

16 Sampling

Recommended Problems

P16.1

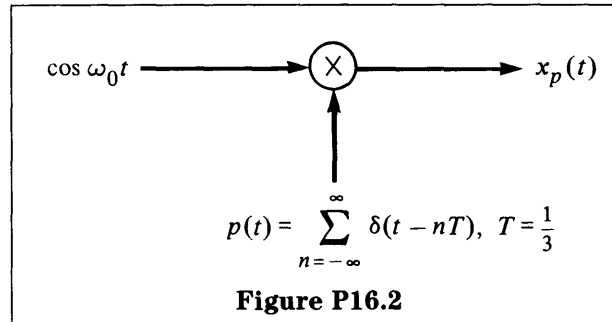
The sequence $x[n] = (-1)^n$ is obtained by sampling the continuous-time sinusoidal signal $x(t) = \cos \omega_0 t$ at 1-ms intervals, i.e.,

$$\cos(\omega_0 nT) = (-1)^n, \quad T = 10^{-3} \text{ s}$$

Determine three *distinct* possible values of ω_0 .

P16.2

Consider the system in Figure P16.2.



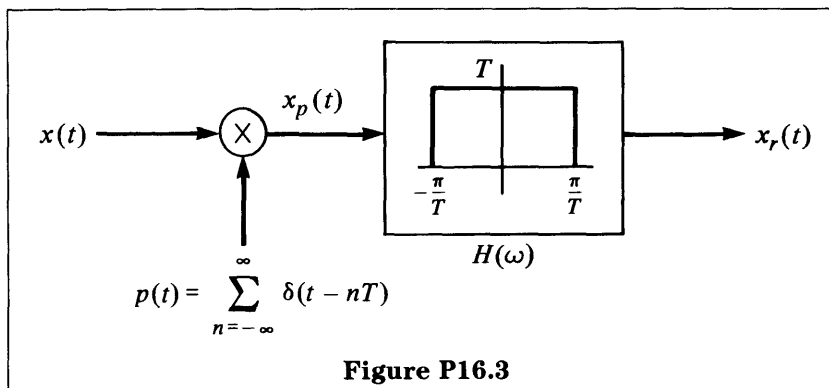
(a) Sketch $X_p(\omega)$ for $-9\pi \leq \omega \leq 9\pi$ for the following values of ω_0 .

- (i) $\omega_0 = \pi$
- (ii) $\omega_0 = 2\pi$
- (iii) $\omega_0 = 3\pi$
- (iv) $\omega_0 = 5\pi$

(b) For which of the preceding values of ω_0 is $x_p(t)$ identical?

P16.3

In the system in Figure P16.3, $x(t)$ is sampled with a periodic impulse train, and a reconstructed signal $x_r(t)$ is obtained from the samples by lowpass filtering.



The sampling period T is 1 ms, and $x(t)$ is a sinusoidal signal of the form $x(t) = \cos(2\pi f_0 t + \theta)$. For each of the following choices of f_0 and θ , determine $x_r(t)$.

- (a) $f_0 = 250$ Hz, $\theta = \pi/4$
- (b) $f_0 = 750$ Hz, $\theta = \pi/2$
- (c) $f_0 = 500$ Hz, $\theta = \pi/2$

P16.4

Figure P16.4 gives a system in which the sampling signal is an impulse train with alternating sign. The Fourier transform of the input signal is as indicated in the figure.

