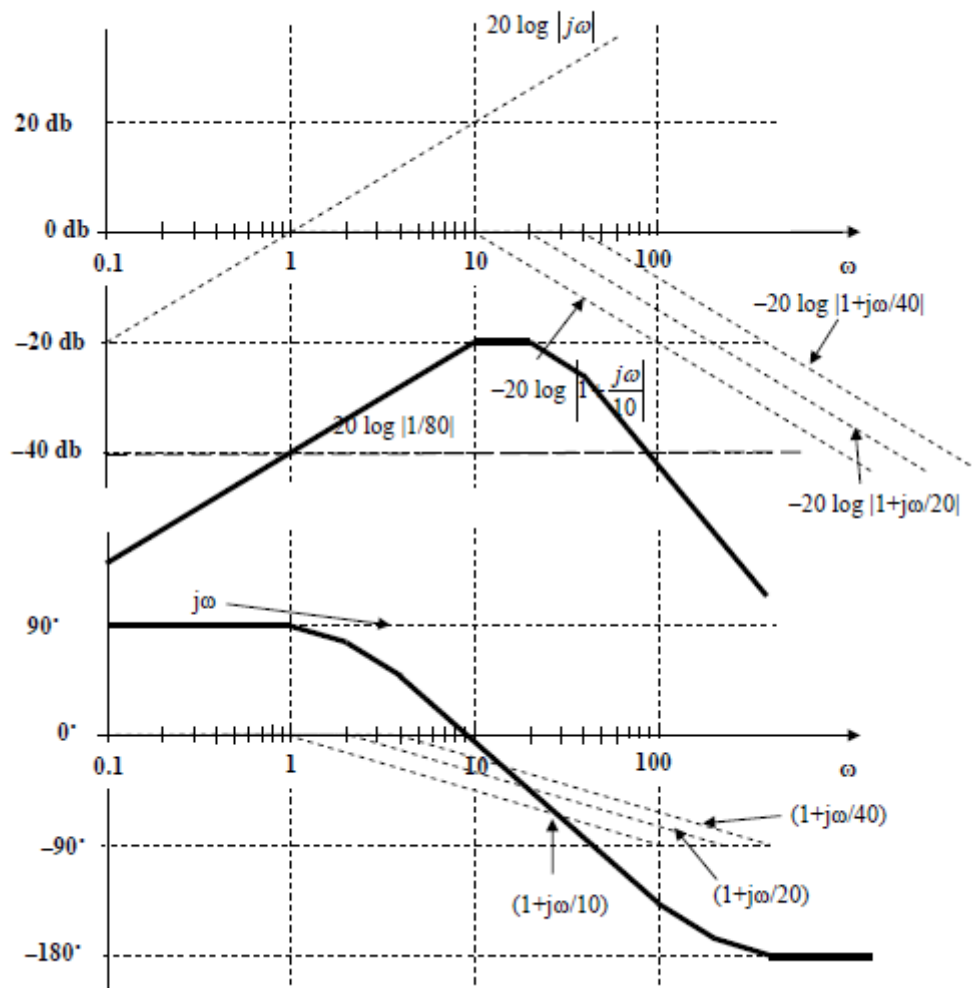
$$H(s) = \frac{80s}{(s + 10)(s + 20)(s + 40)}, \quad s = j\omega$$

$$H(\omega) = 80j\omega / [(10+j\omega)(20+j\omega)(40+j\omega)]$$

$$= [80 / (10 \times 20 \times 40)] (j\omega) / [(1+j\omega/10)(1+j\omega/20)(1+j\omega/40)]$$

$$H_{db} = 20 \log_{10} |0.01| + 20 \log_{10} |j\omega| - 20 \log_{10} |1+j\omega/10| - 20 \log_{10} |1+j\omega/20| - 20 \log_{10} |1+j\omega/40|$$

The magnitude and phase plots are shown below.



14.22 Determine a função de transferência $\mathbf{H}(\omega)$ por meio do gráfico de Bode de magnitude mostrado na Figura 14.74.

