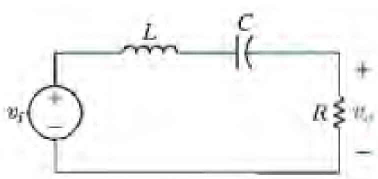
14.18 Calculate the center frequency, the bandwidth, and the quality factor of a bandpass filter that has an upper cutoff frequency of 200 krad/s and a lower cutoff frequency of 180 krad/s.

14.25 Design a series *RLC* bandpass filter (see Fig. 14.19[a]) with a quality of 5 and a center frequency of 20 krad/s, using a 0.05 μF capacitor.

a) Draw your circuit, labeling the component values and output voltage.

b) For the filter in part (a), calculate the bandwidth and the values of the two cutoff frequencies.



c) Plot the asymptotic Bode plot for this filter and compare to computer calculation.

14.40 PSPICE The parameters in the circuit in Fig. P14.39 are $R = 5$ kΩ, $L = 400$ mH, $C = 250$ pF, and $R_L = 20$ kΩ.

a) Find ω_o, β (in kilohertz), and Q.

b) Find $H(j0)$ and $H(j\infty)$.

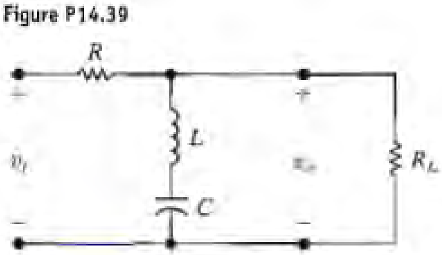
c) Find f_{c2} and f_{c1}.

d) Show that if R_L is expressed in kilohms the Q of the circuit is

$$Q = 8[1 + (5/R_L)].$$

e) Plot Q versus R_L for $2\ \text{k}\Omega \le R_L \le 50\ \text{k}\Omega$.

Figure P14.39



15.5 Design an op amp-based low pass filter with a cutoff frequency of 500 Hz and a passband gain of 10 using a 50 nF capacitor.

a) Draw your circuit, labeling the component values and output voltage.

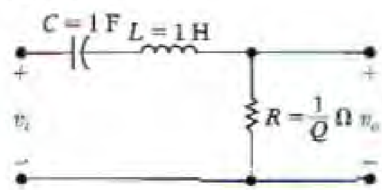
b) If the value of the feedback resistor in the filter is changed but the value of the resistor in the forward path is unchanged, what characteristic of the filter is changed?

15.13 a) Specify the component values for the prototype passive bandpass filter described in Problem 15.12 if the quality factor of the filter is 25.

b) Specify the component values for the bandpass filter described in Problem 15.12 if the quality factor is 25; the center, or resonant, frequency is 100 krad/s; and the impedance at resonance is 3.6 kΩ.

c) Draw a circuit diagram of the scaled filter and label all the components.

Figure P15.12



15.27 DESIGN PROBLEM a) Using 5 nF capacitors, design an active broadband first-order bandreject filter with a lower cutoff frequency of 1000 Hz, an upper cutoff frequency of 5000 Hz, and a passband gain of 10 dB. Use the prototype filter circuits introduced in Problems 15.24 and 15.25 in the design process.

b) Draw the circuit diagram of the filter and label all the components.

c) What is the transfer function of the scaled filter?

d) Evaluate the transfer function derived in (c) at the center frequency of the filter.

e) What is the gain (in decibels) at the center frequency?

f) Using a computer program of your choice, make a Bode magnitude plot of the filter transfer function.

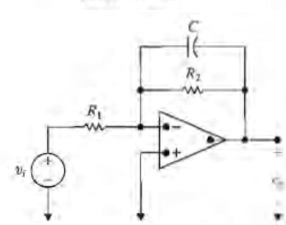


Figure 15.1 ▲ A first-order low-pass filter.

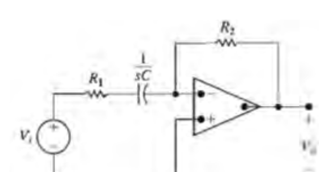


Figure 15.4 ▲ A first-order high-pass filter.