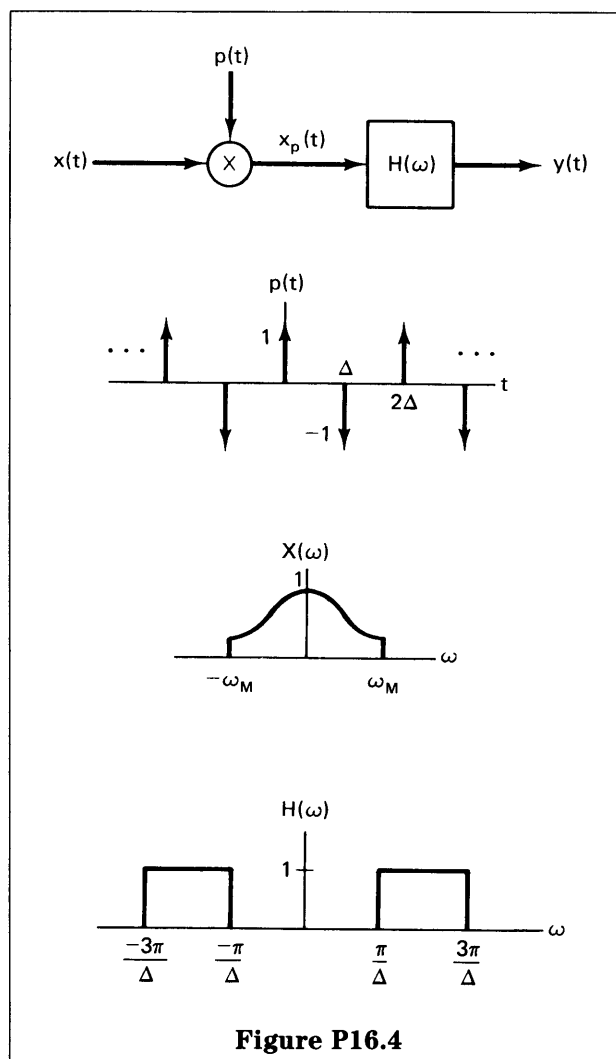
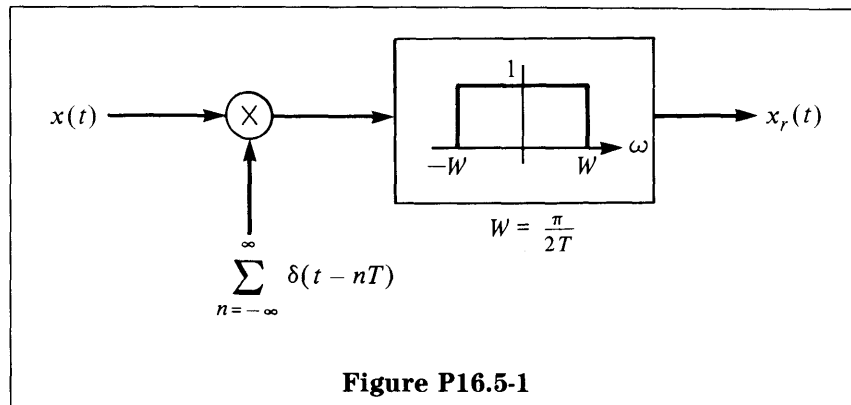


