Solution Manual for Electronics A Physical Approach 1st Edition by Snoke
ISBN 0321551338 9780321551337

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Chapter 2 Exercises

2.1

The electric eld outside a charged sphere is the same as for a point source,

$$E(r) = \frac{Q}{4 \quad {}_0 r^2};$$

where Q is the charge on the inner surface of radius a. The potential drop is the integral

$$V = \int_b^a \frac{Q}{4 \quad {}_0 r^2} dr = \frac{Q}{4 \quad {}_0} \quad \frac{1}{a} \quad \frac{1}{b} :$$

The capacitance is therefore

$$C = \frac{Q}{V} = 4 \quad {}_0 \frac{ab}{b \quad a}$$

This is inversely proportional to the resistance found in Exercise 1.4.

2.2

The planar capacitor formula is

$$C = \frac{A \quad {}_0}{d}:$$

Solving for A,

$$A = \frac{Cd}{{}_0} = \frac{(1\ F)(10 \quad {}^9\ m)}{10(8:85 \quad 10^{12}\ C^2=N^2 \quad m^2)} = 1:1\ m^2 :$$

2.3

The solenoid inductor formula is

$$L = \frac{A \quad {}_0 N^2}{l}:$$

The loop area is $A \quad (5\ cm^2) = 76\ cm^2 = 7:6 \quad 10^{\ 3}\ m^2$. The density of coils is $N=l$ (6 4)=(:05)(2 (:05 m)) = 2:5 10 /m.

Solving for l,

$$l = \frac{L}{A \quad {}_0 (N=l)^2} = \frac{1\ H}{(7:6 \quad 10^{\ 3}\ m^2)(4 \quad 10^{\ 7}\ N=A^2)(2:5 \quad 10^4=m)^2} = 17\ cm:$$

2.4

Integrate the ux over a rectangular section between the wires of length l. The magnetic eld from a wire is

$$B = \frac{{}_{0} I}{2\,r} :$$

14

The ux from one wire is

$$= l \int_b^a \frac{{}_0 I}{2 r} dr = \frac{{}_0 Il}{2} \ln(a=b):$$

The second wire contributes ux in the same direction, so the total ux is

$$_{tot} = \frac{{}_0 Il}{} \ln(b=a):$$

The voltage drop is

$$V = \frac{@}{@t} {}_{tot} = \frac{{}_0 l}{} \ln(a=b) \frac{@I}{@t}:$$

Therefore

$$L = \frac{{}_0 l}{} \ln(a=b):$$

[Note: Technically we should account for the magnetic eld inside each wire. The current inside the radius r is $Ir^2=b^2$. $B(2 r) = {}_0 Ir^2=b^2$, so

$$B = \frac{{}_0 rI}{2 b^2}$$

inside the wire. The integral of the ux is inside the wire is

$$= l \int_0^b \frac{{}_0 rI}{2 b^2} = l \frac{{}_0 I}{4}:$$

The contribution to the inductance L from both wires is then

$$L^0 = \frac{{}_0 l}{2}:$$

which implies $L=L^0 = 2 \ln(a=b)$, which means the eld inside the wire is negligible if a b.]

2.5

The Biot-Savart law is

$$d\tilde{B}(\tilde{r}) = \frac{{}_0}{4} \frac{I d\tilde{l} \quad \tilde{R}}{R^3}:$$

For a loop of radius L centered at (0,0), the unit vector along $d\tilde{l}$ is

$$\hat{} = \hat{x} \sin + \hat{y} \cos :$$

The distance from a point of the circle to a point r on the x-axis is

$$R = jL(\cos ; \sin) \quad (r; 0)j = \sqrt{(L \cos \quad r)^2 + L^2 \sin^2}$$

The direction of $\tilde{R}$ is

$$\hat{R} = \frac{L(\cos ; \sin) \quad (r; 0)}{R} = \frac{1}{R}(\hat{x}(L \cos \quad r) + \hat{y}L \sin):$$