14.18

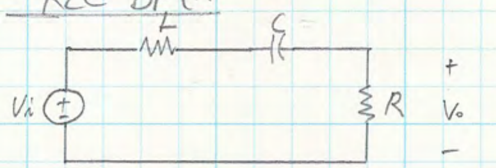
$$\omega_0 = \sqrt{\omega_{c1} \cdot \omega_{c2}} = \sqrt{180 \cdot 200} = 189.74 \ \text{krad/s}.$$

$$\therefore f_0 = \omega_0 / 2\pi = 30.2 \ \text{kHz}$$

$$\beta = \omega_{c2} - \omega_{c1} = 200 - 180 = 20 \ \text{krad/s}$$

$$Q = \frac{\omega_0}{\beta} = \frac{189.74}{20} = 9.49$$

14.25 RLC BPF.



$Q = 5$
$\omega_0 = 20 \ \text{krad/s}$
$C = 0.05 \mu F$

(a) $\omega_0 = 1/\sqrt{LC} \rightarrow L = 1/\omega_0^2 C = 50 \ \text{mH}$

$Q = \frac{\omega_0}{\beta} = 5$ & $\beta = \frac{R}{L} \rightarrow Q = \omega_0 \cdot \frac{L}{R} = 5$

$\therefore R = \frac{\omega_0 \cdot L}{5} = 200 \ \Omega$ $(\beta = 4000)$

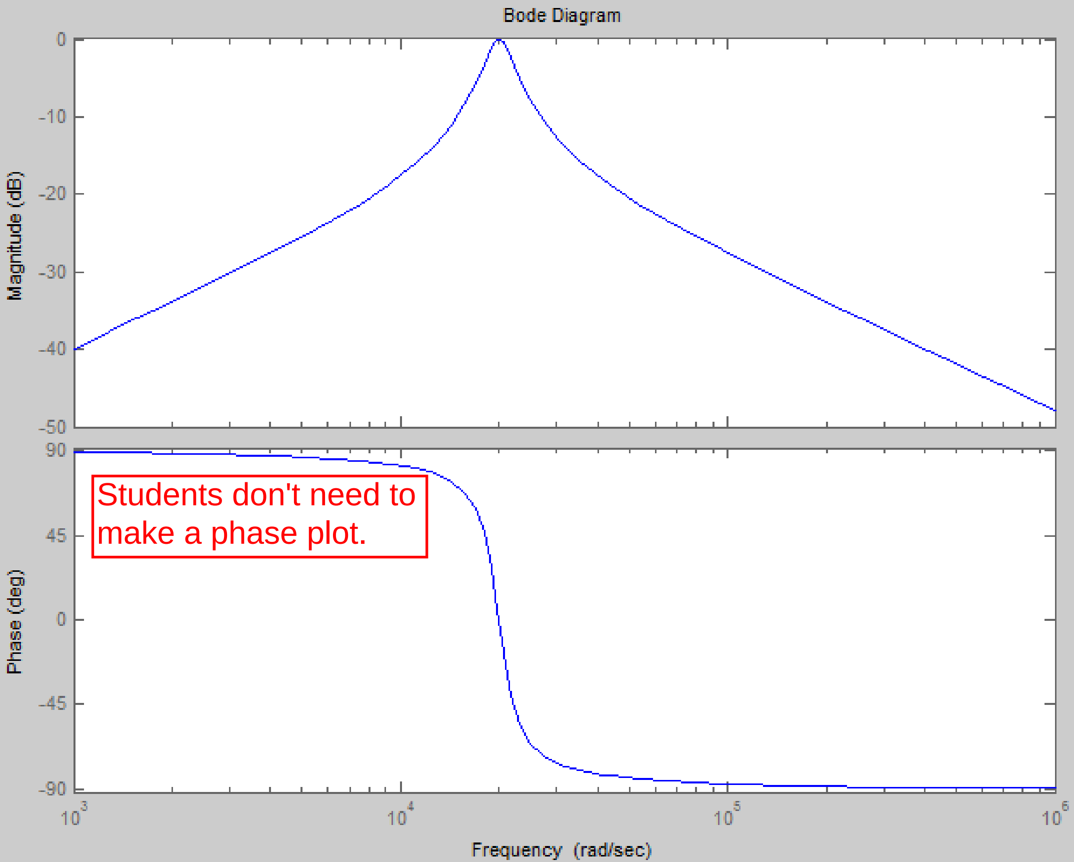
(b) $\omega_{c1,2} = \pm \frac{\beta}{2} + \sqrt{\left(\frac{\beta}{2}\right)^2 + \omega_0^2} = \pm \frac{4000}{2} + \sqrt{\left(\frac{4000}{2}\right)^2 + (20000)^2}$