Figure P16.4

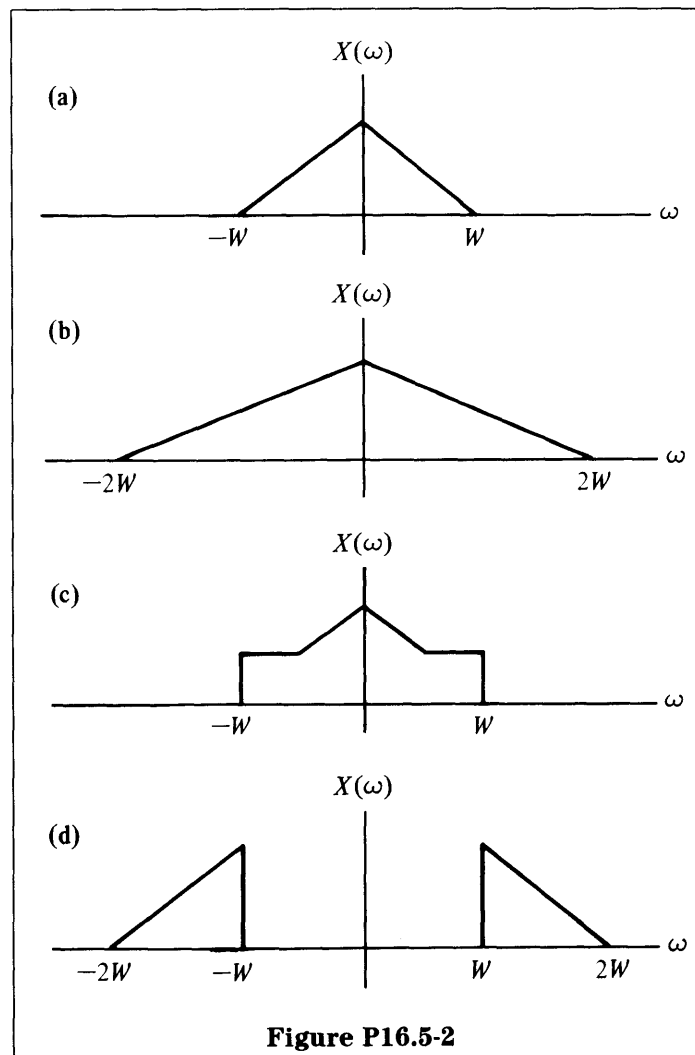
- (a) For $\Delta < \pi/2\omega_M$, sketch the Fourier transform of $x_p(t)$ and $y(t)$.
- (b) For $\Delta < \pi/2\omega_M$, determine a system that will recover $x(t)$ from $x_p(t)$.
- (c) For $\Delta < \pi/2\omega_M$, determine a system that will recover $x(t)$ from $y(t)$.
- (d) What is the *maximum* value of Δ in relation to ω_M for which $x(t)$ can be recovered from either $x_p(t)$ or $y(t)$.

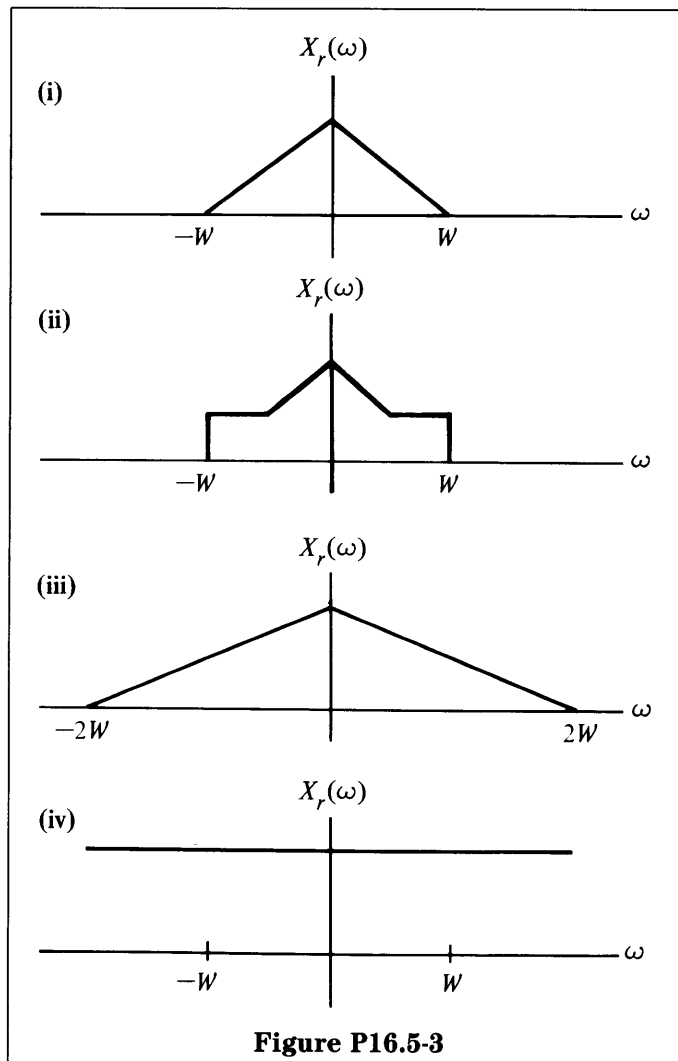
P16.5

Consider the system in Figure P16.5-1.