The cross product is

$$\hat{} \quad \hat{R} = \frac{\hat{z}}{R}(r\cos \quad L):$$

The integral of the Biot-Savart element is then

$$\tilde{B} = \frac{{}_0 I \hat{z}}{4 \; 0} \int^{2} Ld \frac{r\cos \quad L}{[(L\cos \quad r)^2 + L^2\sin^2 \;]^{3=2}}$$

This function involves elliptic integrals. Doing it numerically for r = 0 (the center of the loop), gives

$$\tilde{B} = \frac{{}_0 I \hat{z}}{4L};$$

while at r = L=2, it is

$$\tilde{B} = (3{:}91 = \;) \frac{{}_0 I \hat{z}}{4L}:$$

2.6

$$V_o = IR = RC \frac{@}{@t}(V \quad V_o) = RC \frac{@V_0}{@t}:$$

This has the solution

$$V_o(t) = V e^{\;t=RC}:$$

2.7

Kirchho :

$$0 = RC \frac{@V_0}{@t} + V_o:$$

This has the general solution

$$V_o(t) = V_1 e^{\;t=RC} + V_2:$$

Setting this to V at t = t_0 gives

$$V = V_1 e^{\;t_0=RC} + V_2:$$

The current through the capacitor is

$$I(t_0) = \frac{V}{\;} = C \frac{@}{\;}(V_1 e^{\;t=RC} + V_2 R)_{t=t_0} \qquad \frac{V_1}{\;} \; t_0=RC$$

which implies $V_1 = V e^{\;t_0=RC}$. Plugging this into the above gives $V_2 = 0$, so the solution is

$$V_o(t) = V e^{\;(t \; t_0)=RC}:$$

This is decay to zero with the same time constant RC.

2.8

The integrator circuit of Figure 2.16(a) is governed by equation (2.4.13),

$$V_o + RC\bar{V}_o = V_i:$$

For V_o = sin !t, this implies

$$\sin !t + !RC \cos !t = V_i:$$

When !RC 1, the sin !t term is negligible, and V_i is proportional to $\bar{V}_o$, i.e., V_o is proportional to the antiderivative of V_i.

The di erentiator circuit of Figure 2.16(b) is governed by equation (2.4.17), V

For V_o = sin !t, this implies

$$! \ \cos !t + \frac{1}{RC} \sin !t = \bar{V}_i:$$

When !RC 1, the cos !t term is negligible, and $\bar{V}_i$ is proportional to V_o, i.e., V_o is proportional to the derivative of V_i.

2.9

This is the circuit shown in Fig. 2.18(b). We have

$$\frac{V_0}{V_i} = \frac{R}{R+Z_C} = \frac{R}{R \quad i=!C}$$

$$\frac{V_0}{}^{\,2} \quad \frac{R}{} \quad \frac{R}{} \quad \frac{R^2}{} \quad \frac{1}{} :$$

2.10

$$\frac{V_0}{V_i} = \frac{Z_L}{R+Z_L} = \frac{i!L}{R + i!L}$$

This is a high-pass lter.

2.11 From Exercise 2.9, we have

$$\frac{V_0}{}^{\,2} \quad \frac{1}{}$$

Solve for !:

$$! = RC \;\; jV_o=V_ij^2 \quad \frac{1}{} \quad \frac{1}{} \quad 1^{!} \;\; 1=2$$

a)

$$3 \text{ dB} = 10 \log_{10} jV_o{=}V_ij^2$$

$$jV_o{=}V_ij^2 = 10^{:3} = 0{:}5 \ ! \ ! = 1{=}RC$$

b)

$$jV_o{=}V_ij^2 = 10^{\ 1} = 0{:}1 \ ! \ ! = 1{=}3RC$$

c)

$$jV_o{=}V_ij^2 = 10^{\ 2} = 0{:}01 \ ! \ ! = 1{=}10RC$$

2.12

a)

