the figure. Note again that the greatest change in θ occurs at the corner frequencies, matching the regions of greatest change in the dB plot.

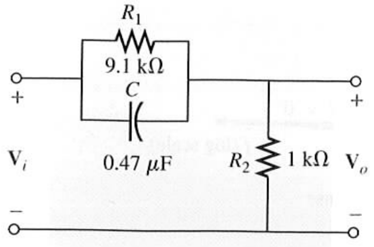


FIG. 21.75
Example 21.11.

EXAMPLE 21.11 For the filter in Fig. 21.75:

a. Sketch the curve of $A_{v_{dB}}$ versus frequency using a log scale.
b. Sketch the curve of θ versus frequency using a log scale.

Solutions:

a. For the break frequencies:

$$f_1 = \frac{1}{2\pi R_1 C} = \frac{1}{2\pi(9.1\text{ k}\Omega)(0.47\ \mu\text{F})} = \mathbf{37.2\ Hz}$$

$$f_c = \frac{1}{2\pi\left(\dfrac{R_1R_2}{R_1+R_2}\right)C} = \frac{1}{2\pi(0.9\text{ k}\Omega)(0.47\ \mu\text{F})} = \mathbf{376.25\ Hz}$$

The maximum low-level attenuation is

$$-20\log_{10}\frac{R_1+R_2}{R_2} = -20\log_{10}\frac{9.1\text{ k}\Omega + 1\text{ k}\Omega}{1\text{ k}\Omega}$$
$$= -20\log_{10}10.1 = \mathbf{-20.09\ dB}$$

The resulting plot appears in Fig. 21.76.

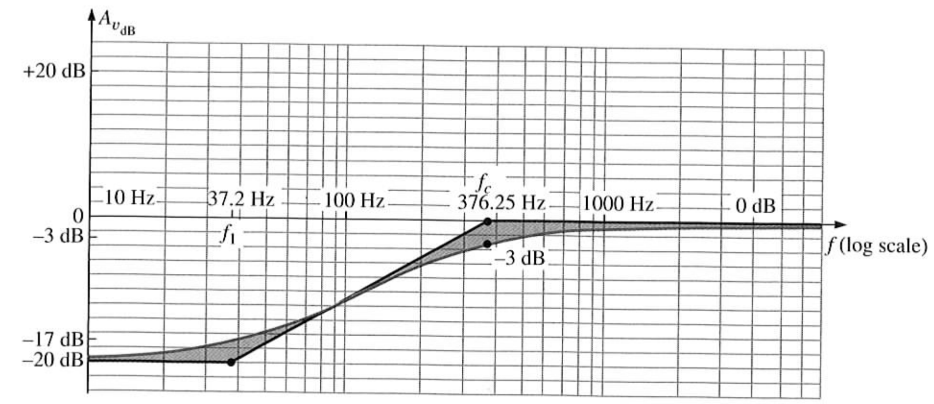


FIG. 21.76
$A_{v_{dB}}$ versus frequency for the filter in Fig. 21.75.

b. For the break frequencies:

At $f = f_1 = 37.2$ Hz,

$$\theta = -\tan^{-1}\frac{f_1}{f} + \tan^{-1}\frac{f_c}{f}$$
$$= -\tan^{-1}1 + \tan^{-1}\frac{376.25\text{ Hz}}{37.2\text{ Hz}}$$
$$= -45^\circ + 84.35^\circ$$
$$= \mathbf{39.35^\circ}$$

At $f = f_c = 376.26$ Hz,

$$\theta = -\tan^{-1}\frac{37.2\text{ Hz}}{376.26\text{ Hz}} + \tan^{-1}1$$
$$= -5.65^\circ + 45^\circ$$
$$= \mathbf{39.35^\circ}$$

At a frequency midway between f_c and f_1 on a log scale, for example, 120 Hz:

$$\theta = -\tan^{-1}\frac{37.2\text{ Hz}}{120\text{ Hz}} + \tan^{-1}\frac{376.26\text{ Hz}}{120\text{ Hz}}$$
$$= -17.22^\circ + 72.31^\circ$$
$$= \mathbf{55.09^\circ}$$

The resulting phase plot appears in Fig. 21.77.

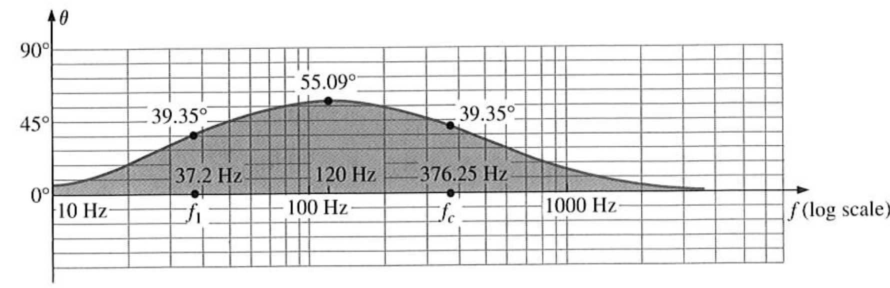


FIG. 21.77
θ (the phase angle associated with A_v) versus frequency for the filter in Fig. 21.75.

21.14 ADDITIONAL PROPERTIES OF BODE PLOTS

Bode plots are not limited to filters but can be applied to any system for which a dB-versus-frequency plot is desired. Although the previous sections did not cover all the functions that lend themselves to the idealized linear asymptotes, many of those most commonly encountered have been introduced.

We now examine some of the special situations that can develop that further demonstrate the adaptability and usefulness of the linear Bode approach to frequency analysis.

In all the situations described in this chapter, there was only one term in the numerator or denominator. For situations where there is more than one term, there will be an interaction between functions that must be examined and understood. In many cases, the use of Eq. (21.5) will prove useful. For example, if $\mathbf{A}_v$ has the format

$$\mathbf{A}_v = \frac{200(1 - jf_2/f)(jf/f_1)}{(1 - jf_1/f)(1 + jf/f_2)} = \frac{(a)(b)(c)}{(d)(e)} \qquad \textbf{(21.50)}$$

we can expand the function in the following manner:

$$A_{v_{dB}} = 20\log_{10}\frac{(a)(b)(c)}{(d)(e)}$$
$$= 20\log_{10}a + 20\log_{10}b + 20\log_{10}c - 20\log_{10}d - 20\log_{10}e$$

revealing that the net or resultant dB level is equal to the algebraic sum of the contributions from all the terms of the original function. We can, therefore, add algebraically the linearized Bode plots of all the terms in each frequency interval to determine the idealized Bode plot for the full function.

