

# **EEE2035F: Signals and Systems I**

## **Class Test 2**

**21 April 2011**

## **SOLUTIONS**

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**Name:**

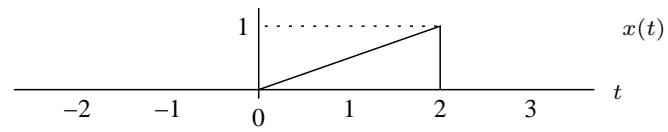
**Student number:**

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### **Information**

- The test is closed-book.
  - This test has *four* questions, totalling 20 marks.
  - Answer *all* the questions.
  - You have 45 minutes.
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1. (5 marks) suppose  $x(t)$  is the signal below



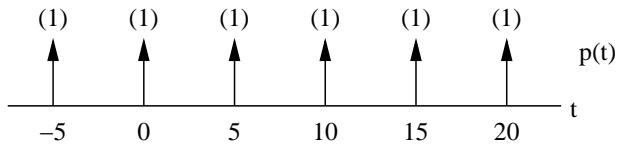
and let

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

be an impulse train with  $T = 5$ .

- (a) Plot  $p(t)$  in the time domain.
- (b) Find and plot  $y(t) = p(t) * x(t)$ .

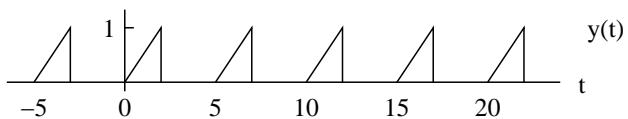
- (a) Plot as follows:



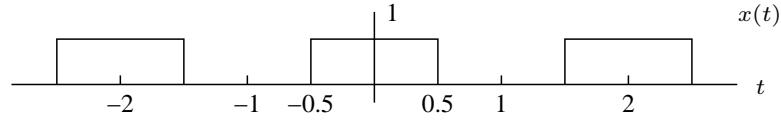
- (b) The signal is

$$\begin{aligned} y(t) &= \left( \sum_{n=-\infty}^{\infty} \delta(t - nT) \right) * x(t) = \sum_{n=-\infty}^{\infty} [\delta(t - nT) * x(t)] \\ &= \sum_{n=-\infty}^{\infty} x(t - nT) = \sum_{n=-\infty}^{\infty} x(t - 5n). \end{aligned}$$

Plot as follows:



2. (5 marks) The signal



has a Fourier series representation

$$x(t) = \sum_{k=-\infty}^{\infty} c_k e^{jk\pi t},$$

where

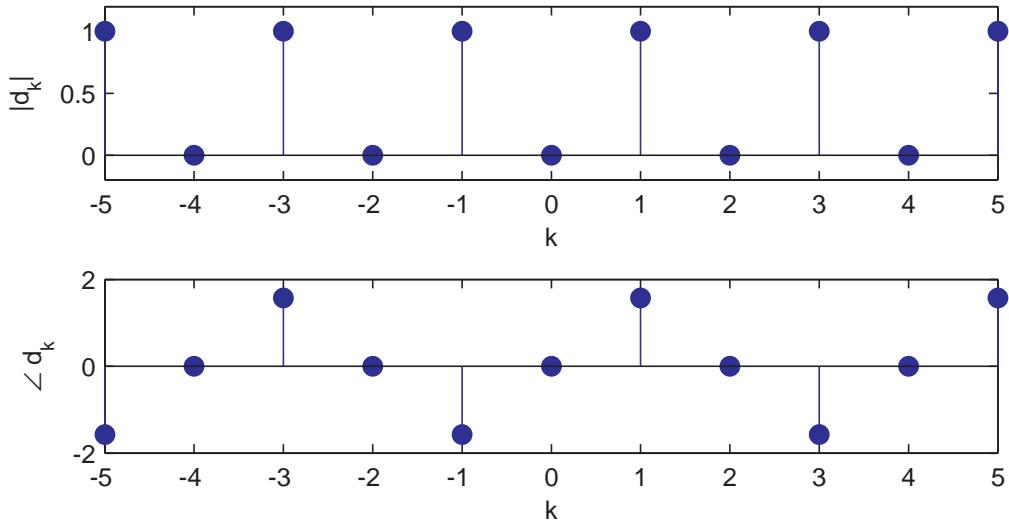
$$c_k = \begin{cases} 1/2 & k = 0 \\ \frac{1}{k\pi} \sin(k\pi/2) & \text{otherwise.} \end{cases}$$

Use this information to find a Fourier series expansion for the signal  $y(t) = \frac{d}{dt}x(t)$ , and plot the magnitude and phase spectrum of  $y(t)$  over the range  $k = -5$  to  $k = 5$ .