$$10 \text{ dBm} = 20 \log_{10}(V{=}V_0)$$

$$\frac{V}{V_0} = 10^{1=2}$$

$$V = 3{:}1V_0 {=} 1V$$

$$P = \frac{V^2}{2R} = 10 \text{ mW:}$$

We could also have done this just by noting that 10 dBm is 10 times greater than 0 dBm. b)

$$35 \text{ dB} = 20 \log_{10} V_2{=}V_1$$

$$\frac{V_2}{V_1} = 10^{35=20} = 56$$

2.13

$$\sin !t = \frac{e^{i!t} \ \ e^{\ i!t}}{2i}$$

From (2.7.11),

$$F(!^0) = 2 \ \frac{(!^0 \qquad !) \ \ (!^0 + !)}{2i}$$

2.14

f(t) is given by (note typo in book)

$$f(t) = \left(\begin{array}{ll} 0; & (n \quad 1{=}2)T < t < nT: \\ 1; & (n \ \ 1)T < t < (n \ \ 1{=}2)T \end{array} \right.$$

$$c_n = \frac{1}{T}\int_{T/2}^{T} e^{-i2\pi nt/T}\,dt$$

$$= \frac{e^{-i2\pi n} - e^{-i\pi n}}{-i2\pi n}$$

$$= \frac{e^{-3i\pi n/2}\left(e^{-i\pi n/2} - e^{i\pi n/2}\right)}{-i2\pi n} = \frac{1}{\pi n} e^{-3i\pi n/2}\sin(\pi n/2)$$

n	c_n
0	$\frac{1}{2}$
1	$i\frac{1}{\pi}$
2	0
3	$i\frac{1}{3\pi}$
4	0
5	$i\frac{1}{5\pi}$
6	0
7	$i\frac{1}{7\pi}$

$$f(t) = \sum_{n=-\infty}^{\infty} c_n e^{i2\pi nt/T} = \frac{1}{2} + \sum_{n=1}^{\infty} \frac{i}{\pi n}\left(e^{i2\pi nt/T} - e^{-i2\pi nt/T}\right) = \frac{1}{2} - \sum_{n=1}^{\infty} \frac{2}{\pi n}\sin(2\pi nt/T)$$

The sum of the terms up through n = 7 (first five nonzero terms) is shown in Figure 6.

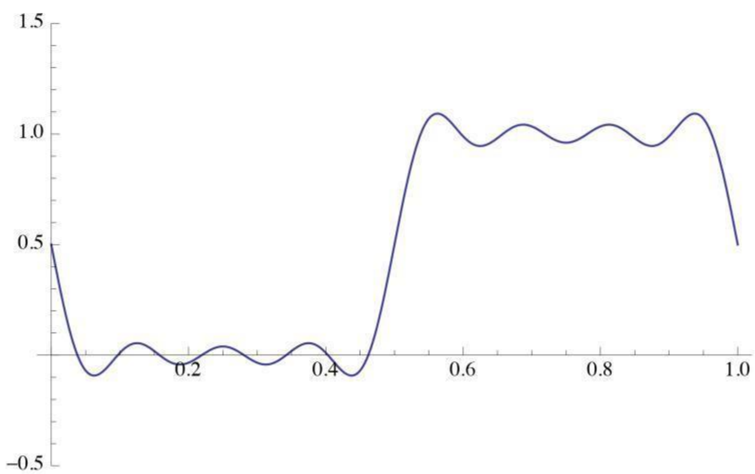

Figure 6: Fourier sum for Exercise 2.14.