If two terms happen to have the same format and corner frequency, as in the function

$$\mathbf{A}_v = \frac{1}{(1 - jf_1/f)(1 - jf_1/f)}$$

the function can be rewritten as

$$\mathbf{A}_v = \frac{1}{(1 - jf_1/f)^2}$$

so that

$$A_{v_{dB}} = 20 \log_{10} \frac{1}{(\sqrt{1 + (f_1/f)^2})^2} = -20 \log_{10}(1 + (f_1/f)^2)$$

for $f << f_1$, $(f_1/f)^2 >> 1$, and

$$A_{v_{dB}} = -20 \log_{10}(f_1/f)^2 = -40 \log_{10} f_1/f$$

versus the $-20 \log_{10}(f_1/f)$ obtained for a single term in the denominator. The resulting dB asymptote will drop, therefore, at a rate of -12 dB/octave (-40 dB/decade) for decreasing frequencies rather than -6 dB/octave. The corner frequency is the same, and the high-frequency asymptote is still at 0 dB. The idealized Bode plot for the above function is provided in Fig. 21.78.

Note the steeper slope of the asymptote and the fact that the actual curve now passes -6 dB below the corner frequency rather than -3 dB, as for a single term.

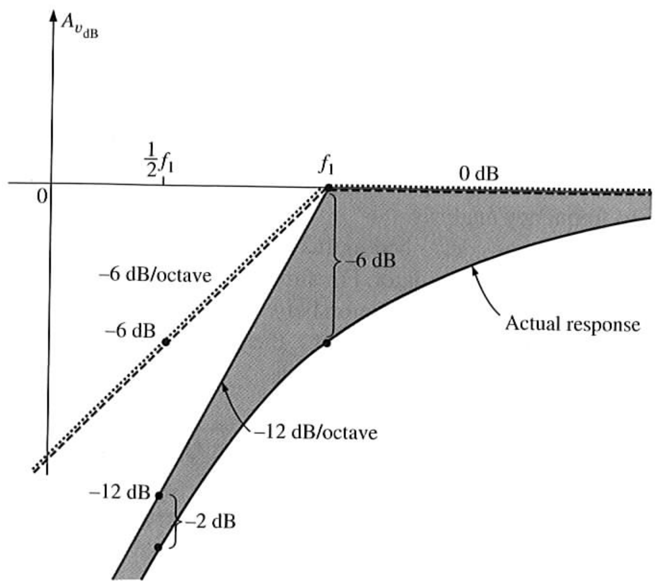


FIG. 21.78

Plotting the linearized Bode plot of $\frac{1}{(1 - j(f_1/f))^2}$.

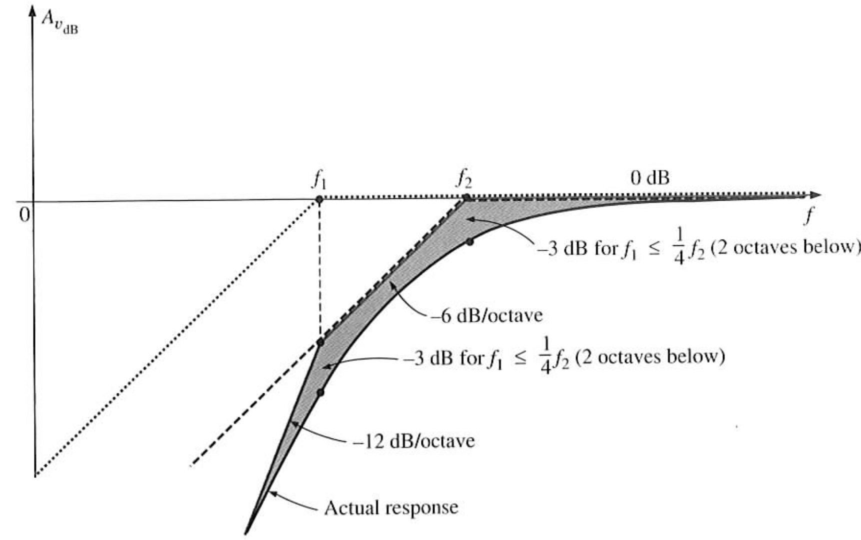


FIG. 21.79

Plot of $A_{v_{dB}}$ *for* $\frac{1}{(1 - j(f_1/f))(1 - j(f_2/f))}$ *with* $f_1 < f_2$.

Keep in mind that if the corner frequencies of the two terms in the numerator or denominator are close but not exactly equal, the total dB drop is the algebraic sum of the contributing terms of the expansion. For instance, consider the linearized Bode plot in Fig. 21.79 with corner frequencies f_1 and f_2.

In region 3, both asymptotes are 0 dB, resulting in an asymptote at 0 dB for frequencies greater than f_2. For region 2, one asymptote is at 0 dB, whereas the other drops at -6 dB/octave for decreasing frequencies. The net result for this region is an asymptote dropping at -6 dB, as shown in the same figure. At f_1, we find two asymptotes dropping off at -6 dB for decreasing frequencies. The result is an asymptote dropping off at -12 dB/octave for this region.

If f_1 and f_2 are at least two octaves apart, the effect of one on the plotting of the actual response for the other can almost be ignored. In other words, for this example, if $f_1 < \frac{1}{4}f_2$, the actual response is down -3 dB at $f = f_2$ and f_1.

The above discussion can be expanded for any number of terms at the same frequency or in the same region. For three equal terms in the denominator, the asymptote will drop at -18 dB/octave, and so on. Eventually, the procedure will become self-evident and relatively straightforward to apply. In many cases, the hardest part of finding a solution is to put the original function in the desired form.