$= \pm 2000 + 20099.75$

$$\left\langle \begin{array}{l} \omega_{c1} = 18099.75 \ \text{rad/s} \\ \omega_{c2} = 22099.75 \ \text{rad/s.} \end{array} \right\rangle$$

(c) Asymptotic bode plot

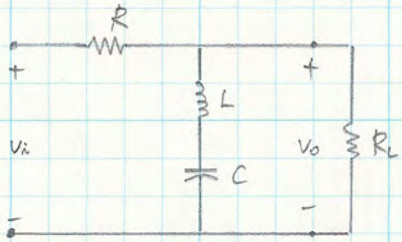
$$H(s) = \frac{R}{sL + 1/sC + R} = \frac{sRC}{s^2 LC + sRC + 1} = \frac{s(R/L)}{s^2 + s(R/L) + 1/LC}$$



Bode Diagram
Magnitude (dB)
0
-10
-20
-30
-40
-50
Phase (deg)
90
45
0
-45
-90
10^3
10^4
10^5
10^6
Frequency (rad/sec)
Students don't need to make a phase plot.

~~14.39~~

14.40



$R = 5\,k\Omega$
$L = 400\,mH$
$C = 250\,pF$
$R_L = 20\,k\Omega$

(a) let $Z = (sL + 1/sC) \parallel R_L$

$$= \frac{R_L(sL + 1/sC)}{sL + 1/sC + R_L} = \frac{R_L(s^2LC + 1)}{s^2LC + sR_LC + 1}$$

$$\therefore H(s) = \frac{Z}{R + Z}$$

$$= \frac{\dfrac{R_L(s^2LC+1)}{s^2LC + sR_LC + 1}}{R + \dfrac{R_L(s^2LC+1)}{s^2LC + sR_LC + 1}} = \frac{R_L(s^2LC+1)}{s^2RLC + sRR_LC + R + s^2R_LLC + R_L}$$

$$= \frac{R_L(s^2LC+1)}{s^2LC(R+R_L) + sRR_LC + (R+R_L)}$$

$$= \frac{R_L(s^2LC+1)}{LC(R+R_L)} \cdot \frac{1}{s^2 + s\underbrace{\frac{RR_L}{(R+R_L)\cdot L}}_{\beta} + \underbrace{\frac{1}{LC}}_{\omega_0^2}}$$

$$= \frac{R_L}{R+R_L} \cdot \frac{(s^2 + \overbrace{1/LC}^{=\omega_0^2})}{s^2 + s\beta + \omega_0^2}$$

$\rightarrow \omega_0^2 = 1/LC \rightarrow \omega_0 = \dfrac{1}{\sqrt{LC}} = 100\ \text{krad/s} = \underline{15.915\ kHz}$

$\beta = \dfrac{RR_L}{(R+R_L)\cdot L} = 10^4\ \text{rad/s} = \underline{1.591\ kHz}$

$Q = \dfrac{\omega_0}{\beta} = \underline{10}.$

(b) $H(j0) = \dfrac{R_L}{R+R_L} \cdot \dfrac{\omega_0^2}{0 + 0 + \omega_0^2} = \dfrac{R_L}{R+R_L} = \dfrac{20}{5+20} = \underline{0.8}$

$H(j\infty) = \dfrac{R_L}{R+R_L} \cdot \left.\dfrac{s^2}{s^2}\right|_{s=j\infty} = \dfrac{R_L}{R+R_L} = \underline{0.8}$

(c) Denominator, $D(s) = s^2 + \beta s + \omega_0^2$

$$\omega_{c1,2} = \pm \frac{\beta}{2} + \sqrt{\left(\frac{\beta}{2}\right)^2 + \omega_0^2}$$

$\beta = 10^4 = 10$ krad/s
$\omega_0 = 100$ krad/s

$$= \pm \frac{10}{2} + \sqrt{\left(\frac{10}{2}\right)^2 + (100)^2}$$

$$= \pm 5 + 100.1249 \text{ krad/s.}$$

$\omega_{c1} = 95.1249$ krad/s $= \underline{15.14 \text{ kHz}}$

$\omega_{c2} = 105.1249$ krad/s $= \underline{16.73 \text{ kHz}}$ (x-check $\beta = \omega_{c2} - \omega_{c1} = 1.591$ kHz)

