

Chapter 4 Answers

4.1. (a) Let $x(t) = e^{-t} \cos(2t)u(t) = 0$. Then the Fourier transform $X(j\omega)$ of $x(t)$ is

$$\begin{aligned} X(j\omega) &= \int_{-\infty}^{\infty} e^{-t} \cos(2t)u(t)(1-j\omega)^{-1} dt \\ &= \int_0^{\infty} e^{-t} \cos(2t) e^{-j\omega t} dt \\ &= e^{-j\omega} / (2 + j\omega) \end{aligned}$$

$|X(j\omega)|$ is as shown in Figure 54.1.

(b) Let $x(t) = e^{-t} \cos(2t)$. Then the Fourier transform $X(j\omega)$ of $x(t)$ is

$$\begin{aligned} X(j\omega) &= \int_{-\infty}^{\infty} e^{-t} \cos(2t) e^{-j\omega t} dt \\ &= \int_{-\infty}^0 e^{-t} \cos(2t) e^{-j\omega t} dt + \int_0^{\infty} e^{-t} \cos(2t) e^{-j\omega t} dt \\ &= e^{-j\omega} / (2 + j\omega) + e^{-j\omega} / (2 - j\omega) \\ &= 2e^{-j\omega} / (4 + \omega^2) \end{aligned}$$

$|X(j\omega)|$ is as shown in Figure 54.2.



4.2. (a) Let $x_1(t) = \delta(t) + \delta(t-1) + \delta(t-2)$. Then the Fourier transform $X_1(j\omega)$ of $x_1(t)$ is

$$\begin{aligned} X_1(j\omega) &= \int_{-\infty}^{\infty} [\delta(t) + \delta(t-1) + \delta(t-2)] e^{-j\omega t} dt \\ &= 1 + e^{-j\omega} + e^{-j2\omega} \end{aligned}$$

$|X_1(j\omega)|$ is as shown in Figure 54.3.

(b) The signal $x_2(t) = \cos(2t-1) + \cos(2t-2)$ is as shown in the figure below. Clearly,

$$\frac{d}{dt} [\cos(2t-1) + \cos(2t-2)] = 2\sin(2t-1) - 2\sin(2t-2)$$

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Therefore, the nonzero Fourier series coefficients of $x_2(t)$ are

$$a_0 = 0, \quad a_1 = \frac{1}{2} e^{-j1} e^{j2\pi k}, \quad a_{-1} = \frac{1}{2} e^{-j2} e^{-j2\pi k}$$

From Section 4.2, we know that for periodic signals, the Fourier transform consists of a train of impulses occurring at $k\omega_0$. Furthermore, the area under each impulse is 2π times the Fourier series coefficient a_k . Therefore, for $x_2(t)$, the corresponding Fourier transform $X_2(j\omega)$ is given by

$$\begin{aligned} X_2(j\omega) &= 2\pi a_1 \delta(\omega - \omega_0) + 2\pi a_{-1} \delta(\omega + \omega_0) + 2\pi a_0 \delta(\omega) \\ &= 2\pi \delta(\omega) + \pi e^{j1} \delta(\omega - 2\pi) + \pi e^{-j2} \delta(\omega + 2\pi) \end{aligned}$$

4.4. (a) The inverse Fourier transform is

$$\begin{aligned} x_1(t) &= (1/2\pi) \int_{-\infty}^{\infty} [2\pi \delta(\omega) + \pi \delta(\omega - 4\pi) + \pi \delta(\omega + 4\pi)] e^{j\omega t} d\omega \\ &= (1/2\pi) [2\pi e^{j0t} + \pi e^{j4\pi t} + \pi e^{-j4\pi t}] \\ &= 1 + (1/2) e^{j4\pi t} + (1/2) e^{-j4\pi t} = 1 + \cos(4\pi t) \end{aligned}$$

(b) The inverse Fourier transform is

$$\begin{aligned} x_2(t) &= (1/2\pi) \int_{-\infty}^{\infty} X_2(j\omega) e^{j\omega t} d\omega \\ &= (1/2\pi) \int_{-\infty}^{\infty} 2\pi e^{j\omega t} d\omega + (1/2\pi) \int_{-\infty}^{\infty} (-1/2) e^{j\omega t} d\omega \\ &= [e^{j\omega t}]_{-\infty}^{\infty} - (1/4) [e^{j\omega t}]_{-\infty}^{\infty} \\ &= -(1/4) \sin^2(0/4\pi t) \end{aligned}$$

4.5. From the given information,

$$\begin{aligned} x(t) &= (1/2\pi) \int_{-\infty}^{\infty} X(j\omega) e^{j\omega t} d\omega \\ &= (1/2\pi) \int_{-\infty}^{\infty} [X(j\omega) e^{j\omega t} + X(j\omega) e^{-j\omega t}] d\omega \\ &= (1/2\pi) \int_{-\infty}^{\infty} 2\cos(\omega t) e^{j\omega t} d\omega \\ &= \frac{-2}{j\omega t} \sin(\omega t) = \frac{2}{\omega t} \sin(\omega t) \end{aligned}$$

The signal $x(t)$ is zero when $\omega t = 1/2\pi$ is a nonzero integer multiple of π . This gives

$$t = \frac{k\pi}{\omega} = \frac{\pi}{2\omega}, \quad \text{for } k \in \mathbb{Z}, \text{ and } k \neq 0.$$

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Therefore,

$$\begin{aligned} X_2(j\omega) &= \int_{-\infty}^{\infty} [x(t) - 2] e^{-j\omega t} dt = X(j\omega) - 2\delta(\omega) \\ &= e^{-j\omega} + e^{j\omega} - 2\delta(\omega) = -2\delta(\omega) \end{aligned}$$

$|X_2(j\omega)|$ is as shown in Figure 54.4.