EXAMPLE 21.12 A transistor amplifier has the following gain:

$$\mathbf{A}_v = \frac{100}{\left(1 - j\frac{50\text{ Hz}}{f}\right)\left(1 - j\frac{200\text{ Hz}}{f}\right)\left(1 + j\frac{f}{10\text{ kHz}}\right)\left(1 + j\frac{f}{20\text{ kHz}}\right)}$$

a. Sketch the normalized response $A'_v = A_v/A_{v_{max}}$, and determine the bandwidth of the amplifier.
b. Sketch the phase response, and determine a frequency where the phase angle is close to 0°.

Solutions:

a. $A'_v = \dfrac{A_v}{A_{v_{max}}} = \dfrac{A_v}{100}$

$$= \frac{1}{\left(1 - j\dfrac{50\text{ Hz}}{f}\right)\left(1 - j\dfrac{200\text{ Hz}}{f}\right)\left(1 + j\dfrac{f}{10\text{ kHz}}\right)\left(1 + j\dfrac{f}{20\text{ kHz}}\right)}$$

$$= \frac{1}{(a)(b)(c)(d)} = \left(\frac{1}{a}\right)\left(\frac{1}{b}\right)\left(\frac{1}{c}\right)\left(\frac{1}{d}\right)$$

and

$$A'_{v_{dB}} = -20\log_{10} a - 20\log_{10} b - 20\log_{10} c - 20\log_{10} d$$

clearly substantiating the fact that the total number of decibels is equal to the algebraic sum of the contributing terms.

A careful examination of the original function reveals that the first two terms in the denominator are high-pass filter functions, whereas the last two are low-pass functions. Fig. 21.80 demonstrates how the combination of the two types of functions defines a bandwidth for the amplifier. The high-frequency filter functions have defined the low cutoff frequency, and the low-frequency filter functions have defined the high cutoff frequency.

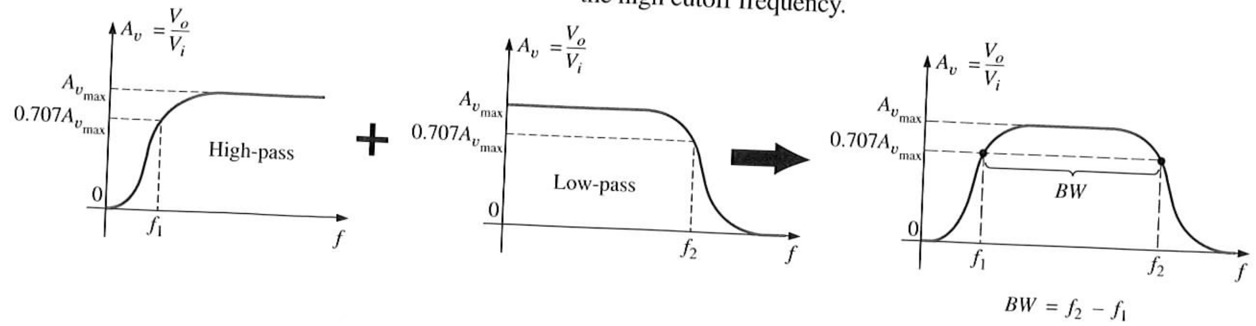


FIG. 21.80
Finding the overall gain versus frequency for Example 21.12.

Plotting all the idealized Bode plots on the same axis results in the plot in Fig. 21.81. Note for frequencies less than 50 Hz that the result-

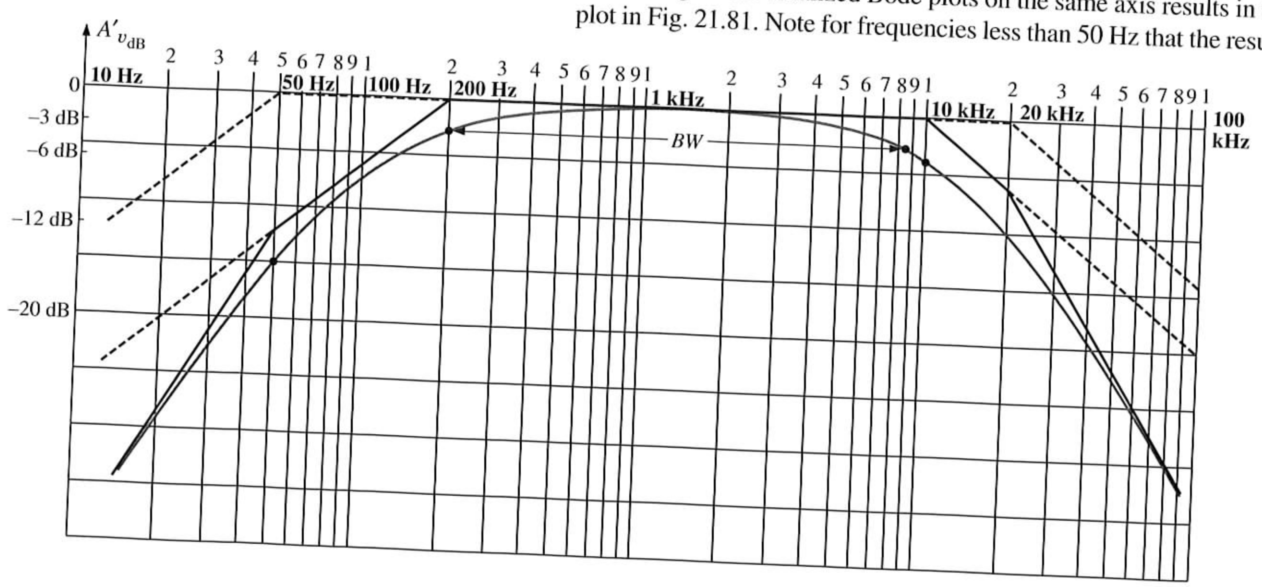


FIG. 21.81
$A'_{v_{dB}}$ versus frequency for Example 21.12.

ing asymptote drops off at −12 dB/octave. In addition, since 50 Hz and 200 Hz are separated by two octaves, the actual response will be down by only about −3 dB at the corner frequencies of 50 Hz and 200 Hz.