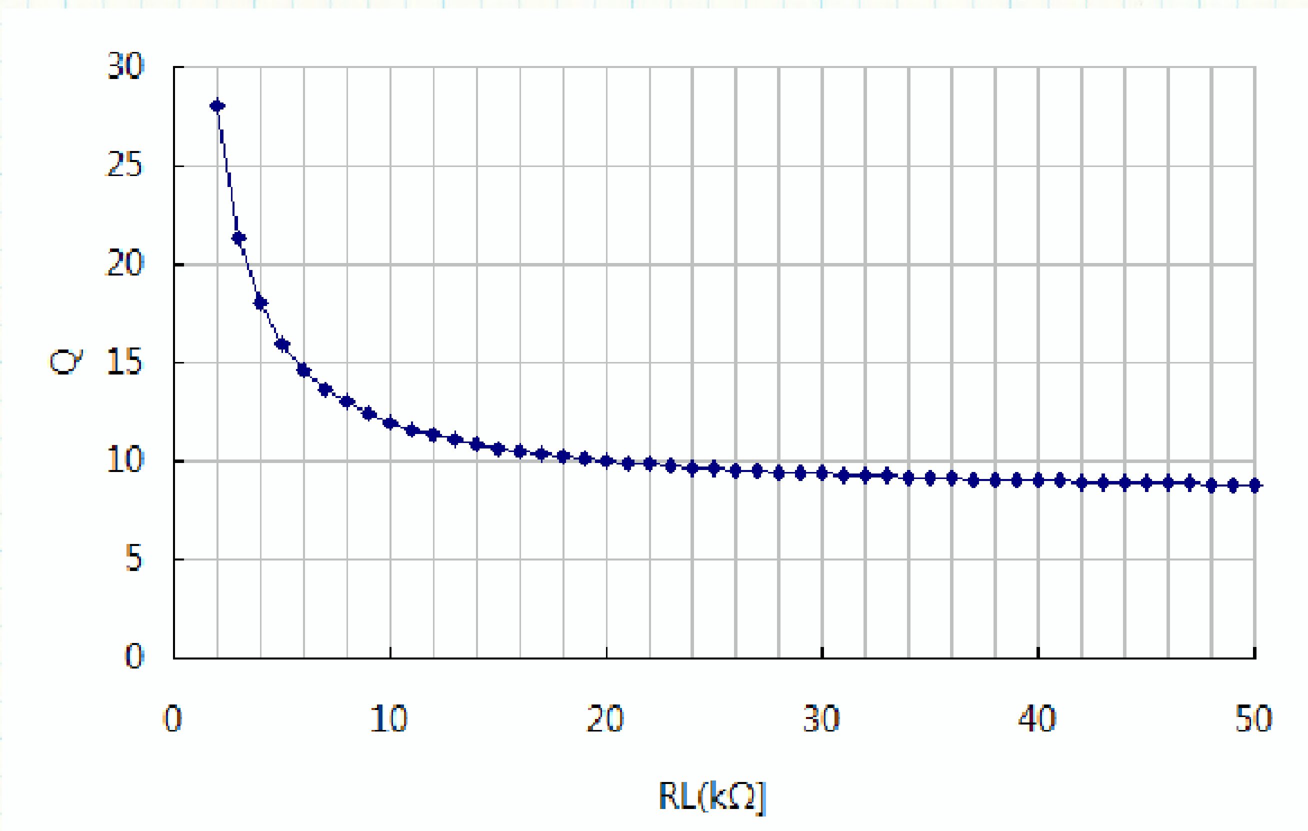
(d) $$Q = \frac{\omega_0}{\beta} = \frac{10^5}{\frac{RR_L}{(R_L+R)\cdot L}} = \frac{10^5 \cdot L \cdot (R_L + R)}{RR_L} = 10^5 \cdot L \cdot \left(\frac{1}{R} + \frac{1}{R_L}\right)$$

$$= 0.4 \times 10^5 \left(\frac{1}{5000} + \frac{1}{R_L}\right) = 0.4 \times 10^5 \times \frac{1}{5000}\left(1 + \frac{5000}{R_L}\right)$$

$$= 8\left(1 + \frac{5000}{R_L}\right) \quad ; R_L \text{ in } \Omega.$$

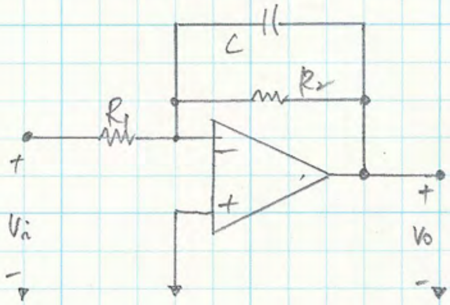
$$= \underline{8\left(1 + \frac{5}{R_L}\right)} \quad ; R_L \text{ in k}\Omega.$$

(e)



~~14.40~~

15.5 op-amp-based LPF. $f_c = 500\ Hz$. gain = 10. $C = 50\ nF$.