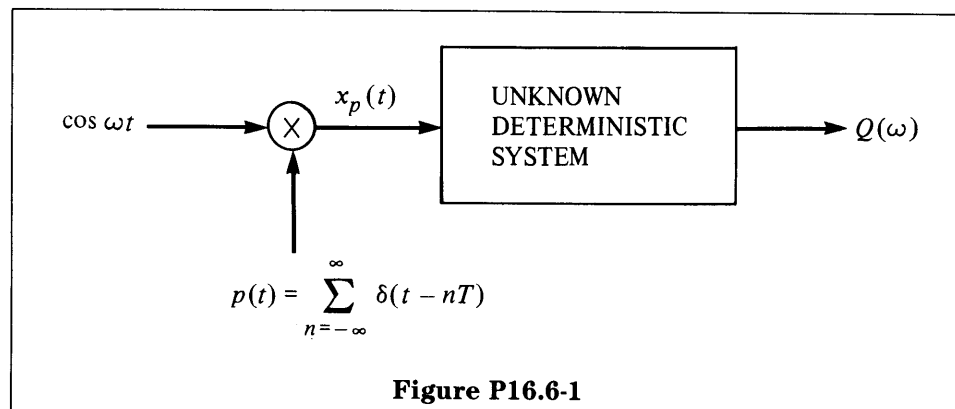
Figures P16.5-2 and P16.5-3 contain several Fourier transforms of $x(t)$ and $x_r(t)$. For each input spectrum $X(\omega)$ in Figure P16.5-2, identify the correct output spectrum $X_r(\omega)$ from Figure P16.5-3.



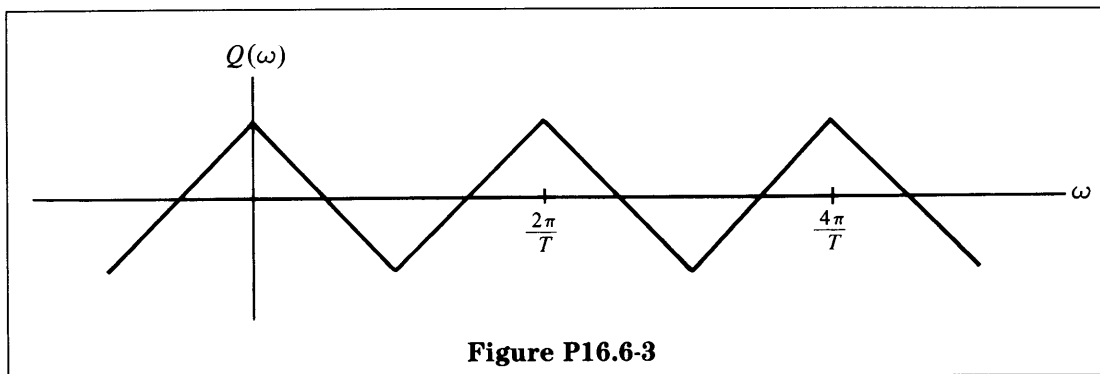
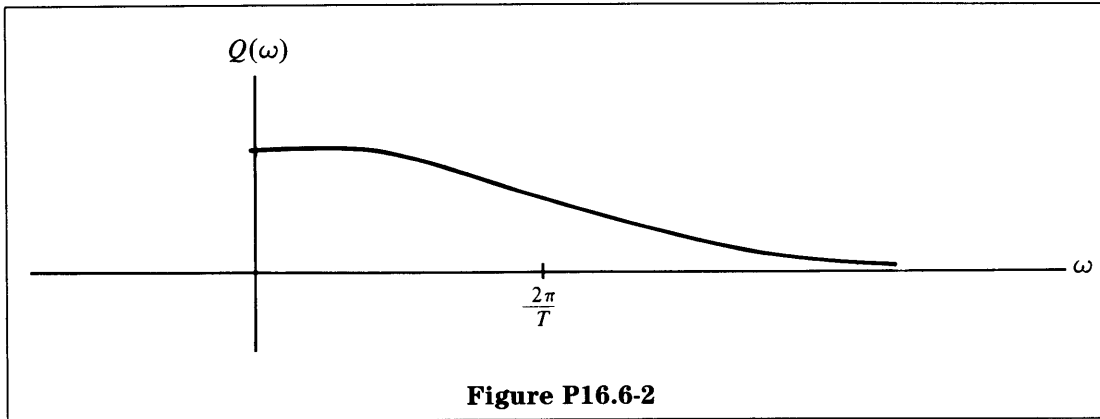