For the high-frequency region, the corner frequencies are not separated by two octaves, and the difference between the idealized plot and the actual Bode response must be examined more carefully. Since 10 kHz is one octave below 20 kHz, we can use the fact that the difference between the idealized response and the actual response for a single corner frequency is 1 dB. If we add an additional −1 dB drop due to the 20 kHz corner frequency to the −3 dB drop at $f = 10$ kHz, we can conclude that the drop at 10 kHz will be −4 dB, as shown on the plot. To check the conclusion, let us write the full expression for the dB level at 10 kHz and find the actual level for comparison purposes.

$$A'_{v_{dB}} = -20\log_{10}\sqrt{1 + \left(\frac{50\text{ Hz}}{10\text{ kHz}}\right)^2} - 20\log_{10}\sqrt{1 + \left(\frac{200\text{ Hz}}{10\text{ kHz}}\right)^2}$$
$$- 20\log_{10}\sqrt{1 + \left(\frac{10\text{ kHz}}{10\text{ kHz}}\right)^2} - 20\log_{10}\sqrt{1 + \left(\frac{10\text{ kHz}}{20\text{ kHz}}\right)^2}$$
$$= -0.00011\text{ dB} - 0.0017\text{ dB} - 3.01\text{ dB} - 0.969\text{ dB}$$
$$= -3.98\text{ dB} \cong \mathbf{-4\text{ dB}} \qquad \text{as before}$$

An examination of the above calculations reveals that the last two terms predominate in the high-frequency region and essentially eliminate the need to consider the first two terms in that region. For the low-frequency region, examining the first two terms is sufficient.

Proceeding in a similar fashion, we find a −4 dB difference at $f = 20$ kHz, resulting in the actual response appearing in Fig. 21.81. Since the bandwidth is defined at the −3 dB level, a judgment must be made as to where the actual response crosses the −3 dB level in the high-frequency region. A rough sketch suggests that it is near 8.5 kHz. Plugging this frequency into the high-frequency terms results in

$$A'_{v_{dB}} = -20\log_{10}\sqrt{1 + \left(\frac{8.5\text{ kHz}}{10\text{ kHz}}\right)^2} - 20\log_{10}\sqrt{1 + \left(\frac{8.5\text{ kHz}}{20\text{ kHz}}\right)^2}$$
$$= -2.148\text{ dB} - 0.645\text{ dB} \cong \mathbf{-2.8\text{ dB}}$$

which is relatively close to the −3 dB level, and

$$BW = f_{high} - f_{low} = 8.5\text{ kHz} - 200\text{ Hz} = \mathbf{8.3\text{ kHz}}$$

In the midrange of the bandwidth, $A'_{v_{dB}}$ approaches 0 dB. At $f =$ 1 kHz:

$$A'_{v_{dB}} = -20\log_{10}\sqrt{1 + \left(\frac{50\text{ Hz}}{1\text{ kHz}}\right)^2} - 20\log_{10}\sqrt{1 + \left(\frac{200\text{ Hz}}{1\text{ kHz}}\right)^2}$$
$$- 20\log_{10}\sqrt{1 + \left(\frac{1\text{ kHz}}{10\text{ kHz}}\right)^2} - 20\log_{10}\sqrt{1 + \left(\frac{1\text{ kHz}}{20\text{ kHz}}\right)^2}$$
$$= -0.0108\text{ dB} - 0.1703\text{ dB} - 0.0432\text{ dB} - 0.0108\text{ dB}$$
$$= \mathbf{-0.235\text{ dB}} \cong \mathbf{-\frac{1}{5}\text{dB}}$$

which is certainly close to the 0 dB level, as shown on the plot.

b. The phase response can be determined by substituting a number of key frequencies into the following equation, derived directly from the original function $\mathbf{A}_v$:

$$\theta = \tan^{-1}\frac{50\text{ Hz}}{f} + \tan^{-1}\frac{200\text{ Hz}}{f} - \tan^{-1}\frac{f}{10\text{ kHz}} - \tan^{-1}\frac{f}{20\text{ kHz}}$$

However, let us make full use of the asymptotes defined by each term of $\mathbf{A}_v$ and sketch the response by finding the resulting phase angle at critical points on the frequency axis. The resulting asymptotes and phase plot are provided in Fig. 21.82. Note that at $f = 50$ Hz, the sum of the two angles determined by the straight-line asymptotes is $45° + 75° = 120°$ (actual $= 121°$). At $f = 1$ kHz, if we subtract 5.7° for one corner frequency, we obtain a net angle of $14° - 5.7° \cong 8.3°$ (actual $= 5.6°$).

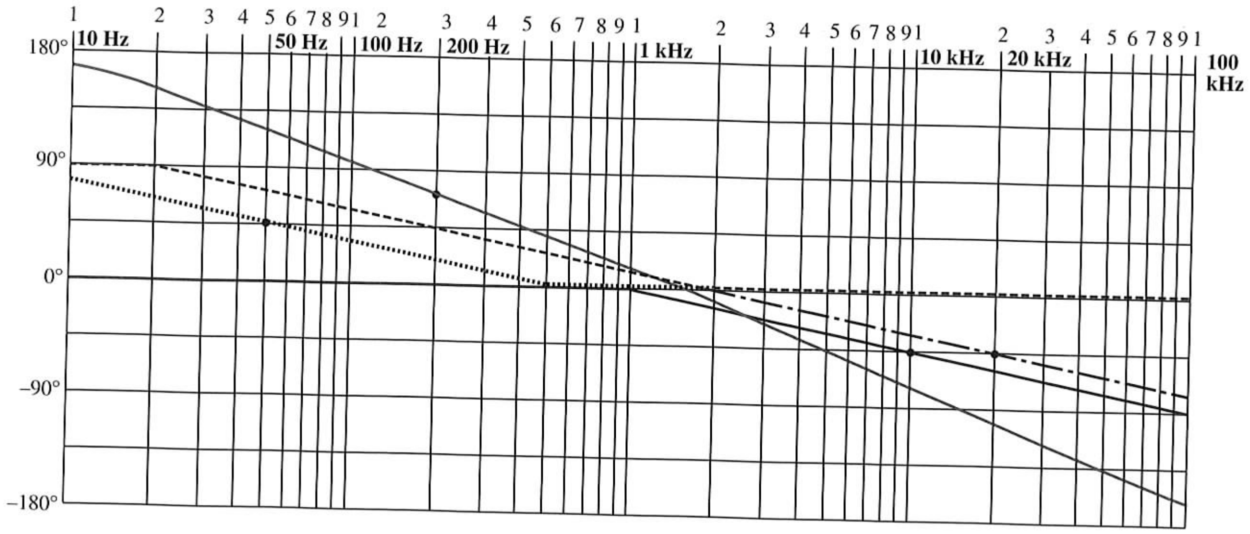


FIG. 21.82
Phase response for Example 21.12.