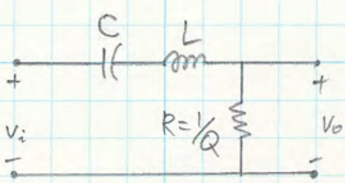
(a) $\omega_c = 1/R_2C$ $\therefore R_2 = \dfrac{1}{\omega_c C} = \dfrac{1}{(2\pi \cdot 500)(50\times 10^{-9})} = 6366.2\ \Omega$

gain. k

$K = \dfrac{R_2}{R_1} = 10$ $\therefore R_1 = 636.6\ \Omega$

(b) (Gain is changed. Cutoff frequency is changed)

15.13.



$Q = 25$

(a) $C = 1F$. $L = 1F$, $Q = 25 \Rightarrow R = 1/Q = 0.04\ \Omega$

(b) $H(s) = \dfrac{R}{1/sC + sL + R} = \dfrac{sRC}{s^2LC + sRC + 1} = \dfrac{s(R/L)}{s^2 + s(R/L) + (1/LC)}$

$= \dfrac{\beta s}{s^2 + \beta s + \omega_o^2}$

i) $Q = 25 \rightarrow \dfrac{\omega_o}{\beta} = 25$ $\omega_o = 1/\sqrt{LC}$, $\beta = R/L$

$\beta = \dfrac{\omega_o}{25} = \dfrac{100\times 10^3}{25} = 4\times 10^3 = \dfrac{R}{L}$

from $R = 3.6\ k\Omega \rightarrow L = \dfrac{R}{4\times 10^3} = 0.9H$

$\omega_o = \dfrac{1}{\sqrt{LC}} \rightarrow C = \dfrac{1}{L\omega_o^2} = 0.111\ nF$

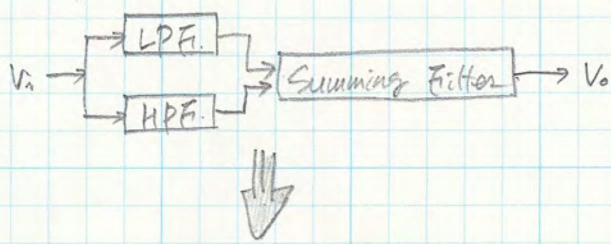
(c) $C = 0.111\ nF$
$L = 0.9\ H$
$R = 3.6\ k\Omega$

15.27 First-order bandreject filter

$f_{c1} = 1000\ Hz$, $f_{c2} = 5000\ Hz$

$gain = 10\ dB$.

*. Bandreject filter



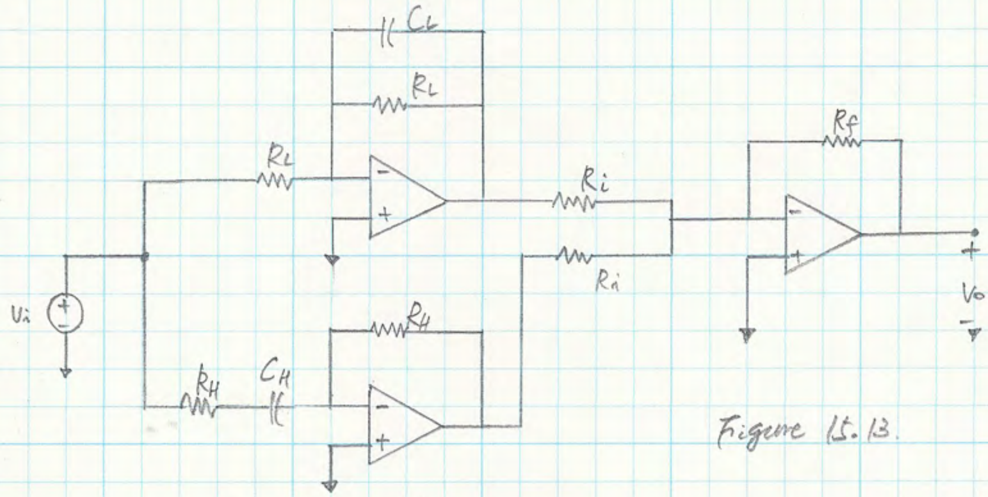


Figure 15.13.