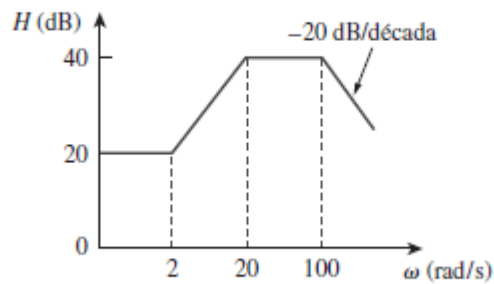


Figura 14.74 Esquema para o Problema 14.22.

$$20 = 20 \log_{10} k \quad \longrightarrow \quad k = 10$$

$$\text{A zero of slope } +20 \text{ dB/dec at } \omega = 2 \quad \longrightarrow \quad 1 + j\omega/2$$

$$\text{A pole of slope } -20 \text{ dB/dec at } \omega = 20 \quad \longrightarrow \quad \frac{1}{1 + j\omega/20}$$

$$\text{A pole of slope } -20 \text{ dB/dec at } \omega = 100 \quad \longrightarrow \quad \frac{1}{1 + j\omega/100}$$

Hence,

$$\mathbf{H}(\omega) = \frac{10(1 + j\omega/2)}{(1 + j\omega/20)(1 + j\omega/100)}$$

$$\mathbf{H}(\omega) = \frac{10^4(2 + j\omega)}{(20 + j\omega)(100 + j\omega)}$$

14.23 O gráfico de Bode de amplitude de $\mathbf{H}(\omega)$ é indicado na Figura 14.75. Determine $\mathbf{H}(\omega)$.

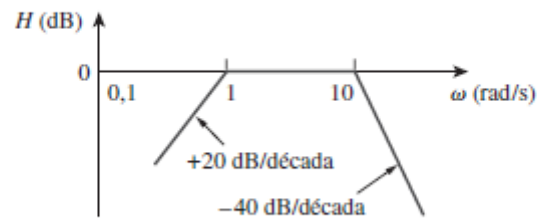


Figura 14.75 Esquema para o Problema 14.23.

A zero of slope + 20 dB / dec at the origin $\longrightarrow j\omega$

A pole of slope - 20 dB / dec at $\omega = 1$ $\longrightarrow \frac{1}{1 + j\omega/1}$

A pole of slope - 40 dB / dec at $\omega = 10$ $\longrightarrow \frac{1}{(1 + j\omega/10)^2}$

Hence,

$$\mathbf{H}(\omega) = \frac{j\omega}{(1 + j\omega)(1 + j\omega/10)^2}$$

$$\mathbf{H}(\omega) = \frac{100 j\omega}{(1 + j\omega)(10 + j\omega)^2}$$

(It should be noted that this function could also have a minus sign out in front and still be correct. The magnitude plot does not contain this information. It can only be obtained from the phase plot.)

14.24 O gráfico de amplitude na Figura 14.76 representa a função de transferência de um pré-amplificador. Determine $H(s)$.

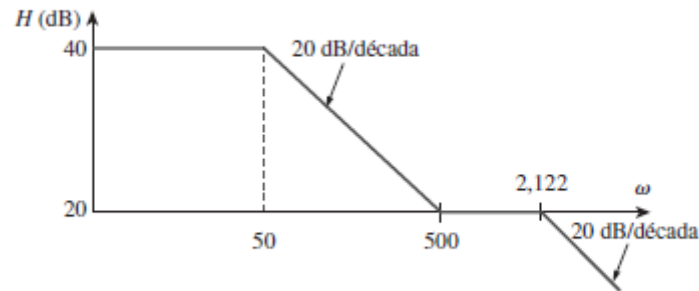


Figura 14.76 Esquema para o Problema 14.24.

$$40 = 20 \log_{10} K \quad \longrightarrow \quad K = 100$$

There is a pole at $\omega=50$ giving $1/(1+j\omega/50)$

There is a zero at $\omega=500$ giving $(1 + j\omega/500)$.

There is another pole at $\omega=2122$ giving $1/(1 + j\omega/2122)$.

Thus,

$$H(j\omega) = 100(1+j\omega)/[(1+j\omega/50)(1+j\omega/2122)]$$

$$= [100(50 \times 2122)/500](j\omega+500)/[(j\omega+50)(j\omega+2122)]$$

or

$$H(s) = 21220(s+500)/[(s+50)(s+2122)].$$

14.29 Seja $v_s = 20 \cos(\omega t)$ V no circuito da Figura 14.77. Determine ω_o , Q e B , visto pelo capacitor.

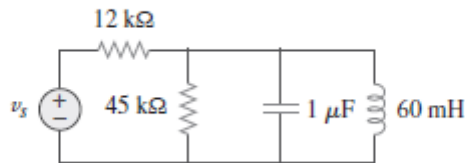
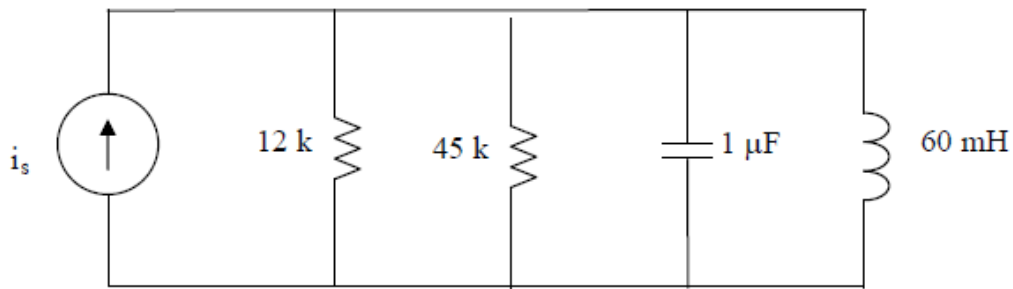