At 10 kHz, the asymptotes leave us with $\theta \cong -45° - 32° = -77°$ (actual $= -71.56°$). The net phase plot appears to be close to 0° at about 1300 Hz. To check on our assumptions and the use of the asymptotic approach, plug in $f = 1300$ Hz into the equation for θ:

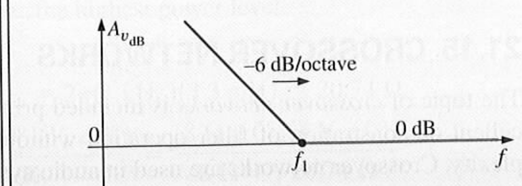
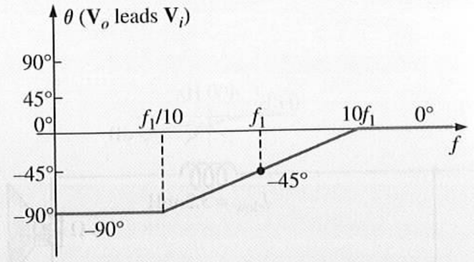
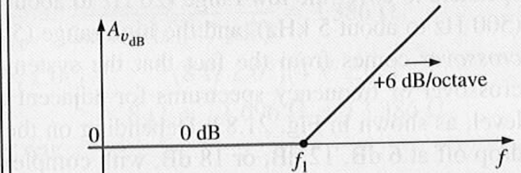
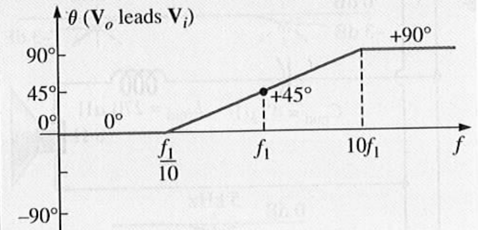
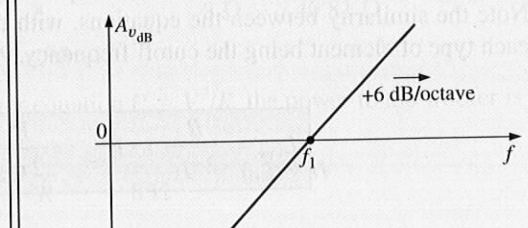
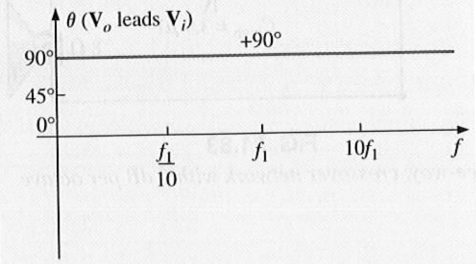
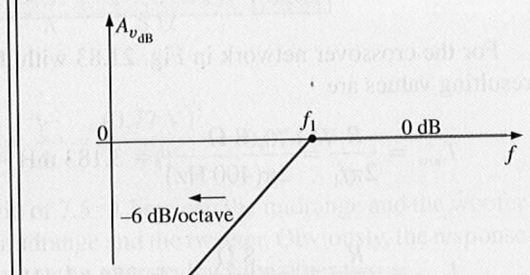
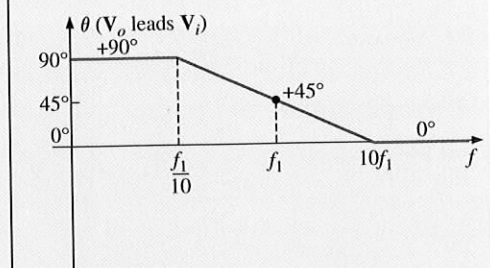
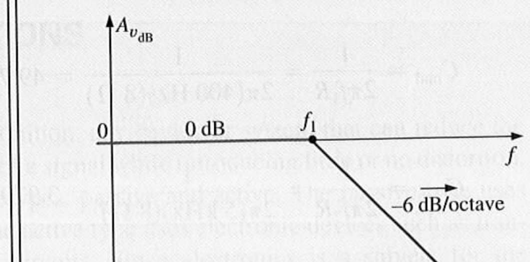
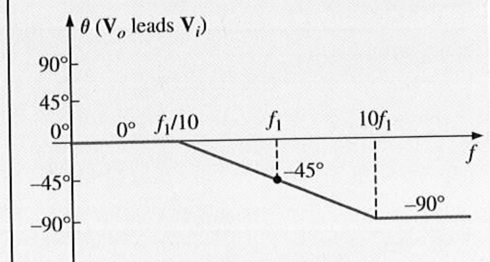
$$\theta = \tan^{-1}\frac{50\text{ Hz}}{1300\text{ Hz}} + \tan^{-1}\frac{200\text{ Hz}}{1300\text{ Hz}} - \tan^{-1}\frac{1300\text{ Hz}}{10\text{ kHz}} - \tan^{-1}\frac{1300\text{ Hz}}{20\text{ kHz}}$$
$$= 2.2° + 8.75° - 7.41° - 3.72°$$
$$= -0.18° \cong 0° \quad \text{as predicted}$$

In total, the phase plot appears to shift from a positive angle of 180° ($\mathbf{V}_o$ leading $\mathbf{V}_i$) to a negative angle of 180° as the frequency spectrum extends from very low frequencies to high frequencies. In the midregion, the phase plot is close to 0° ($\mathbf{V}_o$ in phase with $\mathbf{V}_i$), much like the response to a common-base transistor amplifier.