P16.6

Suppose we sample a sinusoidal signal and then process the resultant impulse train, as shown in Figure P16.6-1.



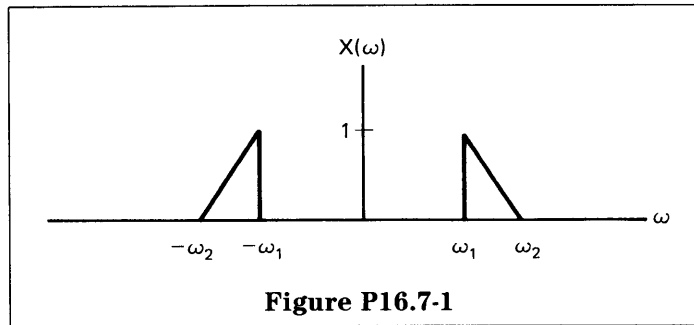
The result of our processing is a value Q . As ω changes, Q may change. Determine which of the plots in Figures P16.6-2 and P16.6-3 are possible candidates for the variation of Q as a function of ω .



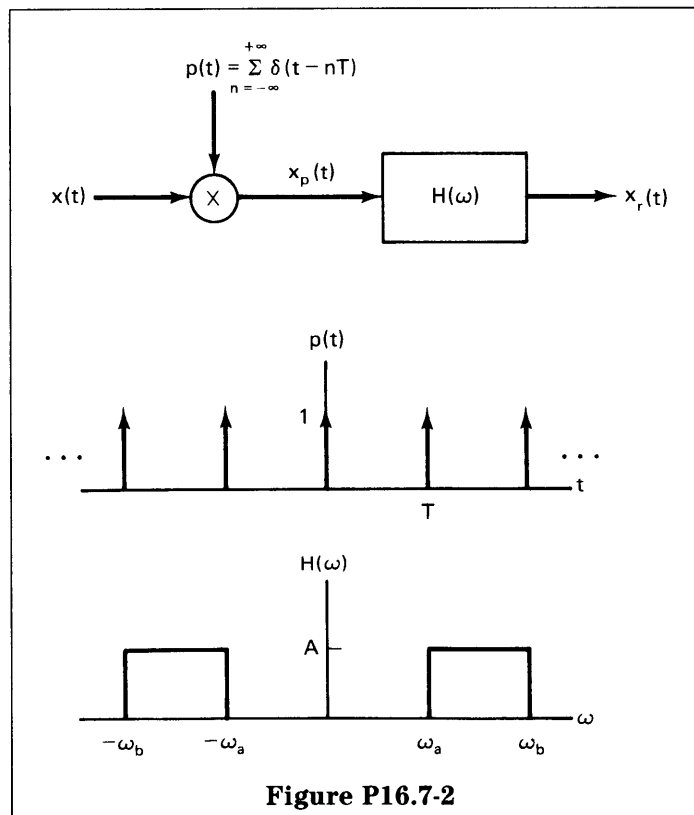
Optional Problems

P16.7

The sampling theorem as we have derived it states that a signal $x(t)$ must be sampled at a rate greater than its bandwidth (or, equivalently, a rate greater than twice its highest frequency). This implies that if $x(t)$ has a spectrum as indicated in Figure P16.7-1, then $x(t)$ must be sampled at a rate greater than $2\omega_2$. Since the signal has most of its energy concentrated in a narrow band, it seems reasonable to expect that a sampling rate lower than twice the highest frequency could be used. A signal whose energy is concentrated in a frequency band is often referred to as a *bandpass signal*. There are a variety of techniques for sampling such signals, and these techniques are generally referred to as *bandpass sampling*.