Figura 14.77 Esquema para o Problema 14.29.

We convert the voltage source to a current source as shown below.



$$i_s = \frac{20}{12} \cos \omega t, \quad R = 12 // 45 = \frac{12 \times 45}{57} = 9.4737 \text{ k}\Omega$$

$$\omega_o = \frac{1}{\sqrt{LC}} = \frac{1}{\sqrt{60 \times 10^{-3} \times 1 \times 10^{-6}}} = \underline{4.082 \text{ krad/s}} = \mathbf{4.082 \text{ krad/s}}$$

$$B = \frac{1}{RC} = \frac{1}{9.4737 \times 10^3 \times 10^{-6}} = \underline{105.55 \text{ rad/s}} = \mathbf{105.55 \text{ rad/s}}$$

$$Q = \frac{\omega_o}{B} = \frac{4082}{105.55} = \underline{38.674} = \mathbf{38.67}$$

14.30 Um circuito formado por uma bobina de indutância 10 mH e por resistência 20Ω é conectado em série a um capacitor e um gerador com tensão RMS igual a 120 V. Determine:

- (a) O valor da capacitância que fará que o circuito entre em ressonância em 15 kHz.
- (b) A corrente que atravessa a bobina na ressonância.
- (c) O fator Q do circuito.

(a) $f_0 = 15,000 \text{ Hz}$ leads to $\omega_0 = 2\pi f_0 = 94.25 \text{ krad/s} = 1/(LC)^{0.5}$ or

$$LC = 1/8.883 \times 10^9 \text{ or } C = 1/(8.883 \times 10^9 \times 10^{-2}) = 11.257 \times 10^{-9} \text{ F} = \mathbf{11.257 \text{ pF}}.$$

(b) since the capacitive reactance cancels out the inductive reactance at resonance, the current through the series circuit is given by

$$I = 120/20 = \mathbf{6 \text{ A}}.$$

(c) $Q = \omega_0 L/R = 94.25 \times 10^3 (0.01)/20 = \mathbf{47.12}$.

* 14.44 Considere o circuito da Figura 14.83 e determine:

- (a) A frequência de ressonância ω_0
- (b) $Z_{\text{ent}}(\omega_0)$

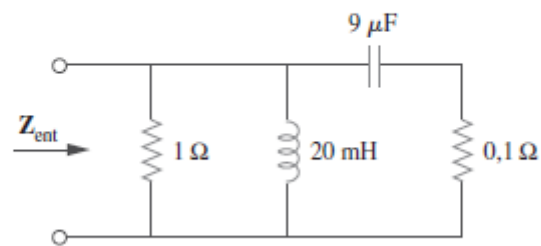
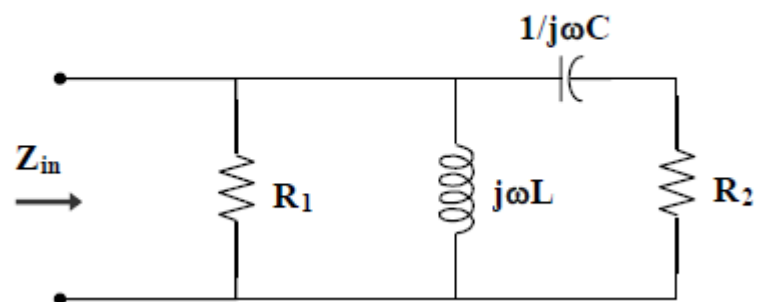


Figura 14.83 Esquema para o Problema 14.44.