Table 21.2 consolidates some of the material introduced in this chapter and provides a reference for future investigations. It includes the linearized dB and phase plots for the functions appearing in the first column. There are many other functions, but these provide a foundation to which others can be added.

Reviewing the development of the filters in Sections 21.12 and 21.13 shows that establishing the function $\mathbf{A}_v$ in the proper form is the most

TABLE 21.2
Idealized Bode plots for various functions.

Function	dB Plot	Phase Plot
$\mathbf{A}_v = 1 - j\frac{f_1}{f}$		
$\mathbf{A}_v = 1 + j\frac{f}{f_1}$		
$\mathbf{A}_v = j\frac{f}{f_1}$		
$\mathbf{A}_v = \frac{1}{1 - j\frac{f_1}{f}}$		
$\mathbf{A}_v = \frac{1}{1 + j\frac{f}{f_1}}$		

26. For the high-pass filter in Fig. 21.103:
 a. Determine f_c.
 b. Find $A_v = V_o/V_i$ at $f = 0.01f_c$, and compare to the minimum level of 0 for the low-frequency region.
 c. Find $A_v = V_o/V_i$ at $f = 100f_c$, and compare to the maximum level of 1 for the high-frequency region.
 d. Determine the frequency at which $V_o = \frac{1}{2}V_i$.

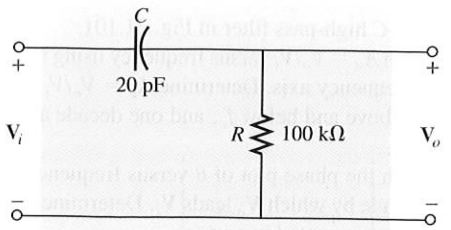


FIG. 21.103
Problems 26 and 54.

SECTION 21.7 Pass-Band Filters

27. For the pass-band filter in Fig. 21.104:
 a. Sketch the frequency response of $A_v = V_o/V_i$ against a log scale extending from 10 Hz to 10 kHz.
 b. What are the bandwidth and the center frequency?

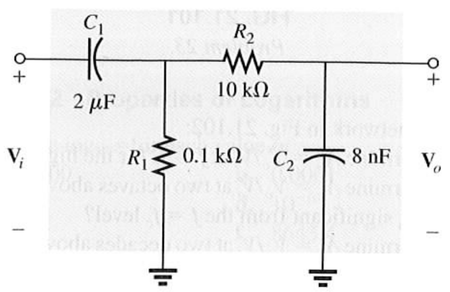


FIG. 21.104
Problems 27 and 28.

*28. Design a pass-band filter such as the one appearing in Fig. 21.104 to have a low cutoff frequency of 4 kHz and a high cutoff frequency of 80 kHz.

29. For the pass-band filter in Fig. 21.105:
 a. Determine f_s.
 b. Calculate Q_s and the BW for $\mathbf{V}_o$.

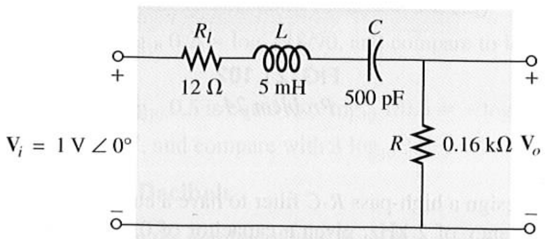


FIG. 21.105
Problem 29.

 c. Sketch $A_v = V_o/V_i$ for a frequency range of 1 kHz to 1 MHz.
 d. Find the magnitude of V_o at $f = f_s$ and the cutoff frequencies.

30. For the pass-band filter in Fig. 21.106:
 a. Determine the frequency response of $A_v = V_o/V_i$ for a frequency range of 100 Hz to 1 MHz.
 b. Find the quality factor Q_p and the BW of the response.

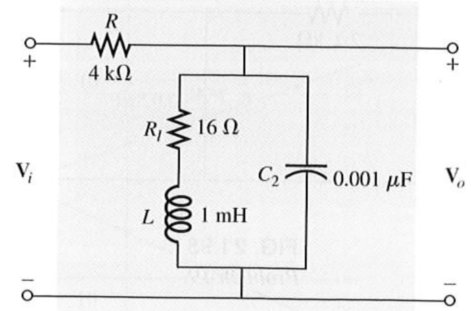


FIG. 21.106
Problems 30 and 55.

SECTION 21.8 Stop-Band Filters

*31. For the stop-band filter in Fig. 21.107:
 a. Determine Q_s.
 b. Find the bandwidth and the half-power frequencies.
 c. Sketch the frequency characteristics of $A_v = V_o/V_i$.
 d. What is the effect on the curve of part (c) if a load of 2 kΩ is applied?

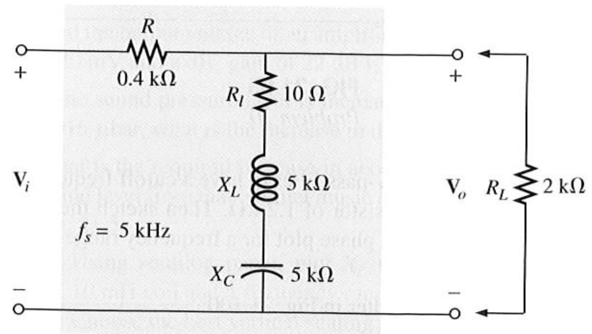


FIG. 21.107
Problem 31.

*32. For the pass-band filter in Fig. 21.108:
 a. Determine Q_p ($R_L = \infty$ Ω, an open circuit).
 b. Sketch the frequency characteristics of $A_v = V_o/V_i$.
 c. Find Q_p (loaded) for R_L = 100 kΩ, and indicate the effect of R_L on the characteristics of part (b).
 d. Repeat part (c) for R_L = 20 kΩ.