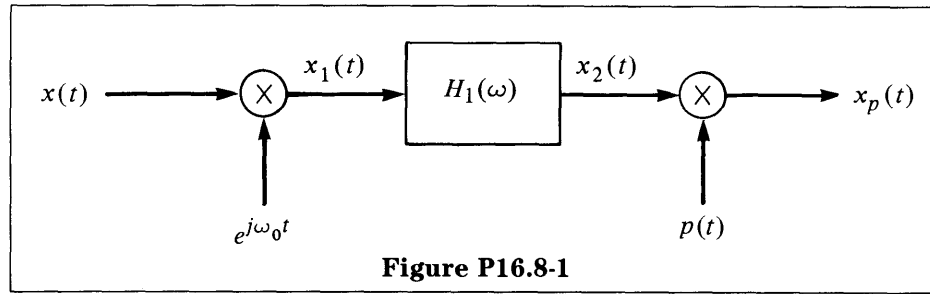


To examine the possibility of sampling a bandpass signal at a rate less than the total bandwidth, consider the system shown in Figure P16.7-2. Assuming that $\omega_1 > (\omega_2 - \omega_1)$, find the maximum value of T and the values of the constants A , ω_a , and ω_b such that $x_r(t) = x(t)$.



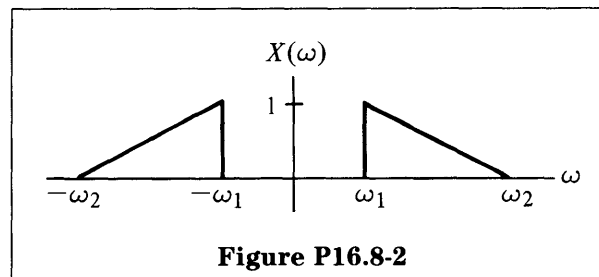
P16.8

In Problem P16.7 we considered one procedure for bandpass sampling and reconstruction. Another procedure when $x(t)$ is real consists of using complex modulation followed by sampling. The sampling system is shown in Figure P16.8-1.



With $x(t)$ real and with $X(\omega)$ nonzero only for $\omega_1 < |\omega| < \omega_2$, the modulating frequency ω_0 is chosen as $\omega_0 = \frac{1}{2}(\omega_1 + \omega_2)$, and the lowpass filter $H_1(\omega)$ has cutoff frequency $\frac{1}{2}(\omega_2 - \omega_1)$.