Consider the circuit below.



$$(a) \quad \mathbf{Z}_{in} = (R_1 \parallel j\omega L) \parallel (R_2 + 1/j\omega C)$$

$$\mathbf{Z}_{in} = \left(\frac{R_1 j\omega L}{R_1 + j\omega L} \right) \parallel \left(R_2 + \frac{1}{j\omega C} \right)$$

$$\mathbf{Z}_{in} = \frac{\frac{j\omega R_1 L}{R_1 + j\omega L} \cdot \left(R_2 + \frac{1}{j\omega C} \right)}{R_2 + \frac{1}{j\omega C} + \frac{jR_1 \omega L}{R_1 + j\omega L}}$$

$$\mathbf{Z}_{in} = \frac{j\omega R_1 L (1 + j\omega R_2 C)}{(R_1 + j\omega L)(1 + j\omega R_2 C) - \omega^2 L C R_1}$$

$$\mathbf{Z}_{in} = \frac{-\omega^2 R_1 R_2 L C + j\omega R_1 L}{R_1 - \omega^2 L C R_1 - \omega^2 L C R_2 + j\omega(L + R_1 R_2 C)}$$

$$\mathbf{Z}_{in} = \frac{(-\omega^2 R_1 R_2 L C + j\omega R_1 L)[R_1 - \omega^2 L C R_1 - \omega^2 L C R_2 - j\omega(L + R_1 R_2 C)]}{(R_1 - \omega^2 L C R_1 - \omega^2 L C R_2)^2 + \omega^2(L + R_1 R_2 C)^2}$$

At resonance, $\text{Im}(\mathbf{Z}_{in}) = 0$, i.e.

$$0 = \omega^3 R_1 R_2 L C (L + R_1 R_2 C) + \omega R_1 L (R_1 - \omega^2 L C R_1 - \omega^2 L C R_2)$$

$$0 = \omega^3 R_1^2 R_2^2 L C^2 + R_1^2 \omega L - \omega^3 R_1^2 L^2 C$$

$$0 = \omega^2 R_2^2 C^2 + 1 - \omega^2 L C$$

$$\omega^2 (L C - R_2^2 C^2) = 1$$

$$\omega_0 = \frac{1}{\sqrt{L C - R_2^2 C^2}}$$

$$\omega_0 = \frac{1}{\sqrt{(0.02)(9 \times 10^{-6}) - (0.1)^2 (9 \times 10^{-6})^2}}$$

$$\omega_0 = \mathbf{2.357 \text{ krad/s}}$$

(b) At $\omega = \omega_0 = 2.357 \text{ krad/s}$,

$$j\omega L = j(2.357 \times 10^3)(20 \times 10^{-3}) = j47.14$$

$$R_1 \parallel j\omega L = \frac{j47.14}{1 + j47.14} = 0.9996 + j0.0212$$

$$R_2 + \frac{1}{j\omega C} = 0.1 + \frac{1}{j(2.357 \times 10^3)(9 \times 10^{-6})} = 0.1 - j47.14$$

$$Z_{in}(\omega_0) = (R_1 \parallel j\omega L) \parallel (R_2 + 1/j\omega C)$$

$$Z_{in}(\omega_0) = \frac{(0.9996 + j0.0212)(0.1 - j47.14)}{(0.9996 + j0.0212) + (0.1 - j47.14)}$$

$$Z_{in}(\omega_0) = \mathbf{1 \Omega}$$

14.45 Considere o circuito mostrado na Figura 14.84 e determine ω_0 , B e Q , visto pela tensão no indutor.

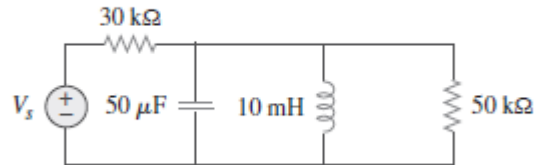
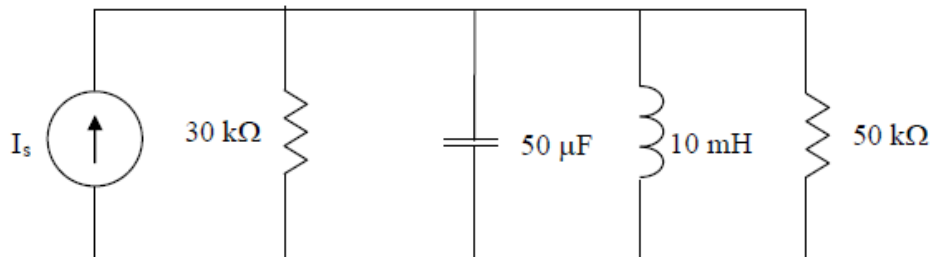


Figura 14.84 Esquema para o Problema 14.45.

