

Chapter 1

Signals and Spectra

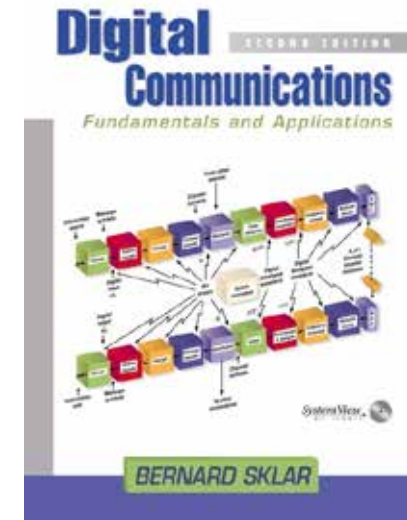
Instructor: Prof. Peter Lian
Department of Electrical
Engineering & Computer Science
Lassonde School of Engineering
York University

CSE4214 Digital Communications

- Instructor: Prof. Peter Lian
 - email: peterlian@cse.yorku.ca
 - tel: 416-736-2100 ext 44647
- Course Web:
 - https://wiki.cse.yorku.ca/course_archive/2013-14/F/4214/
- Schedule:
 - Lectures: TR 14:30 – 16:00, Room CB120
 - Labs: F 10:30 – 13:30, LAS 3057
- Office hours: TR 13:00 – 14:00 @ LAS 1012C

CSE2021 Computer Organization

- Text book:
Digital Communications:
Fundamentals and Applications
2nd Edition, by Bernard Sklar
Prentice Hall (Pearson)
ISBN 0-13-084788-7
- Assessment:
 - Assignments: 10%
 - Quizzes: 10%
 - Lab projects: 20%
 - Midterm test: 25%
 - Final exam: 35%



CSE4214 Digital Communications

- Topics covered:
 - Introduction
 - Signal and Spectra
 - Formatting and baseband modulation
 - Baseband demodulation/detection
 - Bandpass modulation and demodulation/detection
 - Communication link analysis
 - Channel coding