We can write

$$\begin{aligned} y(t) &= \frac{d}{dt}x(t) = \sum_{k=-\infty}^{\infty} c_k \frac{d}{dt} e^{jk\pi t} \\ &= \sum_{k=-\infty}^{\infty} c_k j k \pi e^{jk\pi t}. \end{aligned}$$

This is in the form of a Fourier series  $y(t) = \sum_{k=-\infty}^{\infty} d_k e^{jk\pi t}$  with  $d_k = j k \pi c_k$ , the values of which can be obtained from the expressions given. Plots as follows:



3. (5 marks) An LTI system is driven by the input signal  $x(t) = e^{j\frac{\pi}{2}t}$ .

- (a) Find the output  $y_1(t)$  if the impulse response of the system is  $h_1(t) = \delta(t - 1)$ .
- (b) Find the output  $y_2(t)$  if the impulse response of the system is  $h_2(t) = p_1(t)$  (the pulse of unit width centered on the origin).

- (a) The system delays the input by one time unit, so the output will be

$$y_1(t) = x_1(t - 1) = e^{j\frac{\pi}{2}(t-1)}.$$

- (b) The output will be

$$\begin{aligned} y_2(t) &= \int_{-\infty}^{\infty} h_2(\tau)x(t - \tau)d\tau = \int_{-\infty}^{\infty} p_1(\tau)e^{j\frac{\pi}{2}(t-\tau)}d\tau \\ &= \left( \int_{-\infty}^{\infty} p_1(\tau)e^{-j\frac{\pi}{2}\tau}d\tau \right) e^{j\frac{\pi}{2}t} = P_1(\pi/2)e^{j\frac{\pi}{2}t}, \end{aligned}$$

where  $P_1(\omega) = \mathcal{F}\{p_1(t)\}$ . But from Fourier tables (or otherwise) we know that

$$P_1(\omega) = \text{sinc}\left(\frac{\omega}{2\pi}\right) = \frac{2}{\omega} \sin(\omega/2),$$

so the output is

$$y_2(t) = P_1(\pi/2)e^{j\frac{\pi}{2}t} = \frac{4}{\sqrt{2\pi}}e^{j\frac{\pi}{2}t}.$$

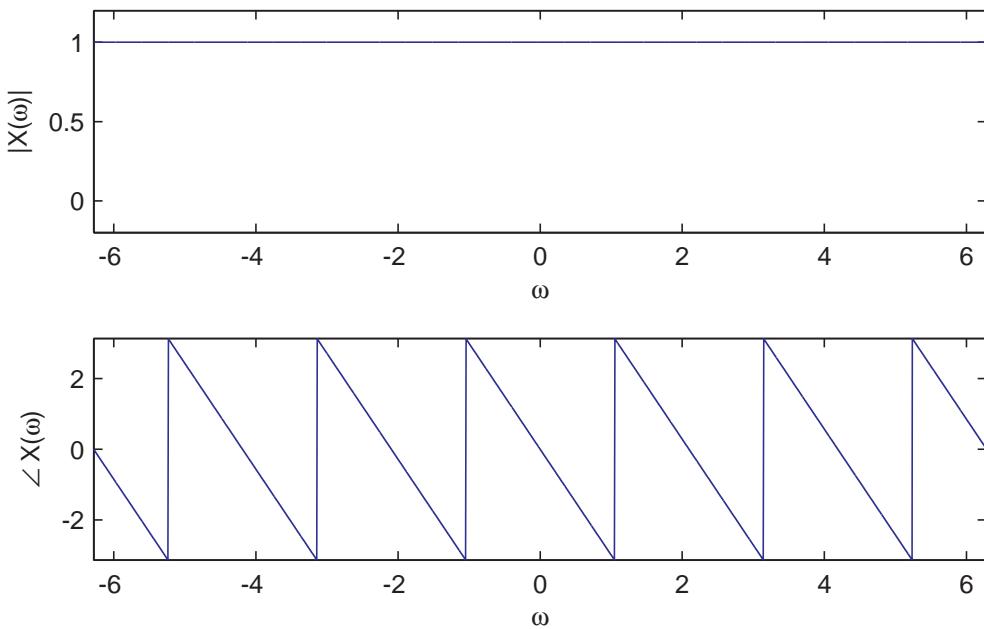

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4. (5 marks) Find the Fourier transform of the signal  $x(t) = \delta(t - 3)$  and plot the resulting magnitude and phase as a function of  $\omega$ . The values in your phase plot should range between  $-\pi$  and  $-\pi$ .