Convert the voltage source to a current source as shown below.



$$R = 30 // 50 = \frac{30 \times 50}{80} = 18.75 \text{ k}\Omega$$

This is a parallel resonant circuit.

$$\omega_0 = \frac{1}{\sqrt{LC}} = \frac{1}{\sqrt{10 \times 10^{-3} \times 50 \times 10^{-6}}} = \underline{447.21 \text{ rad/s}}$$

$$B = \frac{1}{RC} = \frac{1}{18.75 \times 10^3 \times 50 \times 10^{-6}} = \underline{1.067 \text{ rad/s}}$$

$$Q = \frac{\omega_0}{B} = \frac{447.21}{1.067} = \underline{419.13}$$

14.56 (a) Demonstre que para um filtro passa-faixa,

$$\mathbf{H}(s) = \frac{sB}{s^2 + sB + \omega_0^2}, \quad s = j\omega$$

onde B = largura de banda do filtro e ω_0 é a frequência central.

(b) De modo similar, demonstre que, para um filtro rejeita-faixa,

$$\mathbf{H}(s) = \frac{s^2 + \omega_0^2}{s^2 + sB + \omega_0^2}, \quad s = j\omega$$

(a) From Eq 14.54,

$$\mathbf{H}(s) = \frac{R}{R + sL + \frac{1}{sC}} = \frac{sRC}{1 + sRC + s^2LC} = \frac{s \frac{R}{L}}{s^2 + s \frac{R}{L} + \frac{1}{LC}}$$

Since $B = \frac{R}{L}$ and $\omega_0 = \frac{1}{\sqrt{LC}}$,

$$\mathbf{H}(s) = \frac{sB}{s^2 + sB + \omega_0^2}$$

(b) From Eq. 14.56,

$$\mathbf{H}(s) = \frac{sL + \frac{1}{sC}}{R + sL + \frac{1}{sC}} = \frac{s^2 + \frac{1}{LC}}{s^2 + s \frac{R}{L} + \frac{1}{LC}}$$

$$\mathbf{H}(s) = \frac{s^2 + \omega_0^2}{s^2 + sB + \omega_0^2}$$

14.57 Determine a frequência central e a largura de banda dos filtros passa-faixa na Figura 14.88.

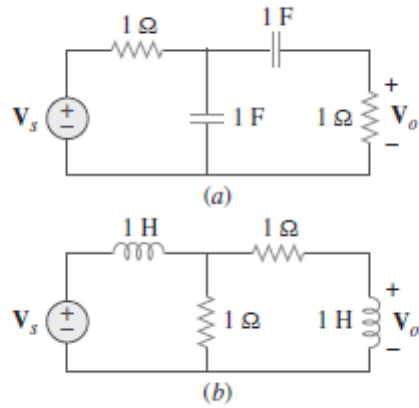
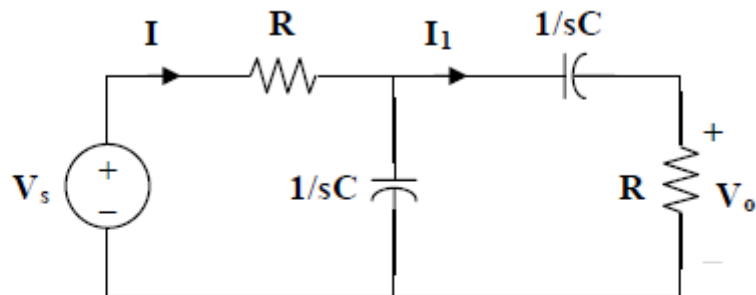


Figura 14.88 Esquema para o Problema 14.57.

(a) Consider the circuit below.



$$Z(s) = R + \frac{1}{sC} \parallel \left(R + \frac{1}{sC} \right) = R + \frac{\frac{1}{sC} \left(R + \frac{1}{sC} \right)}{R + \frac{2}{sC}}$$

$$Z(s) = R + \frac{1 + sRC}{sC(2 + sRC)}$$

$$Z(s) = \frac{1 + 3sRC + s^2 R^2 C^2}{sC(2 + sRC)}$$

$$\mathbf{I} = \frac{\mathbf{V}_s}{\mathbf{Z}}$$

$$\mathbf{I}_1 = \frac{1/sC}{2/sC + R} \mathbf{I} = \frac{\mathbf{V}_s}{\mathbf{Z}(2 + sRC)}$$

$$\mathbf{V}_o = \mathbf{I}_1 R = \frac{R \mathbf{V}_s}{2 + sRC} \cdot \frac{sC(2 + sRC)}{1 + 3sRC + s^2 R^2 C^2}$$

$$\mathbf{H}(s) = \frac{\mathbf{V}_o}{\mathbf{V}_s} = \frac{sRC}{1 + 3sRC + s^2 R^2 C^2}$$