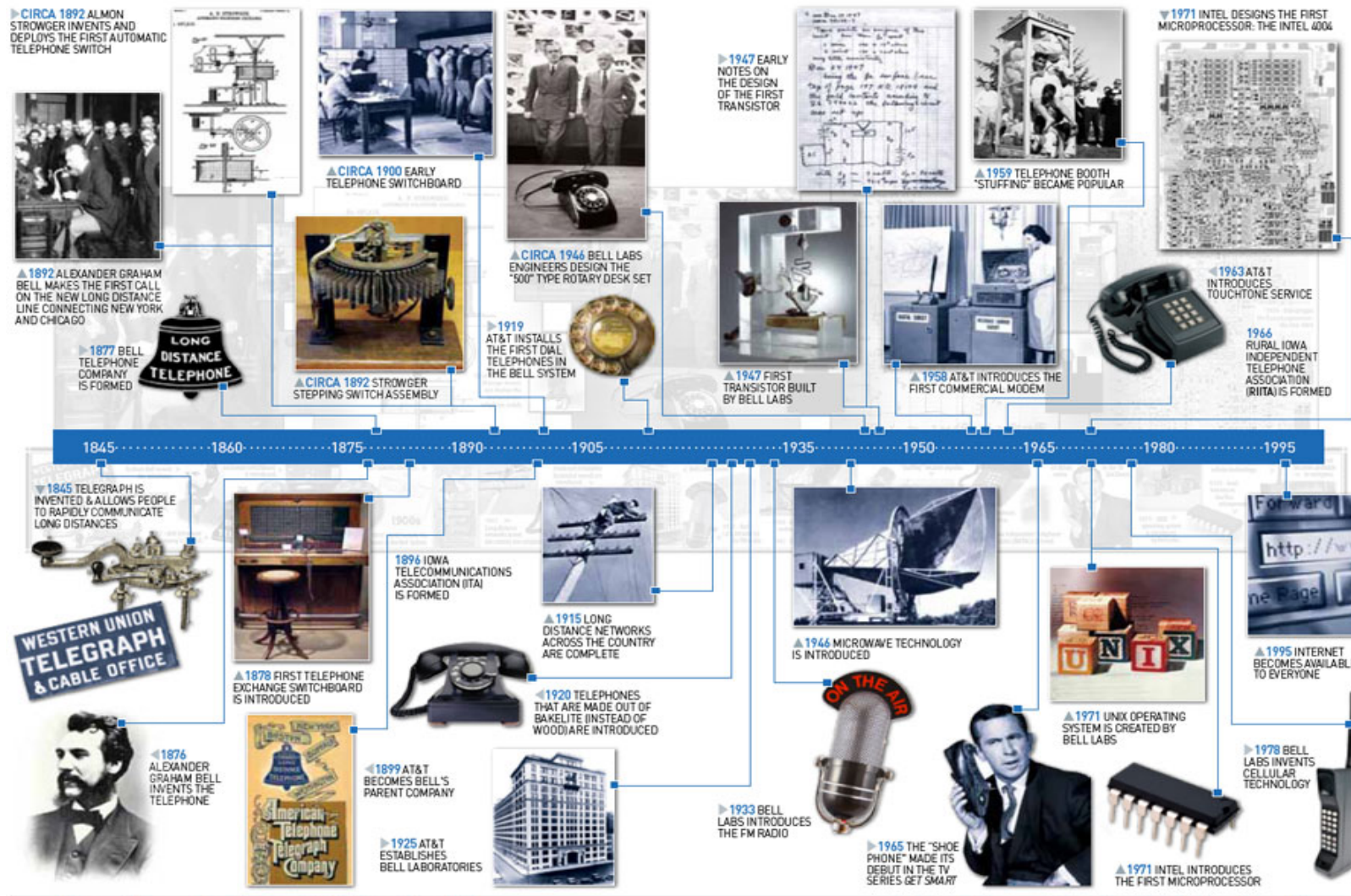
Introduction

Introduction

- The main objective of a communication system is to transfer information over a channel



Evolution of Communications



150 Years of Telecom—From the Telegraph to the Internet; Room 108E

150 Years of Telecom—From the Telegraph to the Internet; Room 108E

Milestones

- Electrical telegraphy ~1840
 - Samuel F. B. Morse inventor of the most practical form of electrical telegraphy – Morse code



International Morse Code

1. A dash is equal to three dots.
2. The space between parts of the same letter is equal to one dot.
3. The space between two letters is equal to three dots.
4. The space between two words is equal to seven dots.



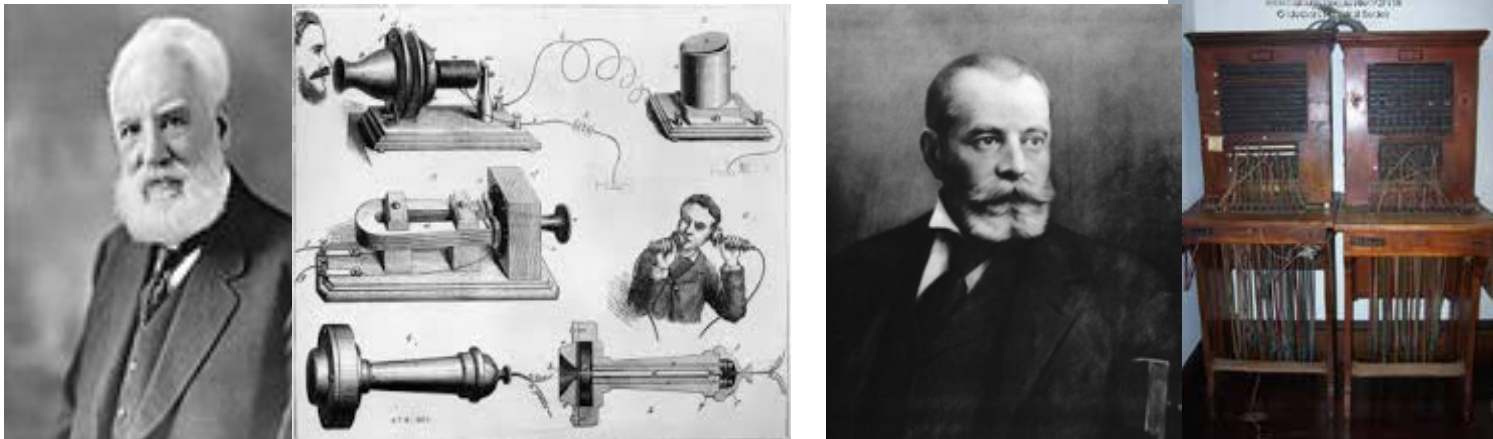
A	• —	U	• • • —
B	• • • — • •	V	• • • — •
C	• • • — • • •	W	• • • — —
D	• • • — •	X	• • • — • •
E	• • •	Y	• • • — • • •
F	• • • — • • •	Z	• • • — • • • •
G	• • • — • • • •		
H	• • • • •		
I	• • • •		
J	• • • — • • • •		
K	• • • — • • • • •		
L	• • • — • • • • • •		
M	• • • — • • • • • • •		
N	• • • — • • • • • • • •		
O	• • • — • • • • • • • • •		
P	• • • — • • • • • • • • • •		
Q	• • • — • • • • • • • • • • •		
R	• • • — • • • • • • • • • • • •		
S	• • • • • • •		
T	• • • • • • • •		
		1	• • • — • • • •
		2	• • • — • • • • •
		3	• • • — • • • • • •
		4	• • • — • • • • • • •
		5	• • • — • • • • • • • •
		6	• • • — • • • • • • • • •
		7	• • • — • • • • • • • • • •
		8	• • • — • • • • • • • • • • •
		9	• • • — • • • • • • • • • • • •
		0	• • • — • • • • • • • • • • • • •



The Americas' first telegram, transmitted via a repeater: "*What hath God wrought*", sent by Samuel F.B. Morse in 1844

Milestones

- Telephone
 - Alexander Graham Bell was awarded the first US patent for the invention of the telephone in 1876
 - Tivadar Puskás invented the telephone exchange switchboard in 1876



Milestones

- Wireless telegraphy
 - Guglielmo Marconi begin his wireless experiments in 1895, and the patent for wireless telegraphy in 1896.
 - In 1896, Alexandr Popov demonstrated a similar wireless system in Russia.