2.15

The Fourier transform is

$$F(!) = \int_{1} f(t)e^{i!t}dt:$$

f(t) is given by

$$f(t) = \begin{cases} 0; & (n\ 1)\ 1=2)T < t < nT: \\ 1; & (n\ \ T < t < n\ 1=2)T \end{cases}$$

The transform is

$$X^{1} \int^{(n\ 1=2)T} \qquad X^{1} \frac{i}{} \ \ i!(n\ 1=2)T\ )\ e^{i!(n\ 1)T\ )})$$

$$= \frac{i}{!}(e^{i!T=2} \quad e^{i!T})) \sum_{n=}^{1} e^{i!nT}:$$

The sum will be equal to in nity for $! = 2\ n^0=T$ and zero otherwise (this is equivalent to a -function). Thus we have

$$F(!) = \begin{cases} \frac{i}{2\ n^0=T}\ \frac{i}{=n^0}; & ! = 2\ n^0=T \\ 0; & \text{else:} \end{cases}$$

This is the same as the result of Exercise 2.14.

2.16

The Fourier transform is

$$F(!)= \int_{1} (t)e^{st}e^{i!t}dt = \int_{0}^{1} e^{st}e^{i!t}dt = \frac{1}{s\quad i!} = \frac{i}{!\quad is}$$

The response function (2.5.7) is

$$\frac{V_0}{} = \frac{i=!C}{R\quad i=!C} = \frac{i=RC}{!\quad i=RC}\ V_i$$

and the product is

$$F_0(!) = \frac{i=RC}{!\quad i=RC} \frac{i}{!\quad is}$$

The reverse Fourier transform is

$$f(t) = \frac{1}{2}\int_{1} \frac{i=RC}{!\quad i=RC} \frac{i}{!\quad is} e^{i!t}dt:$$

For t > 0, ! ! +i1 converges, so this becomes

$$f(t) = i(\ i=RC)\frac{i}{i=RC\quad is}e^{i(i=RC)t} + i\frac{(\ i=RC)}{is\quad i=RC}(\ i)e^{i(is)t}:$$

Setting s = 0 gives

$$f(t) = 1\ e^{t=RC}:$$

2.17

Loops:

$V_i = IR + I_c Z_C$

$V_i = IR + I_L Z_L$

Node:

$I = I_C + I_L$

Solution:

$$I_C = \frac{Z_L}{RZ_C + RZ_L + Z_C Z_L} V_i = \frac{i!L}{iR=!C + i!RL + L=C} V_i$$

$$V_C = I_C Z_C = \frac{L=C}{iR=!C + i!RL + L=C} V_i$$

2.18

(2.8.2) is

$$\frac{V_0}{V_i} = \frac{R}{R \quad i=!C + i!L}:$$

(2.8.12) is

$$V_i = IR + \frac{I}{C} + LI:$$

For $V_i = V_i(0)e^{i!t}$ and $I = I_0 e^{i!t+}$, this becomes

$$i!V_i(0)e^{i!t} = i!I_0 Re^{i(!t+)} + \frac{I_0}{C} e^{i(!t+)} \quad L!^2 I_0 e^{i(!t+)} :$$

The output V_o is across R, so $V_o = I_0 Re^{i(!t+)}$. The above equation therefore becomes

$$i!V_i = i!V_o + \frac{V_0}{RC} \quad \frac{L}{R} !^2 V_o:$$

Solving for $V_o = V_i$ gives

$$\frac{V_0}{V_i} = \frac{i!}{i! + 1=RC \quad !^2 L=R}$$

which is the same as (2.8.2).

2.19

We want a high-pass lter like that shown in Fig. 2.18(b), which has response (see Exercise 2.9)

$$\frac{V_0}{\;}^{2} \qquad \frac{1}{\qquad\qquad}$$

We solve for C:

$$\frac{C = \frac{}{R} S}{!} \quad \frac{1}{\qquad} \; - \; \frac{}{2\,(100\ \text{Hz})} \quad q \quad \frac{1=(:95)^2}{\qquad} \quad 1=0:6\ \text{F}:$$