$$\mathbf{H}(s) = \frac{1}{3} \left[\frac{\frac{3}{RC} s}{s^2 + \frac{3}{RC} s + \frac{1}{R^2 C^2}} \right]$$

$$\text{Thus, } \omega_0^2 = \frac{1}{R^2 C^2} \quad \text{or} \quad \omega_0 = \frac{1}{RC} = \mathbf{1 \text{ rad/s}}$$

$$B = \frac{3}{RC} = \mathbf{3 \text{ rad/s}}$$

(b) Similarly,

$$\mathbf{Z}(s) = sL + R \parallel (R + sL) = sL + \frac{R(R + sL)}{2R + sL}$$

$$\mathbf{Z}(s) = \frac{R^2 + 3sRL + s^2L^2}{2R + sL}$$

$$\mathbf{I} = \frac{\mathbf{V}_s}{\mathbf{Z}}, \quad \mathbf{I}_1 = \frac{R}{2R + sL} \mathbf{I} = \frac{R \mathbf{V}_s}{\mathbf{Z}(2R + sL)}$$

$$\mathbf{V}_o = \mathbf{I}_1 \cdot sL = \frac{sLR \mathbf{V}_s}{2R + sL} \cdot \frac{2R + sL}{R^2 + 3sRL + s^2L^2}$$

$$\mathbf{H}(s) = \frac{\mathbf{V}_o}{\mathbf{V}_s} = \frac{sRL}{R^2 + 3sRL + s^2L^2} = \frac{\frac{1}{3} \left(\frac{3R}{L} s \right)}{s^2 + \frac{3R}{L} s + \frac{R^2}{L^2}}$$

$$\text{Thus, } \omega_0 = \frac{R}{L} = \mathbf{1 \text{ rad/s}}$$

$$B = \frac{3R}{L} = \mathbf{3 \text{ rad/s}}$$

14.59 Determine a largura de banda e a frequência de corte do filtro rejeita-faixa da Figura 14.89.

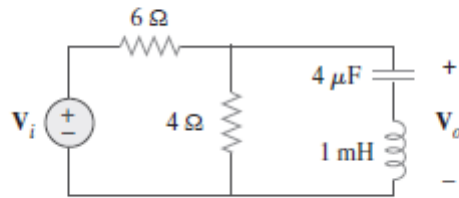
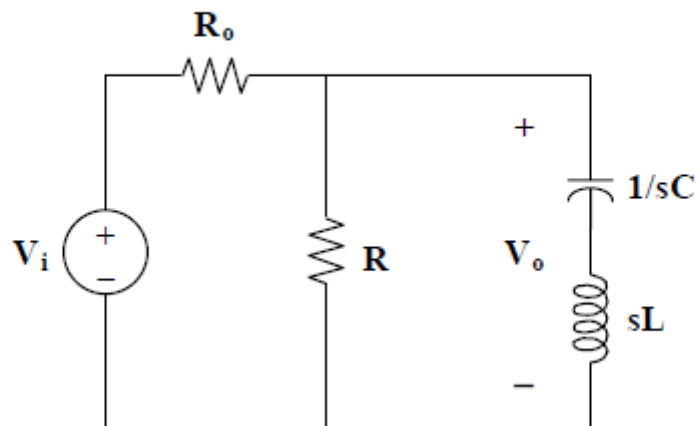


Figura 14.89 Esquema para o Problema 14.59.

Consider the circuit below.



where $L = 1 \text{ mH}$, $C = 4 \text{ } \mu\text{F}$, $R_o = 6 \text{ } \Omega$, and $R = 4 \text{ } \Omega$.

$$\mathbf{Z}(s) = R \parallel \left(sL + \frac{1}{sC} \right) = \frac{R (sL + 1/sC)}{R + sL + 1/sC}$$

$$\mathbf{Z}(s) = \frac{R (1 + s^2 LC)}{1 + sRC + s^2 LC}$$

$$\mathbf{H} = \frac{\mathbf{V}_o}{\mathbf{V}_i} = \frac{\mathbf{Z}}{\mathbf{Z} + R_o} = \frac{R (1 + s^2 LC)}{R_o + sRR_o C + s^2 LCR_o + R + s^2 LCR}$$

$$\mathbf{Z}_{in} = R_o + \mathbf{Z} = R_o + \frac{R(1+s^2LC)}{1+sRC+s^2LC}$$

$$\mathbf{Z}_{in} = \frac{R_o + sRR_oC + s^2LCR_o + R + s^2LCR}{1+sRC+s^2LC}$$

$$s = j\omega$$

$$\mathbf{Z}_{in} = \frac{R_o + j\omega RR_oC - \omega^2LCR_o + R - \omega^2LCR}{1 - \omega^2LC + j\omega RC}$$

$$\mathbf{Z}_{in} = \frac{(R_o + R - \omega^2LCR_o - \omega^2LCR + j\omega RR_oC)(1 - \omega^2LC - j\omega RC)}{(1 - \omega^2LC)^2 + (\omega RC)^2}$$