Wireless Communications

1973
The first public phone call on a cell phone is made to a land line.

1975
Personal computers become widely available.

1979
The Advanced Research Projects Agency (a division of the U.S. Department of Defense) develops a computer network called ARPAnet, which evolves into the Internet.

1983
The first commercial cellular system begins operating in Chicago.

1984
The "brick" is introduced. It's the first commercially available mobile radiotelephone and cost almost \$4,000.

1985
There are about 340,000 cell phone subscribers in the U.S.

1991
The precursor to Wi-Fi is created.

1993
The first smartphone (IBM's Simon) is released, offering features like email.

1994
The digital camera is invented.

1995
The average U.S. cell phone subscriber uses his/her phone for 115 minutes per month.

2000
The first Bluetooth® wireless headset for mobilephones is released. And Samsung Mobile introduces the first mobilephone with an MP3 player to the U.S.

2003
Samsung Mobile launches the first touchscreen phone, the SPH-1700 with Verizon Wireless.

2005
Cell phone subscribers number almost 208 million in the U.S.

2008
The average U.S. wireless consumer uses his/her phone for 708 minutes per month.

2009
Samsung Mobile launches the Samsung Reclaim™ with Sprint, the first phone in the U.S. constructed from eco-friendly bio-plastic materials.

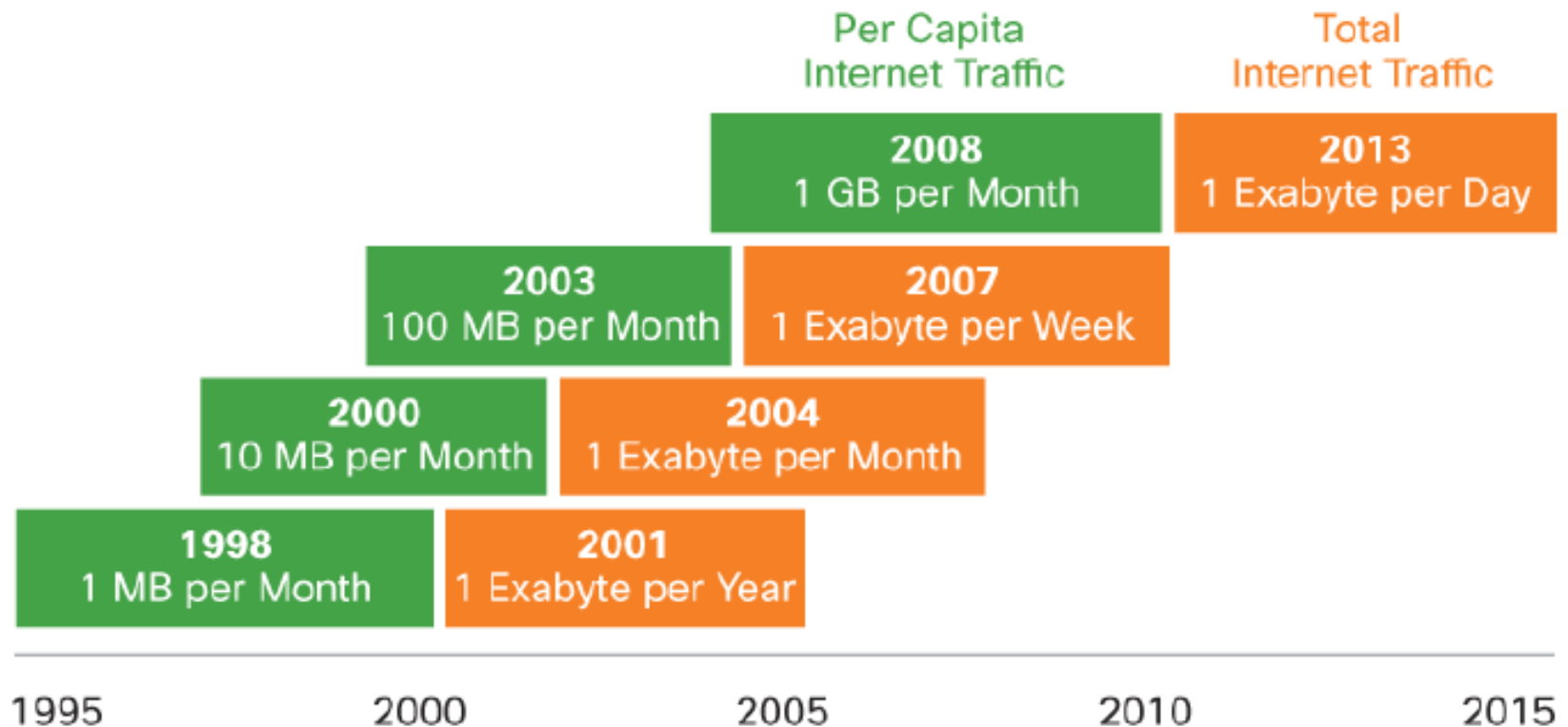
2010
Tablet computers and 4G handsets become available.