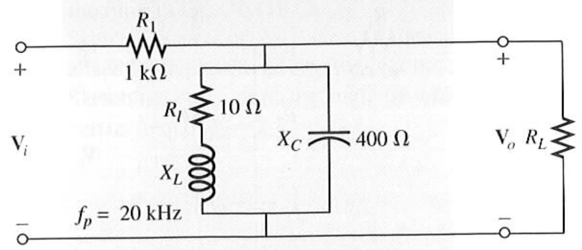


FIG. 21.108
Problem 32.

SECTION 21.9 Double-Tuned Filter

33. a. For the network in Fig. 21.43(a), if L_p = 400 μH (Q > 10), L_s = 60 μH, and C = 120 pF, determine the rejected and accepted frequencies.
 b. Sketch the response curve for part (a).

34. a. For the network in Fig. 21.43(b), if the rejected frequency is 30 kHz and the accepted is 100 kHz, determine the values of L_s and L_p (Q > 10) for a capacitance of 200 pF.
 b. Sketch the response curve for part (a).

SECTION 21.10 Bode Plots

35. a. Sketch the idealized Bode plot for $A_v = V_o/V_i$ for the high-pass filter in Fig. 21.109.
 b. Using the results of part (a), sketch the actual frequency response for the same frequency range.
 c. Determine the decibel level at f_c, $\frac{1}{2}f_c$, $2f_c$, $\frac{1}{10}f_c$, and $10f_c$.
 d. Determine the gain $A_v = V_o/V_i$ as $f = f_c$, $\frac{1}{2}f_c$, and $2f_c$.
 e. Sketch the phase response for the same frequency range.

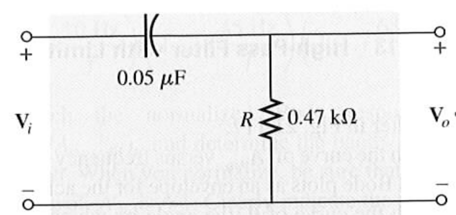


FIG. 21.109
Problem 35.

*36. a. Sketch the response of the magnitude of V_o (in terms of V_i) versus frequency for the high-pass filter in Fig. 21.110.
 b. Using the results of part (a), sketch the response $A_v = V_o/V_i$ for the same frequency range.
 c. Sketch the idealized Bode plot.
 d. Sketch the actual response, indicating the dB difference between the idealized and the actual response at $f = f_c$, $0.5f_c$, and $2f_c$.
 e. Determine $A_{v_{dB}}$ at $f = 1.5f_c$ from the plot of part (d), and then determine the corresponding magnitude of $A_v = V_o/V_i$.
 f. Sketch the phase response for the same frequency range (the angle by which $\mathbf{V}_o$ leads $\mathbf{V}_i$).

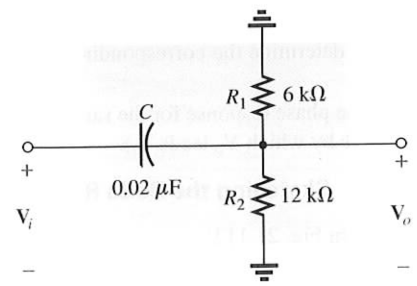


FIG. 21.110
Problem 36.

37. a. Sketch the idealized Bode plot for $A_v = V_o/V_i$ for the low-pass filter in Fig. 21.111.
 b. Using the results of part (a), sketch the actual frequency response for the same frequency range.
 c. Determine the decibel level at f_c, $\frac{1}{2}f_c$, $2f_c$, $\frac{1}{10}f_c$, and $10f_c$.
 d. Determine the gain $A_v = V_o/V_i$ at $f = f_c$, $\frac{1}{2}f_c$, and $2f_c$.
 e. Sketch the phase response for the same frequency range.

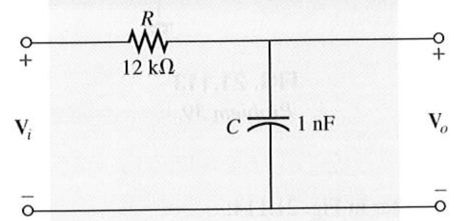


FIG. 21.111
Problem 37.

*38. a. Sketch the response of the magnitude of V_o (in terms of V_i) versus frequency for the low-pass filter in Fig. 21.112.
 b. Using the results of part (a), sketch the response $A_v = V_o/V_i$ for the same frequency range.
 c. Sketch the idealized Bode plot.
 d. Sketch the actual response indicating the dB difference between the idealized and the actual response at $f = f_c$, $0.5f_c$, and $2f_c$.

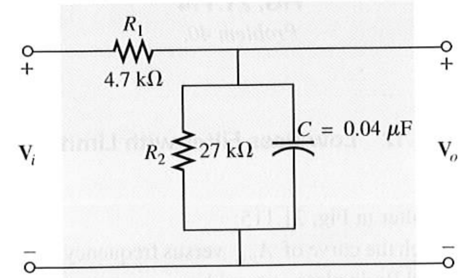


FIG. 21.112
Problem 38.

e. Determine $A_{v_{dB}}$ at $f = 0.25f_c$ from the plot of part (d), and then determine the corresponding magnitude of $A_v = V_o/V_i$.

f. Sketch the phase response for the same frequency range (the angle by which $\mathbf{V}_o$ leads $\mathbf{V}_i$).

SECTION 21.11 Sketching the Bode Response

39. For the filter in Fig. 21.113:

a. Sketch the curve of $A_{v_{dB}}$ versus frequency using a log scale.

b. Sketch the curve of θ versus frequency for the same frequency range as in part (a).

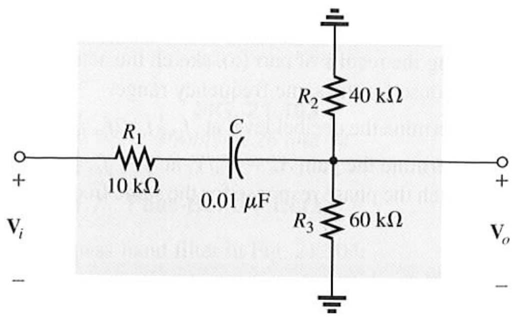


FIG. 21.113
Problem 39.

***40.** For the filter in Fig. 21.114:

a. Sketch the curve of $A_{v_{dB}}$ versus frequency using a log scale.

b. Sketch the curve of θ versus frequency for the same frequency range as in part (a).