4.6. (a) The signal $x_1(t) = \cos(2\pi t + \pi/4)$ is periodic with a fundamental period of $T = 1$. This translates to a fundamental frequency of $\omega_0 = 2\pi$. The nonzero Fourier series coefficients of this signal may be found by writing it in the form

$$\begin{aligned} x_1(t) &= \frac{1}{2j} (e^{j(2\pi t + \pi/4)} - e^{-j(2\pi t + \pi/4)}) \\ &= \frac{1}{2j} e^{j\pi/4} e^{j2\pi t} - \frac{1}{2j} e^{-j\pi/4} e^{-j2\pi t} \end{aligned}$$

Therefore, the nonzero Fourier series coefficients of $x_1(t)$ are

$$a_1 = \frac{1}{2j} e^{j\pi/4} e^{j\pi/4}, \quad a_{-1} = -\frac{1}{2j} e^{-j\pi/4} e^{-j\pi/4}$$

From Section 4.2, we know that for periodic signals, the Fourier transform consists of a train of impulses occurring at $k\omega_0$. Furthermore, the area under each impulse is 2π times the Fourier series coefficient a_k . Therefore, for $x_1(t)$, the corresponding Fourier transform $X_1(j\omega)$ is given by

$$\begin{aligned} X_1(j\omega) &= 2\pi a_1 \delta(\omega - \omega_0) + 2\pi a_{-1} \delta(\omega + \omega_0) \\ &= (1/2) \pi e^{j\pi/2} \delta(\omega - 2\pi) - (1/2) \pi e^{-j\pi/2} \delta(\omega + 2\pi) \end{aligned}$$

(b) The signal $x_2(t) = 1 + \cos(4\pi t + \pi/2)$ is periodic with a fundamental period of $T = 1/2$. This translates to a fundamental frequency of $\omega_0 = 4\pi$. The nonzero Fourier series coefficients of this signal may be found by writing it in the form

$$\begin{aligned} x_2(t) &= 1 + \frac{1}{2} (e^{j(4\pi t + \pi/2)} + e^{-j(4\pi t + \pi/2)}) \\ &= 1 + \frac{1}{2} e^{j\pi/2} e^{j4\pi t} + \frac{1}{2} e^{-j\pi/2} e^{-j4\pi t} \end{aligned}$$

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4.8. Throughout this problem, we assume that

$$x(t) \stackrel{\text{FT}}{\longleftrightarrow} X(j\omega).$$

(a) Using the time reversal property (Sec. 4.3.1), we have

$$x(-t) \stackrel{\text{FT}}{\longleftrightarrow} X(-j\omega).$$

Using the time shifting property (Sec. 4.3.2) on this, we have

$$x(-t+1) \stackrel{\text{FT}}{\longleftrightarrow} e^{j\omega} X(-j\omega) \quad \text{and} \quad x(-t-1) \stackrel{\text{FT}}{\longleftrightarrow} e^{-j\omega} X(-j\omega).$$

Therefore,

$$x_1(t) = x(-t+1) + x(-t-1) \stackrel{\text{FT}}{\longleftrightarrow} e^{j\omega} X(-j\omega) + e^{-j\omega} X(-j\omega) = 2X(-j\omega) \cos \omega$$

(b) Using the time scaling property (Sec. 4.3.5), we have

$$x(t) \stackrel{\text{FT}}{\longleftrightarrow} \frac{1}{2} X\left(\frac{\omega}{2}\right)$$

Using the time shifting property on this, we have

$$x_2(t) = x(2t-2) + x(2t+2) \stackrel{\text{FT}}{\longleftrightarrow} e^{-j\omega} \frac{1}{2} X\left(\frac{\omega}{2}\right) + e^{j\omega} \frac{1}{2} X\left(\frac{\omega}{2}\right)$$

(c) Using the differentiation in time property (Sec. 4.3.4), we have

$$\frac{dx(t)}{dt} \stackrel{\text{FT}}{\longleftrightarrow} j\omega X(j\omega)$$

Applying this property again, we have

$$\frac{d^2 x(t)}{dt^2} \stackrel{\text{FT}}{\longleftrightarrow} -\omega^2 X(j\omega).$$

Using the time shifting property, we have

$$x_3(t) = \frac{d^2 x(t)}{dt^2} + \frac{1}{2} \frac{dx(t)}{dt} \stackrel{\text{FT}}{\longleftrightarrow} -\omega^2 X(j\omega) + \frac{j\omega}{2} X(j\omega).$$

4.9. (a) Since $X_1(j\omega)$ is not conjugate symmetric, the corresponding signal $x_1(t)$ is not real. Since $X_2(j\omega)$ is neither even nor odd, the corresponding signal $x_2(t)$ is neither even nor odd.

(b) The Fourier transform of a real and odd signal is purely imaginary and odd. Therefore, we may conclude that the Fourier transform of a purely imaginary and odd signal is real and odd. Since $X_3(j\omega)$ is real and odd, we may therefore conclude that the corresponding signal $x_3(t)$ is purely imaginary and odd.

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