2010
U.S. wireless consumers use more than 2.2 trillion minutes, and send and receive more than 2 billion text messages a year.

2011
Worldwide, about 30,000,000 apps are downloaded each day.

Source: <http://www.samsung.com/us/wow/wireless.html>

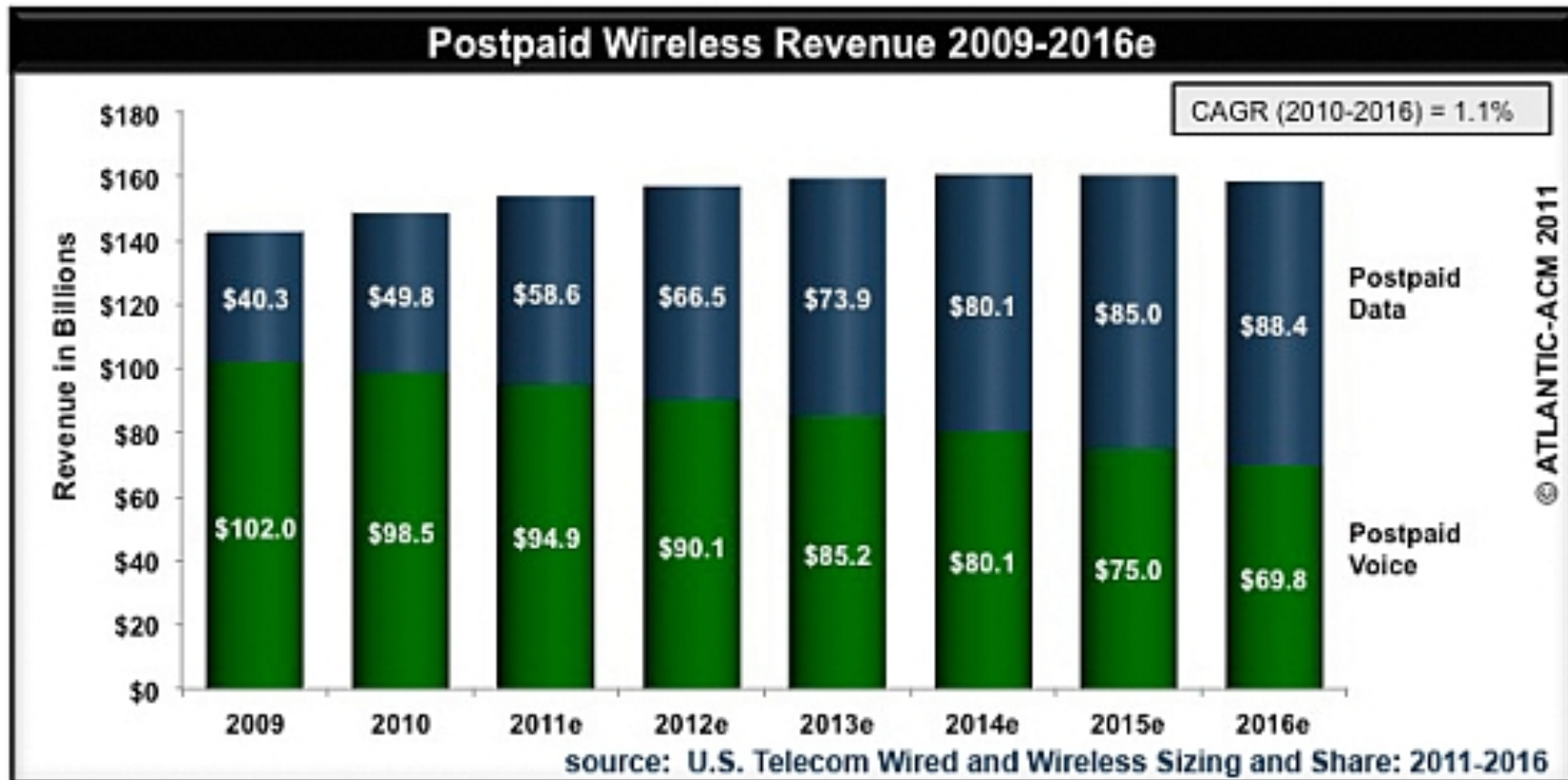
Internet Traffic Trend



Source: Cisco VNI, 2011

By the end of 2015, annual global IP traffic will reach the zettabyte threshold

Wireless Revenue

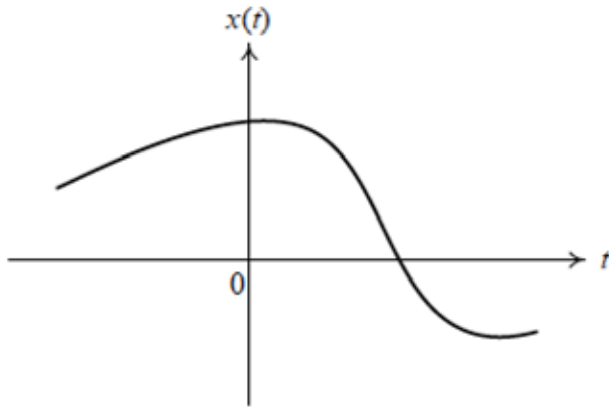


Share	2009	2010	2011e	2012e	2013e	2014e	2015e	2016e	CAGR (10-16e)
Postpaid Data	28.3%	33.6%	38.2%	42.5%	46.4%	50.0%	53.1%	55.9%	10.0%
Postpaid Voice	71.7%	66.4%	61.8%	57.5%	53.6%	50.0%	46.9%	44.1%	-5.6%

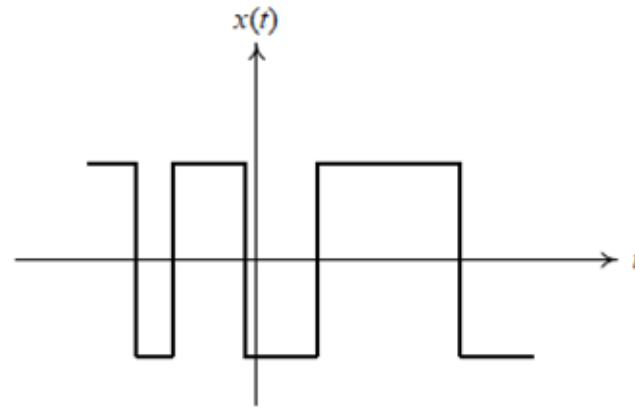
Source: <http://www.billingworld.com/blogs/fedor/2011/08/changing-wireless-market-revenues.aspx>

Why digital ?

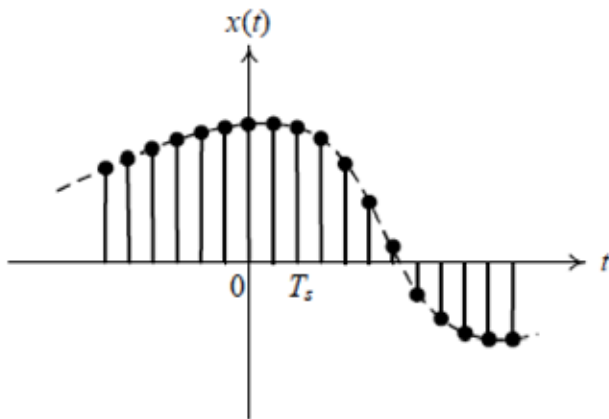
Analog and Digital Signals



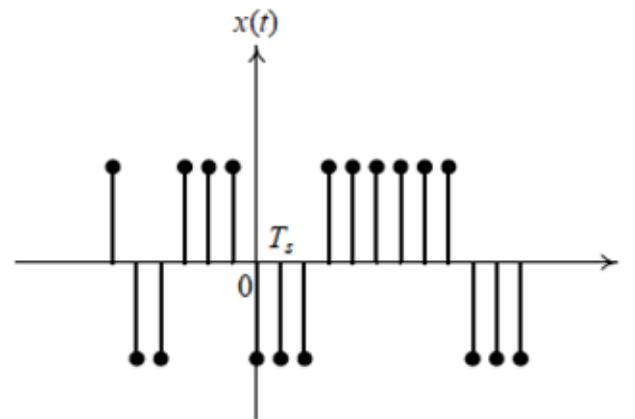
(a)



(b)



(c)