$\text{Im}(\mathbf{Z}_{in}) = 0$ implies that

$$-\omega RC[R_o + R - \omega^2LCR_o - \omega^2LCR] + \omega RR_oC(1 - \omega^2LC) = 0$$

$$R_o + R - \omega^2LCR_o - \omega^2LCR - R_o + \omega^2LCR_o = 0$$

$$\omega^2LCR = R$$

$$\omega_0 = \frac{1}{\sqrt{LC}} = \frac{1}{\sqrt{(1 \times 10^{-3})(4 \times 10^{-6})}} = \mathbf{15.811 \text{ krad/s}}$$

$$\mathbf{H} = \frac{R(1 - \omega^2LC)}{R_o + j\omega RR_oC + R - \omega^2LCR_o - \omega^2LCR}$$

$$H_{\max} = H(0) = \frac{R}{R_o + R}$$

$$\text{or } H_{\max} = H(\infty) = \lim_{\omega \rightarrow \infty} \frac{R\left(\frac{1}{\omega^2} - LC\right)}{\frac{R_o + R}{\omega^2} + j\frac{RR_oC}{\omega} - LC(R + R_o)} = \frac{R}{R + R_o}$$

$$\text{At } \omega_1 \text{ and } \omega_2, |\mathbf{H}| = \frac{1}{\sqrt{2}} H_{\max}$$

$$\frac{R}{\sqrt{2}(R_o + R)} = \left| \frac{R(1 - \omega^2 LC)}{R_o + R - \omega^2 LC(R_o + R) + j\omega RR_o C} \right|$$

$$\frac{1}{\sqrt{2}} = \frac{(R_o + R)(1 - \omega^2 LC)}{\sqrt{(\omega RR_o C)^2 + (R_o + R - \omega^2 LC(R_o + R))^2}}$$

$$\frac{1}{\sqrt{2}} = \frac{10(1 - \omega^2 \cdot 4 \times 10^{-9})}{\sqrt{(96 \times 10^{-6} \omega)^2 + (10 - \omega^2 \cdot 4 \times 10^{-8})^2}}$$

$$0 = \frac{10(1 - \omega^2 \cdot 4 \times 10^{-9})}{\sqrt{(96 \times 10^{-6} \omega)^2 + (10 - \omega^2 \cdot 4 \times 10^{-8})^2}} - \frac{1}{\sqrt{2}}$$

$$(10 - \omega^2 \cdot 4 \times 10^{-8})(\sqrt{2}) - \sqrt{(96 \times 10^{-6} \omega)^2 + (10 - \omega^2 \cdot 4 \times 10^{-8})^2} = 0$$

$$(2)(10 - \omega^2 \cdot 4 \times 10^{-8})^2 = (96 \times 10^{-6} \omega)^2 + (10 - \omega^2 \cdot 4 \times 10^{-8})^2$$

$$(96 \times 10^{-6} \omega)^2 - (10 - \omega^2 \cdot 4 \times 10^{-8})^2 = 0$$

$$1.6 \times 10^{-15} \omega^4 - 8.092 \times 10^{-7} \omega^2 + 100 = 0$$

$$\omega^4 - 5.058 \times 10^8 + 6.25 \times 10^{16} = 0$$

$$\omega^2 = \begin{cases} 2.9109 \times 10^8 \\ 2.1471 \times 10^8 \end{cases}$$

Hence,

$$\omega_1 = 14.653 \text{ krad/s}$$

$$\omega_2 = 17.061 \text{ krad/s}$$

$$B = \omega_2 - \omega_1 = 17.061 - 14.653 = \mathbf{2.408 \text{ krad/s}}$$

14.65 Um filtro passa-altas é mostrado na Figura 14.92. Demonstre que a função de transferência é

$$H(\omega) = \left(1 + \frac{R_f}{R_i}\right) \frac{j\omega RC}{1 + j\omega RC}$$

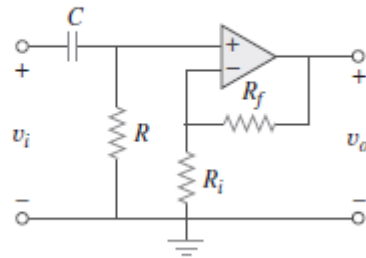


Figura 14.92 Esquema para o Problema 14.65.