2.20

Solve for 10% value:

$$e^{\;t^2_{10}=2\;^2} = :1$$

$$t_{10} = q\,\overline{2\;^2\ \ln(0:1)}:$$

For 90% value,

$$t_{90} = q\,\overline{2\;^2\ \ln(0:9)}:$$

On the positive side,

$$t_{10} \quad t_{90} = q\,\overline{2\;^2\ \ln(0:9)} \quad q\,\overline{2\;^2\ \ln(0:1)} = p\,\overline{2}\,(q\,\overline{\ln(0:1)} \quad q\,\overline{\ln(0:9)}) = 1:2\ p\,\overline{2}\;:$$

2.21

The electric eld is purely radial. For charge +Q on the inner sphere and Q on the outer sphere, the electric eld is

$$E(r) = \frac{Q}{4\;\;_0 r^2}$$

and the potential drop is

$$V(r) = \int_{r_1}^{r_2} E(r)dr = \frac{Q}{4\;\;_0 r_1} \quad \frac{Q}{4\;\;_0 r_2}\;:$$

Comparing to the de nition Q = C V , this gives

$$C = 4\;\;_0 \left(\frac{1}{r_1} \quad \frac{1}{r_2} \right)^{1} :$$

2.22

The electric eld from a line charge is found from Gauss's law,

$$E = \frac{\;}{\qquad};$$

$$V = \int_b^a E(r)dr = \frac{Q/l}{2\ 0} \ln(a/b):$$

By superposition, the other wire contributes the same, so we multiply by 2. This implies

$$C = \frac{l\ _0}{\ln(a/b)}:$$

2.23

$$C = \frac{A\ _0}{d} = \frac{lw\ _0}{d}$$

$$L = \frac{_0 ld}{w}$$

$$\omega_0 = \frac{1}{\sqrt{LC}} = \frac{1}{\sqrt{\frac{_0 ld}{w}\frac{lw\ _0}{d}}} = \frac{1}{\sqrt{\ _0\ _0 l^2}} = \frac{c}{l}:$$

2.24

The high-pass lter of Fig. 2.18(b) has response (see Exercise 2.9)

$$\frac{V_0}{V_i} = \frac{R}{R\ \ i/\omega C} = \frac{R(R + i/\omega C)}{R^2 + 1/\omega^2 C^2}:$$

From (2.5.9),

$$\tan\ = \frac{\mathrm{Im}\ V_0/V_i}{\mathrm{Re}\ V_0/V_i} = \frac{1/\omega C}{R}$$

At high frequency, = 0. At low frequency, = /2.

2.25

$$\frac{V_0}{V_i} = \frac{i\omega L}{i\omega L + R} = \frac{i\omega L/R}{i\omega L/R + 1}.$$

Figure ?? shows the plot with frequency in units of R/L.

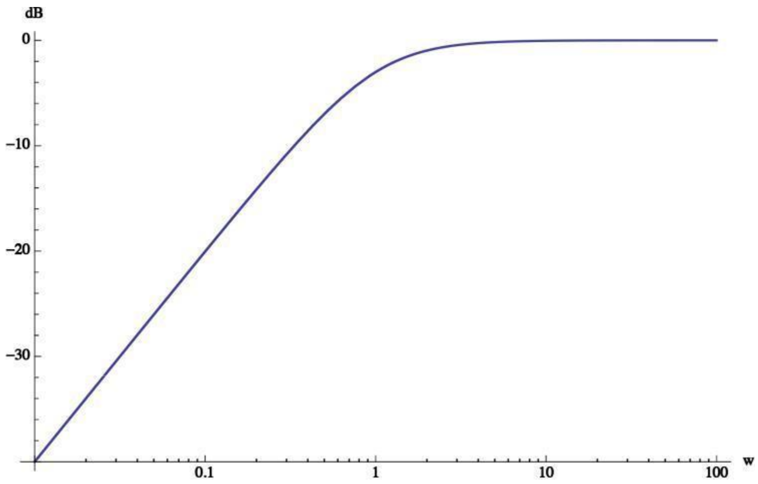

Figure 7: Response function for Exercise 2.25.

2.26

$|V_0|^2$ is increased by $(3/2)^2 = 2.25$.