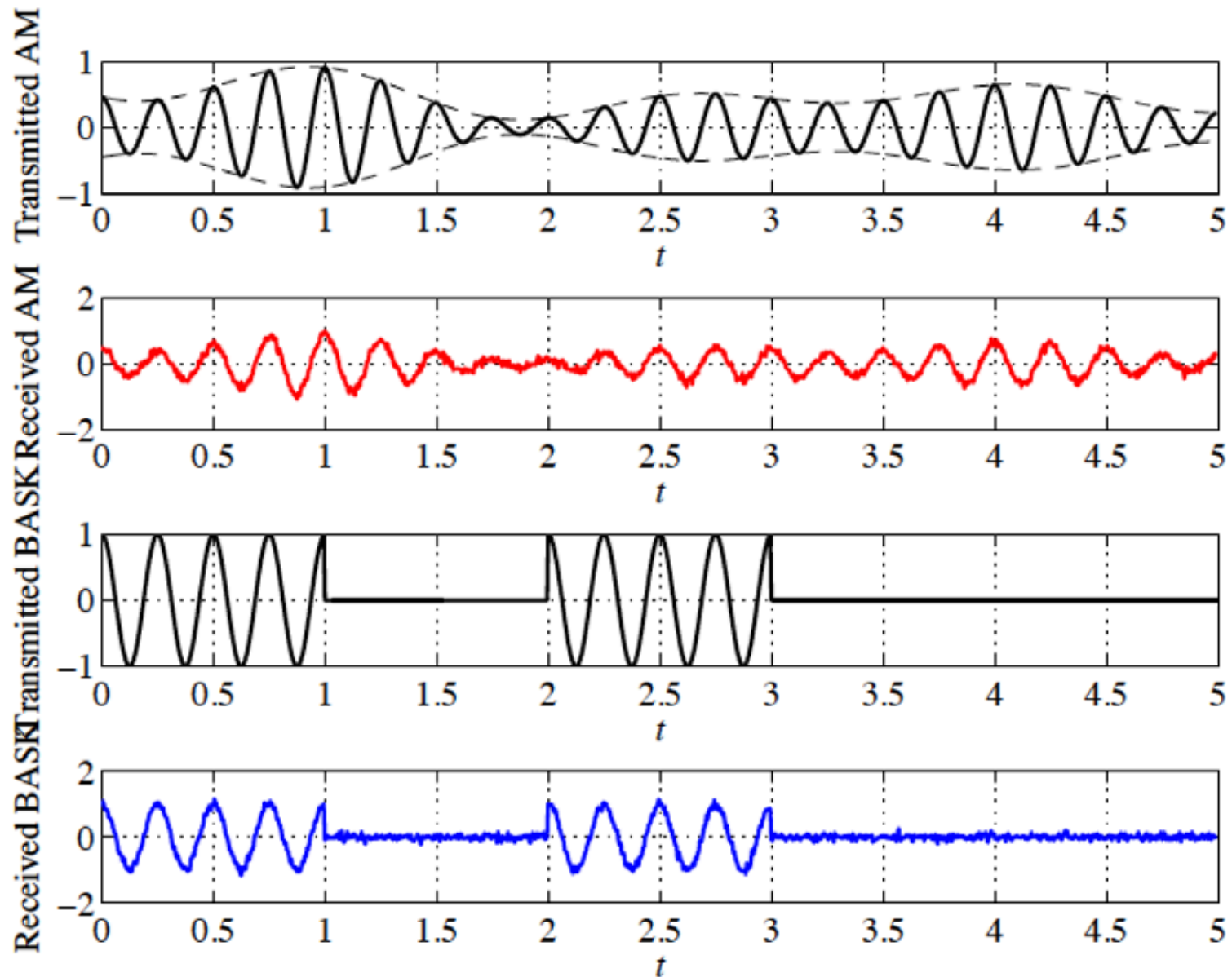


(d)

Analog versus Digital

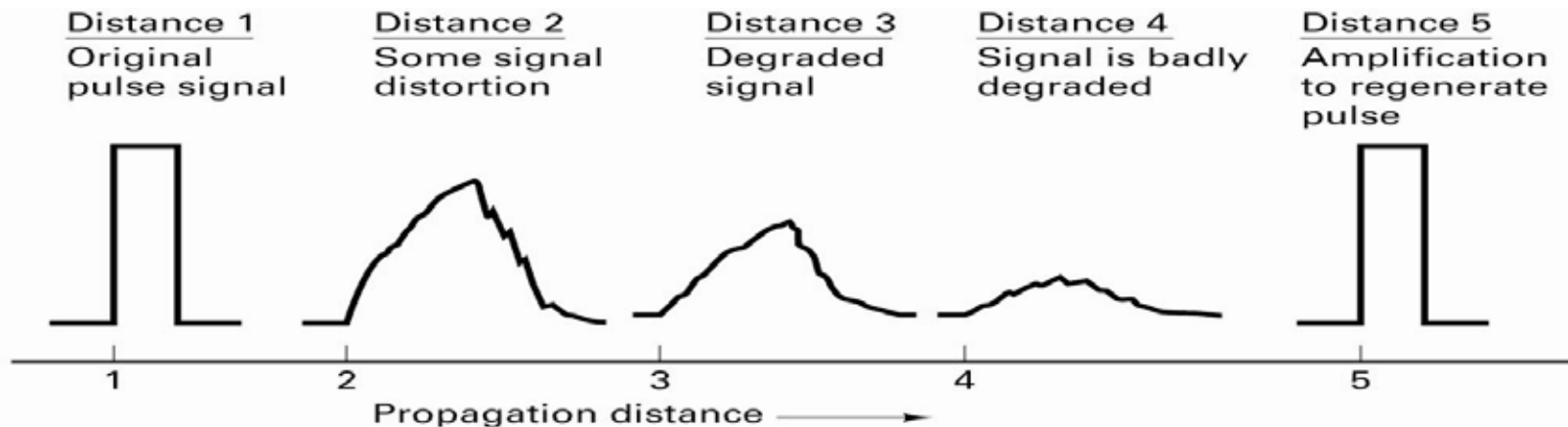
Analog	Digital
Compute on a continuous set, e.g. real numbers	Compute on a discrete set, e.g. 0,1
Difficult to implement arbitrary nonlinear operations	Can implement arbitrary nonlinear operations
Noise prone	Less sensitive to variations in environment
Graceful degradation	No-graceful degradation
Generally not programmable	Is programmable
High cost	Low cost