$$V_+ = \frac{R}{R + 1/j\omega C} V_i = \frac{j\omega RC}{1 + j\omega RC} V_i$$

$$V_- = \frac{R_i}{R_i + R_f} V_o$$

Since $V_+ = V_-$,

$$\frac{R_i}{R_i + R_f} V_o = \frac{j\omega RC}{1 + j\omega RC} V_i$$

$$H(\omega) = \frac{V_o}{V_i} = \left(1 + \frac{R_f}{R_i}\right) \left(\frac{j\omega RC}{1 + j\omega RC}\right)$$

It is evident that as $\omega \rightarrow \infty$, the gain is $1 + \frac{R_f}{R_i}$ and that the corner frequency is $\frac{1}{RC}$.

14.66 Um filtro de primeira ordem “genérico” é exposto na Figura 14.93.

(a) Demonstre que a função de transferência é

$$\mathbf{H}(s) = \frac{R_4}{R_3 + R_4} \times \frac{s + (1/R_1C)[R_1/R_2 - R_3/R_4]}{s + 1/R_2C},$$

$s = j\omega$

(b) Que condição deve ser satisfeita para o circuito operar como um filtro passa-altas?

(c) Que condição deve ser satisfeita para o circuito operar como um filtro passa-baixas?

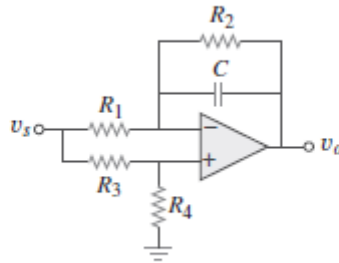


Figura 14.93 Esquema para o Problema 14.66.

(a) **Proof**

(b) When $\mathbf{R}_1\mathbf{R}_4 = \mathbf{R}_2\mathbf{R}_3$,

$$\mathbf{H}(s) = \frac{R_4}{R_3 + R_4} \cdot \frac{s}{s + 1/R_2C}$$

(c) When $\mathbf{R}_3 \rightarrow \infty$,

$$\mathbf{H}(s) = \frac{-1/R_1C}{s + 1/R_2C}$$

14.67 Projete um filtro passa-baixas ativo com ganho CC igual **0,25** e frequência de corte **500 Hz**.

$$\text{DC gain} = \frac{R_f}{R_i} = \frac{1}{4} \longrightarrow R_i = 4R_f$$

$$\text{Corner frequency} = \omega_c = \frac{1}{R_f C_f} = 2\pi(500) \text{ rad/s}$$

If we select $R_f = 20 \text{ k}\Omega$, then $R_i = 80 \text{ k}\Omega$ and

$$C = \frac{1}{(2\pi)(500)(20 \times 10^3)} = 15.915 \text{ nF}$$

Therefore, if $R_f = 20 \text{ k}\Omega$, then $R_i = 80 \text{ k}\Omega$ and $C = 15.915 \text{ nF}$

* 14.70 Um filtro ativo de segunda ordem conhecido como filtro Butterworth é mostrado na Figura 14.95.

(a) Determine a função de transferência V_o/V_i .

(b) Demonstre que se trata de um filtro passa-baixas.

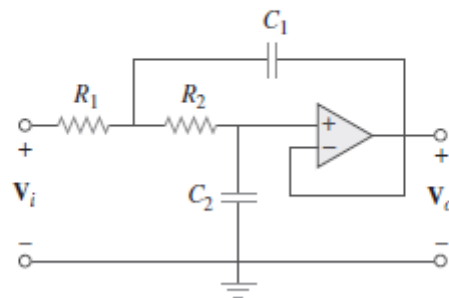


Figura 14.95 Esquema para o Problema 14.70.

$$(a) \quad \mathbf{H}(s) = \frac{V_o(s)}{V_i(s)} = \frac{Y_1 Y_2}{Y_1 Y_2 + Y_4 (Y_1 + Y_2 + Y_3)}$$

$$\text{where } Y_1 = \frac{1}{R_1} = G_1, \quad Y_2 = \frac{1}{R_2} = G_2, \quad Y_3 = sC_1, \quad Y_4 = sC_2.$$

$$\mathbf{H}(s) = \frac{G_1 G_2}{G_1 G_2 + sC_2 (G_1 + G_2 + sC_1)}$$

$$(b) \quad H(0) = \frac{G_1 G_2}{G_1 G_2} = 1, \quad H(\infty) = 0$$

showing that **this circuit is a lowpass filter.**