

Chapter 4 Answers

4.1. (a) Let $x(t) = e^{-t/2} \cos(2t) = 1$. Then the Fourier transform $X(j\omega)$ of $x(t)$ is

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

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

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

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

$|X(j\omega)|$ 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 $x_2(t) = \cos(2 - t) + \cos(t - 2) = \cos(t - 2)$ is as shown in the figure below. Clearly,

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

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

$$a_0 = 1, \quad a_1 = \frac{1}{2} e^{j2} e^{-j\omega_0}, \quad a_{-1} = \frac{1}{2} e^{-j2} e^{j\omega_0}$$

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

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

4.4. (a) The inverse Fourier transform is

$$\begin{aligned} x_1(t) &= (1/2\pi) \int_{-\infty}^{\infty} [2\pi \delta(\omega) + \pi e^{j2} \delta(\omega - \omega_0) + \pi e^{-j2} \delta(\omega + \omega_0)] e^{j\omega t} d\omega \\ &= (1/2\pi) [2\pi e^{j0t} + \pi e^{j2} e^{j\omega_0 t} + \pi e^{-j2} e^{-j\omega_0 t}] \\ &= 1 + (1/2) e^{j2} e^{j\omega_0 t} + (1/2) e^{-j2} e^{-j\omega_0 t} = 1 + \cos(4\omega_0 t) \end{aligned}$$

(b) The inverse Fourier transform is

$$\begin{aligned} x_2(t) &= (1/2\pi) \int_{-\infty}^{\infty} X_2(j\omega) e^{j\omega t} d\omega \\ &= (1/2\pi) \int_{-\infty}^{\infty} 2\pi \delta(\omega) e^{j\omega t} d\omega + (1/2\pi) \int_{-\infty}^{\infty} \pi e^{j2} \delta(\omega - \omega_0) e^{j\omega t} d\omega \\ &= [e^{j0t} + (1/2) e^{j2} e^{j\omega_0 t}] - [1 - e^{-j2} e^{-j\omega_0 t}] \\ &= -(1/2) \sin^2(0.5\omega_0 t) \end{aligned}$$

4.5. From the given information,

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

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

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

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Therefore,

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

$|X_2(j\omega)|$ 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 $x_2(t) = 1 + \cos(2\pi t + \pi/4)$ 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

$$\begin{aligned} x_2(t) &= 1 + \frac{1}{2} (e^{j(2\pi t + \pi/4)} + e^{-j(2\pi t + \pi/4)}) \\ &= 1 + \frac{1}{2} e^{j\pi/4} e^{j2\pi t} + \frac{1}{2} e^{-j\pi/4} e^{-j2\pi t} \end{aligned}$$

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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

$$x_2(t) = x(2t - 2) \stackrel{\text{FT}}{\longleftrightarrow} e^{-j2\omega} \frac{1}{2} X\left(\frac{\omega}{2}\right)$$

(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

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

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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Continuous and Discrete Signals and Systems Samir S. Soliman, Mandyam Dhati Srinath, 1990 Signals & Systems 2nd Edition Alan V. Oppenheim, 2008-02-01 *Signals and Systems* Alan Oppenheim (etc), Alan S. Willsky, Ian T. Young, 1983 This exploration of signals and systems develops continuous time and discrete time concepts methods in parallel and features introductory treatments of the applications of these basic methods in such areas as filtering communication sampling discrete time processing of continuous time signals and feedback

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