Analog versus Digital

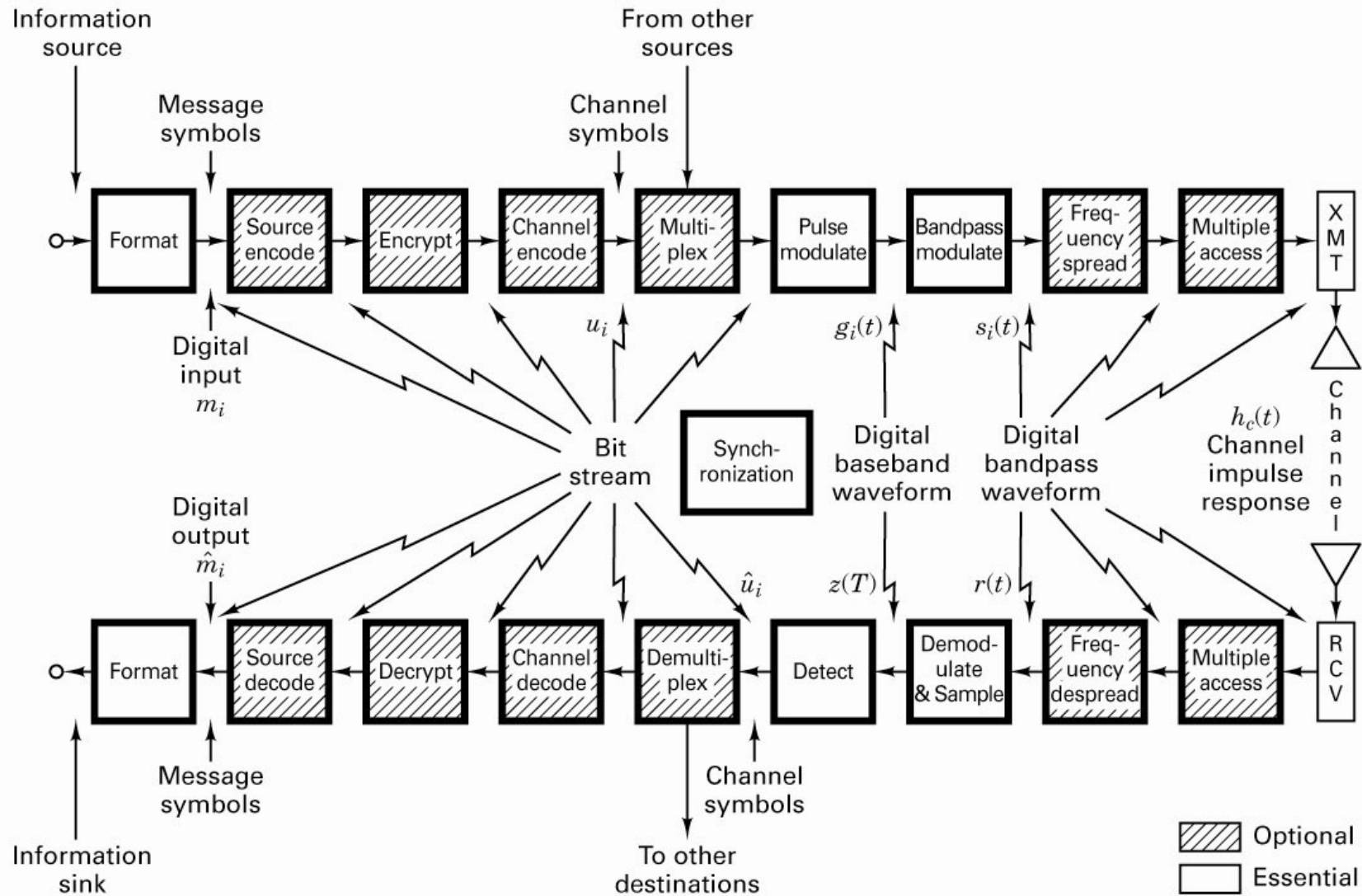


Why Digital?