The Fourier transform is

$$\begin{aligned} X(\omega) &= \int_{-\infty}^{\infty} x(t)e^{-j\omega t} dt = \int_{-\infty}^{\infty} \delta(t - 3)e^{-j\omega t} dt = \int_{-\infty}^{\infty} \delta(t - 3)e^{-j\omega 3} dt \\ &= e^{-j\omega 3} \int_{-\infty}^{\infty} \delta(t - 3)dt = e^{-j\omega 3}. \end{aligned}$$

This is already in polar form so  $|X(\omega)| = 1$  and  $\angle X(\omega) = -3\omega$ . Plots as follows:



# INFORMATION SHEET

## Fourier transform properties

Property	Transform Pair/Property
Linearity	$ax(t) + bv(t) \leftrightarrow aX(\omega) + bV(\omega)$
Time shift	$x(t - c) \leftrightarrow X(\omega)e^{-j\omega c}$
Time scaling	$x(at) \leftrightarrow \frac{1}{a}X(\frac{\omega}{a}) \quad a > 0$
Time reversal	$x(-t) \leftrightarrow X(-\omega) = \overline{X(\omega)}$
Multiplication by power of $t$	$t^n x(t) \leftrightarrow j^n \frac{d^n}{d\omega^n} X(\omega) \quad n = 1, 2, \dots$
Frequency shift	$x(t)e^{j\omega_0 t} \leftrightarrow X(\omega - \omega_0) \quad \omega_0 \text{ real}$
Multiplication by $\cos(\omega_0 t)$	$x(t)\cos(\omega_0 t) \leftrightarrow \frac{1}{2}[X(\omega + \omega_0) + X(\omega - \omega_0)]$
Differentiation in time domain	$\frac{d^n}{dt^n}x(t) \leftrightarrow (j\omega)^n X(\omega) \quad n = 1, 2, \dots$
Integration	$\int_{-\infty}^t x(\lambda)d\lambda \leftrightarrow \frac{1}{j\omega}X(\omega) + \pi X(0)\delta(\omega)$
Convolution in time domain	$x(t) * v(t) \leftrightarrow X(\omega)V(\omega)$
Multiplication in time domain	$x(t)v(t) \leftrightarrow \frac{1}{2\pi}X(\omega) * V(\omega)$
Parseval's theorem	$\int_{-\infty}^{\infty} x(t)v(t)dt = \frac{1}{2\pi} \int_{-\infty}^{\infty} \overline{X(\omega)}V(\omega)d\omega$
Parseval's theorem (special case)	$\int_{-\infty}^{\infty} x^2(t)dt = \frac{1}{2\pi} \int_{-\infty}^{\infty}  X(\omega) ^2 d\omega$
Duality	$X(t) \leftrightarrow 2\pi x(-\omega)$

## Common Fourier Transform Pairs

$x(t) = \frac{1}{2\pi} \int_{-\infty}^{\infty} X(\omega)e^{j\omega t} d\omega$	$X(\omega) = \int_{-\infty}^{\infty} x(t)e^{-j\omega t} dt$
1 ( $-\infty < t < \infty$ )	$2\pi\delta(\omega)$
$-0.5 + u(t)$	$\frac{1}{j\omega}$
$u(t)$	$\pi\delta(\omega) + \frac{1}{j\omega}$
$\delta(t)$	1
$\delta(t - c)$	$e^{-j\omega c} \quad (c \text{ any real number})$
$e^{-bt}u(t)$	$\frac{1}{j\omega+b} \quad (b > 0)$
$e^{j\omega_0 t}$	$2\pi\delta(\omega - \omega_0) \quad (\omega_0 \text{ any real number})$
$p_{\tau}(t)$	$\tau \text{sinc} \frac{\tau\omega}{2\pi}$
$\tau \text{sinc} \frac{\tau t}{2\pi}$	$2\pi p_{\tau}(\omega)$
$\left(1 - \frac{2 t }{\tau}\right) p_{\tau}(t)$	$\frac{\tau}{2} \text{sinc}^2 \left(\frac{\tau\omega}{4\pi}\right)$
$\frac{\tau}{2} \text{sinc}^2 \frac{\tau t}{4\pi}$	$2\pi \left(1 - \frac{2 \omega }{\tau}\right) p_{\tau}(\omega)$
$\cos(\omega_0 t + \theta)$	$\pi[e^{-j\theta}\delta(\omega + \omega_0) + e^{j\theta}\delta(\omega - \omega_0)]$
$\sin(\omega_0 t + \theta)$	$j\pi[e^{-j\theta}\delta(\omega + \omega_0) - e^{j\theta}\delta(\omega - \omega_0)]$

## Trigonometric identities

$$\begin{aligned}
 \sin(-\theta) &= -\sin(\theta) & \cos(-\theta) &= \cos(\theta) & \tan(-\theta) &= -\tan(\theta) \\
 \sin^2(\theta) + \cos^2(\theta) &= 1 & \sin(2\theta) &= 2\sin(\theta)\cos(\theta) \\
 \cos(2\theta) &= \cos^2(\theta) - \sin^2(\theta) = 2\cos^2(\theta) - 1 = 1 - 2\sin^2(\theta) \\
 \sin(\theta_1 + \theta_2) &= \sin(\theta_1)\cos(\theta_2) + \cos(\theta_1)\sin(\theta_2) & \cos(\theta_1 + \theta_2) &= \cos(\theta_1)\cos(\theta_2) - \sin(\theta_1)\sin(\theta_2) \\
 e^{j\theta} &= \cos(\theta) + j\sin(\theta)
 \end{aligned}$$