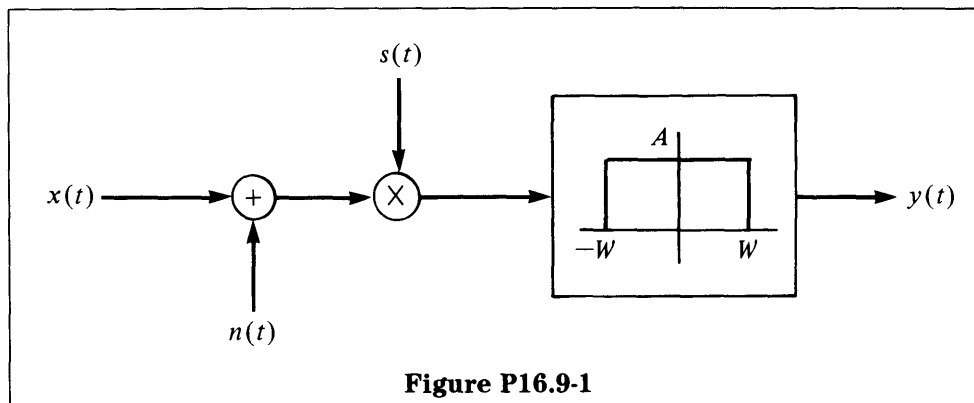
- (a) For $X(\omega)$ as shown in Figure P16.8-2, sketch $X_p(\omega)$.
- (b) Determine the maximum sampling period T such that $x(t)$ is recoverable from $x_p(t)$.
- (c) Determine a system to recover $x(t)$ from $x_p(t)$.

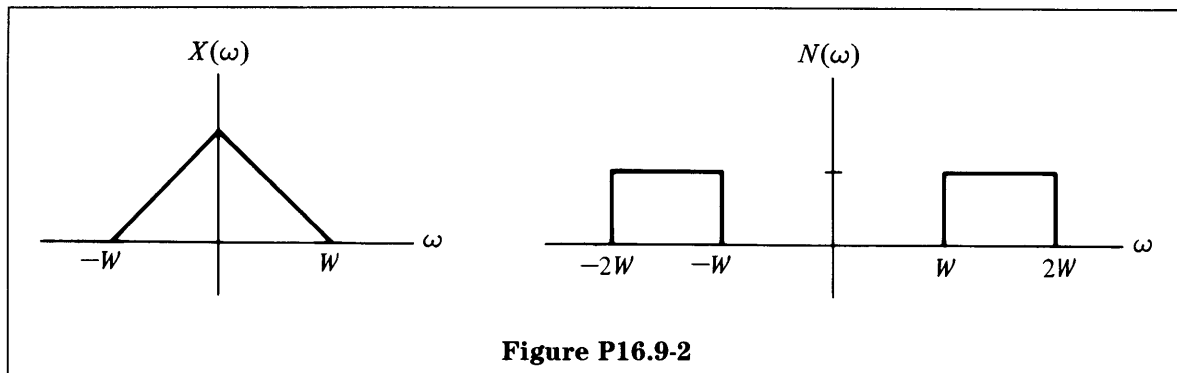


P16.9

Given the system in Figure P16.9-1 and the Fourier transforms in Figure P16.9-2, determine A and find the maximum value of T in terms of W such that $y(t) = x(t)$ if $s(t)$ is the impulse train

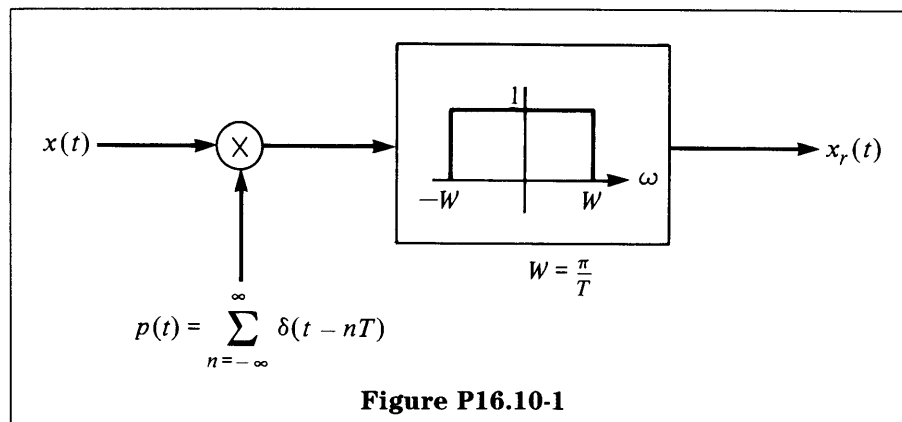
$$s(t) = \sum_{n=-\infty}^{\infty} \delta(t - nT)$$