(a) $W_{c1} = \dfrac{1}{R_L C_L}$ $C = 5\,nF.$ $\therefore R_L = \dfrac{1}{W_{c1} C_L} = \dfrac{1}{2\pi(1000)(5\times10^{-9})} = 31.83\,k\Omega$

$W_{c2} = \dfrac{1}{R_H C_H}$ $\therefore R_H = \dfrac{1}{W_{c2} C_H} = \dfrac{1}{2\pi(5000)(5\times10^{-9})} = 6.37\,k\Omega$

gain $20\log_{10}\left(\dfrac{R_f}{R_i}\right) = 10.$ $\therefore R_f = \sqrt{10}\,R_i$

choose $R_i = 31.83\,k\Omega$ (← Any value for R_i is ok)
→ $R_f = 100.66\,k\Omega$.

(b) The circuit diagram is shown above.

$R_L = 31.83\,k\Omega$. $C_L = 5\,nF$.
$R_H = 6.37\,k\Omega$. $C_H = 5\,nF$.
$R_i = 31.83\,k\Omega$.
$R_f = 100.66\,k\Omega$.

(c) i) LPF

$$H_L(s) = -\frac{Z_L}{R_L} \quad \left(Z_L = R_L \parallel \frac{1}{sC} = \frac{R_L/sC_L}{R_L + 1/sC_L} = \frac{R_L}{1+sR_LC_L} \right)$$

$$= -\frac{1}{R_L} \cdot \left(\frac{R_L}{1+sR_LC} \right)$$

$$= -\frac{1}{1+sR_LC} = \underline{\frac{-\omega_{c1}}{s+\omega_{c1}}} \qquad \left(\omega_{c1} = \frac{1}{R_LC_L} \right)$$

HPF

$$H_H(s) = -\frac{R_H}{Z_H} \quad \left(Z_H = \frac{1}{sC_H} + R_H \right)$$

$$= -\frac{R_H}{\frac{1}{sC_H} + R_H} = -\frac{sR_HC_H}{1+sR_HC_H} = \underline{-\frac{s}{s+\omega_{c2}}}$$

Summing filter

$$H_s(s) = -\frac{R_f}{R_i} = -\sqrt{10}$$

$$\therefore H(s) = \left(H_L(s) + H_H(s) \right) \cdot H_s(s)$$

$$= \left(\frac{2000\pi}{s+2000\pi} + \frac{s}{s+10000\pi} \right) \cdot \sqrt{10}$$

$$= \underline{\sqrt{10} \left(\frac{s^2 + 4000\pi s + 20\times10^6\pi^2}{(s+2000\pi)(s+10000\pi)} \right)}$$

(d) $\omega_0 = \sqrt{\omega_{c1}\omega_{c2}} = \sqrt{(2000\pi)(10000\pi)} = 2000\pi\sqrt{5}$ rad/s.

$$H(j\omega_0) = \sqrt{10}\, \frac{\cancel{-4\times10^6\pi^2\times5} + 4000\pi(j2000\pi\sqrt{5}) + \cancel{20\times10^6\pi^2}}{(2000\pi + j2000\pi\sqrt{5})(10000\pi + 2000\pi\sqrt{5})}$$

$$= \sqrt{10}\, \frac{\cancel{(2000\pi)^2} \times 2 \times j\sqrt{5}}{\cancel{2000\pi}(1+j\sqrt{5}) \times \cancel{2000\pi}(5+j\sqrt{5})}$$

$$= \frac{\sqrt{10}\times2\times j\sqrt{5}}{(1+j\sqrt{5})(5+j\sqrt{5})} = \frac{j2\cancel{\sqrt{5}}\sqrt{10}}{\cancel{5} + j6\cancel{\sqrt{5}} - \cancel{5}}$$

$$= \frac{2\sqrt{10}}{6} = \underline{1.054}$$

(e) from (d) gain = 1.05

$\therefore\ 20 \log_{10} 1.05 = \underline{0.46\ dB}$

(f) Bode plot