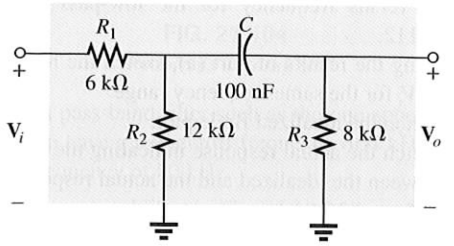


FIG. 21.114
Problem 40.

SECTION 21.12 Low-Pass Filter with Limited Attenuation

41. For the filter in Fig. 21.115:

a. Sketch the curve of $A_{v_{dB}}$ versus frequency using the idealized Bode plots as a guide.

b. Sketch the curve of θ versus frequency.

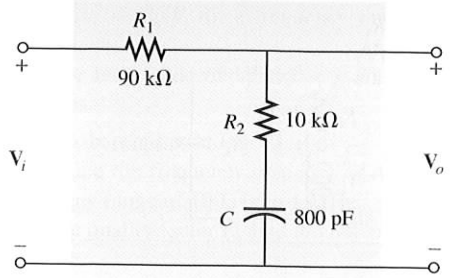


FIG. 21.115
Problem 41.

***42.** For the filter in Fig. 21.116:

a. Sketch the curve of $A_{v_{dB}}$ versus frequency using the idealized Bode plots as a guide.

b. Sketch the curve of θ versus frequency.

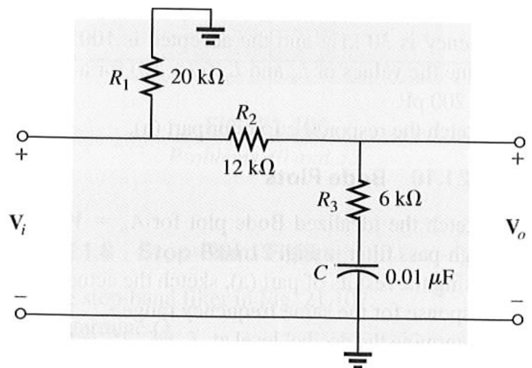


FIG. 21.116
Problem 42.

SECTION 21.13 High-Pass Filter with Limited Attenuation

43. For the filter in Fig. 21.117:

a. Sketch the curve of $A_{v_{dB}}$ versus frequency using the idealized Bode plots as an envelope for the actual response.

b. Sketch the curve of θ (the angle by which $\mathbf{V}_o$ leads $\mathbf{V}_i$) versus frequency.

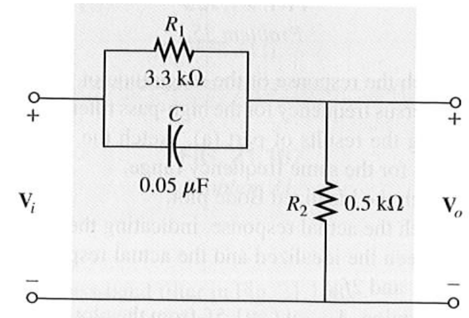


FIG. 21.117
Problem 43.

***44.** For the filter in Fig. 21.118:

a. Sketch the curve of $A_{v_{dB}}$ versus frequency using the idealized Bode plots as an envelope for the actual response.

b. Sketch the curve of θ (the angle by which $\mathbf{V}_o$ leads $\mathbf{V}_i$) versus frequency.

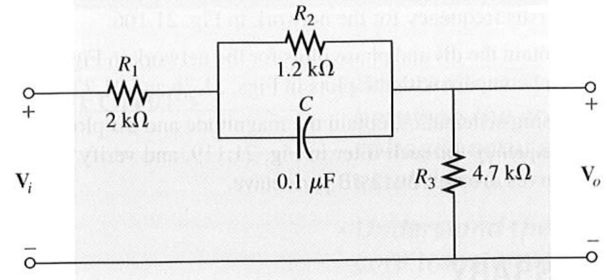


FIG. 21.118
Problem 44.

SECTION 21.14 Additional Properties of Bode Plots

45. A bipolar transistor amplifier has the following gain:

$$\mathbf{A}_v = \frac{160}{\left(1 - j\frac{100\text{ Hz}}{f}\right)\left(1 - j\frac{130\text{ Hz}}{f}\right)\left(1 + j\frac{f}{20\text{ kHz}}\right)\left(1 + j\frac{f}{50\text{ kHz}}\right)}$$

a. Sketch the normalized Bode response $A'_{v_{dB}} = (A_v/A_{v_{max}})|_{dB}$, and determine the bandwidth of the amplifier. Be sure to note the corner frequencies.

b. Sketch the phase response, and determine a frequency where the phase angle is relatively close to 45°.

46. A JFET transistor amplifier has the following gain:

$$\mathbf{A}_v = \frac{-5.6}{\left(1 - j\frac{10\text{ Hz}}{f}\right)\left(1 - j\frac{45\text{ Hz}}{f}\right)\left(1 - j\frac{68\text{ Hz}}{f}\right)\left(1 + j\frac{f}{23\text{ kHz}}\right)\left(1 + j\frac{f}{50\text{ kHz}}\right)}$$

a. Sketch the normalized Bode response $A'_{v_{dB}} = (A_v/A_{v_{max}}|_{dB})$, and determine the bandwidth of the amplifier. When you normalize, be sure that the maximum value of A'_v is $+1$. Clearly indicate the cutoff frequencies on the plot.

b. Sketch the phase response, and note the regions of greatest change in phase angle. How do the regions correspond to the frequencies appearing in the function $\mathbf{A}_v$?

47. A transistor amplifier has a midband gain of -120, a high cutoff frequency of 36 kHz, and a bandwidth of 35.8 kHz. In addition, the actual response is also about -15 dB at $f = 50$ Hz. Write the transfer function $\mathbf{A}_v$ for the amplifier.

48. Sketch the Bode plot of the following function:

$$\mathbf{A}_v = \frac{0.05}{0.05 - j\,100/f}$$

49. Sketch the Bode plot of the following function:

$$\mathbf{A}_v = \frac{200}{200 + j\,0.1f}$$