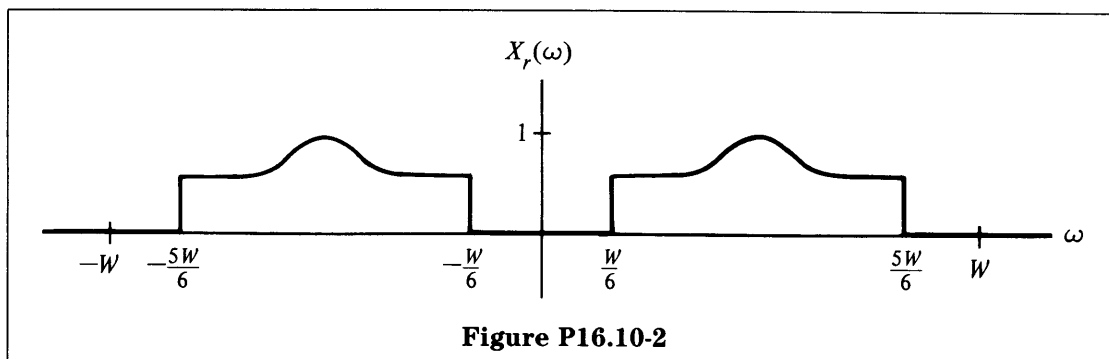


P16.10

Consider the system in Figure P16.10-1.

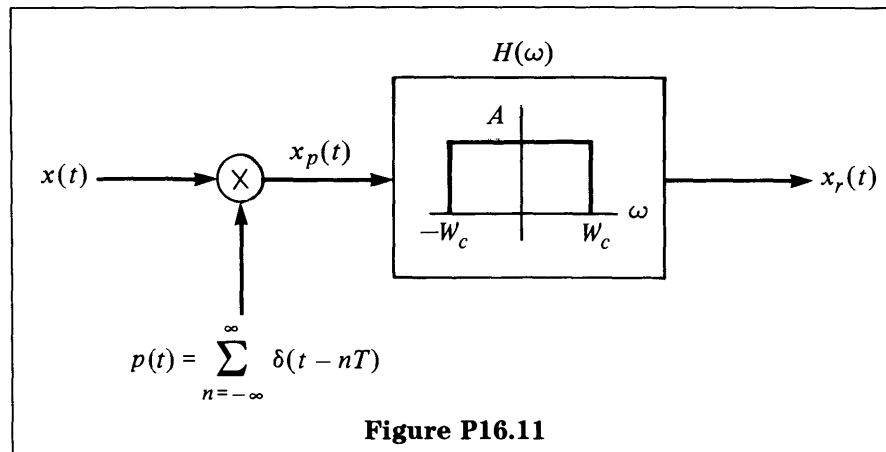


Given the Fourier transform of $x_r(t)$ in Figure P16.10-2, sketch the Fourier transform of two different signals $x(t)$ that could have generated $x_r(t)$.



P16.11

Consider the system in Figure P16.11.



- (a) If $X(\omega) = 0$ for $|\omega| > W$, find the maximum value of T , W_c , and A such that $x_r(t) = x(t)$.
- (b) Let $X_1(\omega) = 0$ for $|\omega| > 2W$ and $X_2(\omega) = 0$ for $|\omega| > W$. Repeat part (a) for the following.
- (i) $x(t) = x_1(t) * x_2(t)$
 - (ii) $x(t) = x_1(t) + x_2(t)$
 - (iii) $x(t) = x_1(t)x_2(t)$
 - (iv) $x(t) = x_1(10t)$