$10(\log_{10} 2.25) = 3.52$ dB

2.27

From Exercises 2.9 and 2.18:

$$\left|\frac{V_0}{V_i}\right|^2 = \frac{1}{1 + \frac{1}{\omega^2 R^2 C^2}}$$

Solving for ω,

$$\omega = \frac{1}{RC}\left(\frac{1}{|V_i/V_o|^2 - 1}\right)^{1/2} = \frac{0.1}{RC}$$

2.28

The low-pass filter response (2.5.7) is

$$\frac{V_0}{V_i} = \frac{-i/\omega C}{R - i/\omega C}.$$

Power response is

$$\frac{V_0}{}^{2} \quad \frac{i=!C}{} \; \frac{i=!C}{} = \frac{1=!^2C^2}{} = \frac{1}{} :$$

Solve for !:

$$\frac{1}{} \; s \; \frac{1}{}$$

10%:

$$! = \frac{3}{RC} :$$

90%:

$$! = \frac{1}{3RC} :$$

10-90 range:

$$! = \frac{2:667}{RC} :$$

2.29

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

$$\frac{V_2}{V_1} = 10^{dB=20} = 10^{13=20} = 4:5$$

The amplitude signal-to-noise ratio increases by a factor of 4.5, i.e. from 2 to 9. It is also common to talk in terms of the signal-to-noise power ratio.

2.30

The circuit is shown in Figure 8.

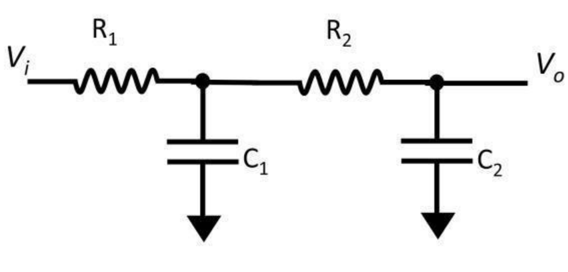

Figure 8: Circuit for Exercise 2.30.

Loops:

$V_i = I_1R_1 + I_{C1}Z_{C1}$
$V_i = I_1R_1 + I_2R_2 + V_o$
$V_o = I_2 Z_{C2}$

Node:
$I_1 = I_{C1} + I_2$

Set $R_1 = R_2 = R$, $C_1 = C_2 = C$. Solution:

$$\frac{V_o}{V_i} = \frac{Z_C^2}{R^2 + 3RZ_C + Z_C^2} :$$

$$V_o^2 \quad 1$$

In the Figure 9, the lower curve is this response function, while the upper curve is the single low-pass response, from Exercise 2.27.

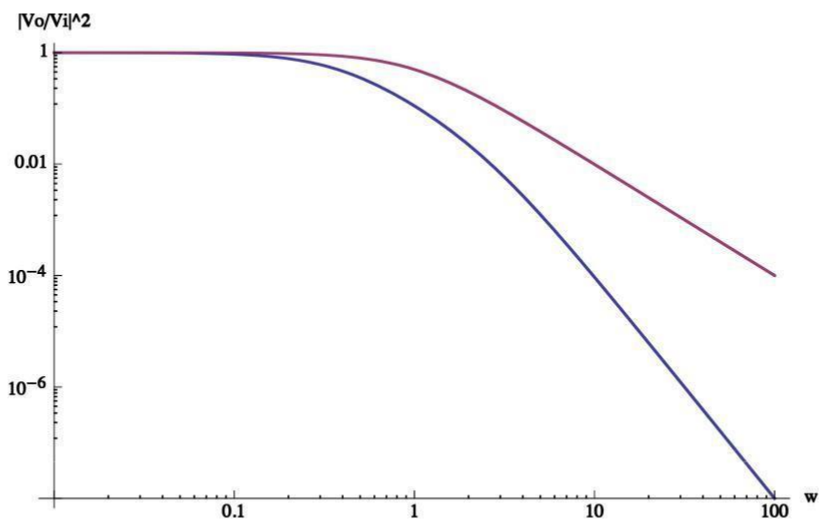

Figure 9: Response functions for Exercise 2.30.

2.31

Assuming perfect detector; no current ows into output; I_o is the current owing from top to bottom in the right side of the circuit.

Loops:

$$V_i = I_{C1} Z_C + I \frac{R}{}$$

R3 2

$V_i = I_{R1}R + I_{C3}\frac{Z_C}{2}$

$V_i = I_{R1}R + I_oR + V_o$

$V_o = I_oZ_C + I_{R3}\frac{R}{2}$

Nodes:

$I_{R1} = I_{C3} + I_o$

$I_{C1} + I_o = I_{R3}$

Solution:

$$\frac{V_0}{V_i} = \frac{(1+C^2R^2 !^2)}{1 \;\; 4iCR! + C^2R^2!^2}$$

This is plotted in Figure 10. When ! = 1=RC, this equals 0. When ! ! 0 or ! ! 1, it approaches unity.

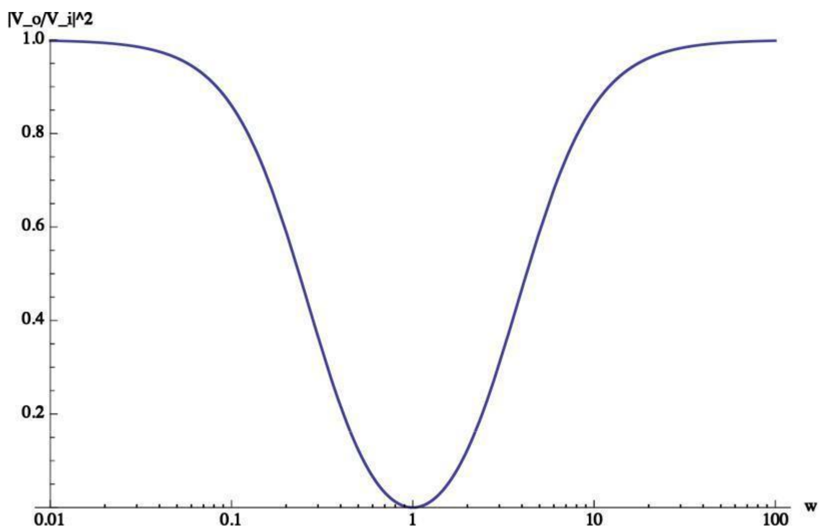

Figure 10: Response function for Exercise 2.31.

2.32

The circuit in the book is missing a 50- resistor between V_i and the rest of the circuit|as drawn, the circuit will give $V_o = V_i$ for all inputs. Putting a resistor there gives

Loops:

$V_i = IR + V_o$

$V_o = I_1(Z_{C1} + Z_{L1})$

$V_o = I_2(Z_{C2} + Z_{L2})$

Node:
$I = I_1 + I_2$

Solution:

$$\frac{V_0}{V_i} = \frac{(1 + C_1L_1!^2)(1 + C_2L_2!^2)}{1 + iC_1R! + iC_2R! \;\; C_1L_1 \;\; !^2 \;\; C_2L_2!^2 \;\; iC_1C_2L_1R!^3 \;\; iC_1C_2L_2R!^3 + C_1C_2L_1L_2!^4}$$

This is a double notch lter, with zeroes where the two terms in the numerator vanish. Figure 11 shows a plot for the values given:

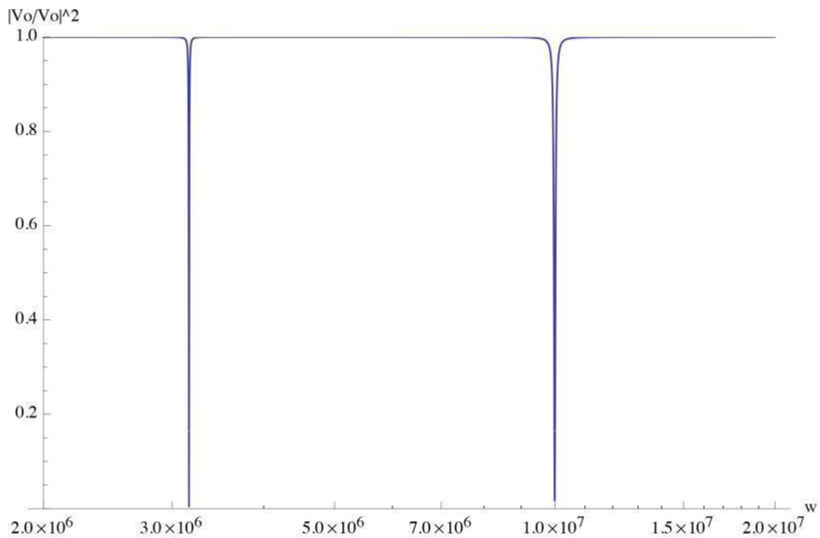

Figure 11: Double notch response function, for Exercise 2.32.

2.33

a) Capacitor relation:

$$I = C\frac{@\,V_C}{@t}$$

Loops:

$V_s = I_1R_1 + I_2R_2$

$V_i = V_C + V_o \; ! \; \bar{V}_i = \frac{I_C}{C} + \bar{V}_o$

$V_o = I_2R_2$

These become

$V_s = I_1R_1 + I_2R_2$

$i!V_1e^{i!t} = \frac{I_C}{C} + i!V_{AC}\, e^{i(!t+\ )}$

$V_{DC} + V_{AC}\, e^{i(!t+\ )} = I_2R_2$

Node:

$I_C + I_1 = I_2.$

Write $I_1 = I_{1DC} + I_{1AC}$ and $I_2 = I_{2DC} + I_{2AC}$ (note that there is no DC component through the capacitor), and set DC terms equal and AC terms equal:

$$V_s = I_{1DC}R_1 + I_{2DC}R_2$$

$$0 = I_{1AC}R_1 + I_{2AC}R_2$$

$$i!V_1e^{i!t} = \frac{I_C}{C} + i!V_{AC}\, e^{i(!t+\ )}$$

$$V_{DC} = I_{2DC}R_2$$

$$V_{AC}\, e^{i(!t+\ )} = I_{2AC}R_2$$

$$I_C + I_{1AC} = I_{2AC}$$

$$I_{1DC} = I_{2DC}$$

We solve these for I_C; I_{1DC}; I_{1AC}; I_{2DC}; I_{2AC}; V_{DC}; and $V_{AC}\, e^{i}$, which gives

$$V_{DC} = \frac{R_2V_s}{R_1+R_2};$$

$$V_{AC}\, e^{i} = \frac{CR_1R_2!}{iR_1\ \ iR_2 + CR_1R_2!}V_1$$

$$= \frac{CR_e\ !}{i + CR_e\ !}V_1$$

where

$$R_e = \frac{R_1R_2}{R_1+R_2}:$$

2.34

We want a low-pass lter that eliminates AC frequency of 60 Hz. We use the circuit shown in Fig. 2.18(a) with a polarized capacitor with the negative side grounded. Formula (2.5.11) gives us

$$|V_o/V_i|^2 = \frac{1}{1 + !^2R^2C^2}:$$

We would like low series R to prevent DC droop of the voltage supply. Pick R = 1 , which is small compared to a typical 50 load impedance. Solve for C:

$$C = \frac{1}{\omega R}\sqrt{1/|V_o/V_i|^2 - 1}$$

To eliminate 99% of the ripple, pick $|V_o/V_i|^2 = .01$. Setting $\omega = 2\pi(60\text{ Hz}) = 377\text{ s}^{-1}$, we then have

$$C = \frac{1}{(377\text{ s}^{-1})(50\ \Omega)}\sqrt{99} = 0.00053\text{ F} = 530\ \mu\text{F}.$$