- Less subject to distortion and interference
- Digital signal processing is more reliable and less expensive than analog signal processing
- Digital communication techniques lend themselves naturally to channel coding for:
 - Protection against jamming and interference
 - Secure transmission



Digital Communication System



Transformation in Digital Communications

Formatting

Character coding
Sampling
Quantization
Pulse code modulation (PCM)

Source Coding

Predictive coding
Block coding
Variable length coding
Synthesis/analysis coding
Lossless compression
Lossy compression

Baseband Signaling

PCM waveforms (line codes)
Nonreturn-to-zero (NRZ)
Return-to-zero (RZ)
Phase encoded
Multilevel binary
M-ary pulse modulation
PAM, PPM, PDM

Equalization

Maximum-likelihood sequence estimation (MLSE)
Equalization with filters
Transversal or decision feedback
Preset or Adaptive
Symbol spaced or fractionally spaced

Bandpass Signaling

Coherent

Phase shift keying (PSK)
Frequency shift keying (FSK)
Amplitude shift keying (ASK)
Continuous phase modulation (CPM)
Hybrids

Noncoherent

Differential phase shift keying (DPSK)
Frequency shift keying (FSK)
Amplitude shift keying (ASK)
Continuous phase modulation (CPM)
Hybrids

Channel Coding

Waveform

M-ary signaling
Antipodal
Orthogonal
Trellis-coded modulation

Structured Sequences

Block
Convolutional
Turbo

Synchronization

Frequency synchronization
Phase synchronization
Symbol synchronization
Frame synchronization
Network synchronization

Multiplexing/Multiple Access

Frequency division (FDM/FDMA)
Time division (TDM/TDMA)
Code division (CDM/CDMA)
Space division (SDMA)
Polarization division (PDMA)

Spreading

Direct sequencing (DS)
Frequency hopping (FH)
Time hopping (TH)
Hybrids

Encryption

Block
Data stream

Classification of Signals

Classification of Signals

- Deterministic versus Random Signals.
- Continuous-time (CT) versus Discrete-time (DT) Signals.
- Analog versus Digital Signals.
- Periodic versus Aperiodic Signals
- Odd and Even Signals.
- Energy versus Power Signals.

Deterministic vs Random Signals

■ Deterministic Signals:

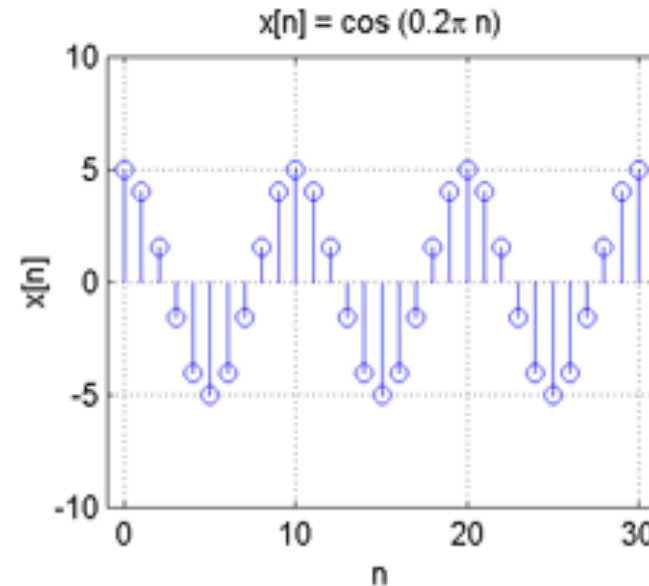
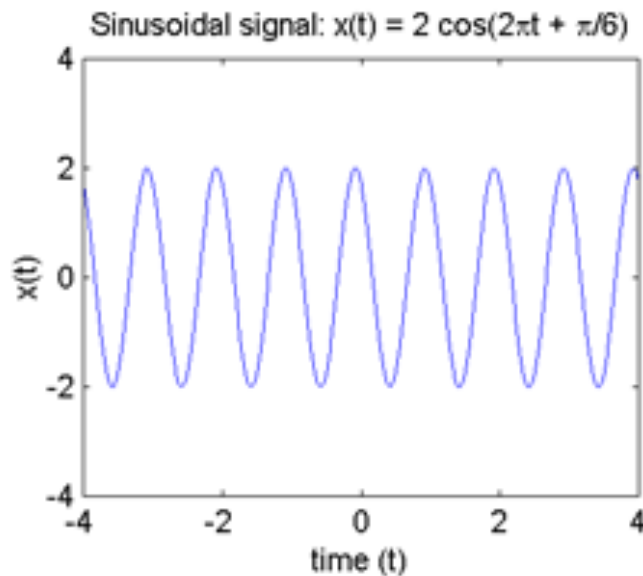
- Defined for all time
- No uncertainty with respect to the value of the signal
- Represented using a mathematical expression, e.g., $x(t) = \sin(5\pi t + 30^\circ)$.

■ Random Signals:

- Are not known accurately for all instants of times
- Different observations may lead to different results
- Statistical properties such as mean, variance, or probability density function (pdf) are used to define the random signal

Continuous-time vs Discrete-time Signals

- Continuous-time Signals
 - Defined for all instants of time.
- Discrete-time Signals
 - Defined at discrete values of time

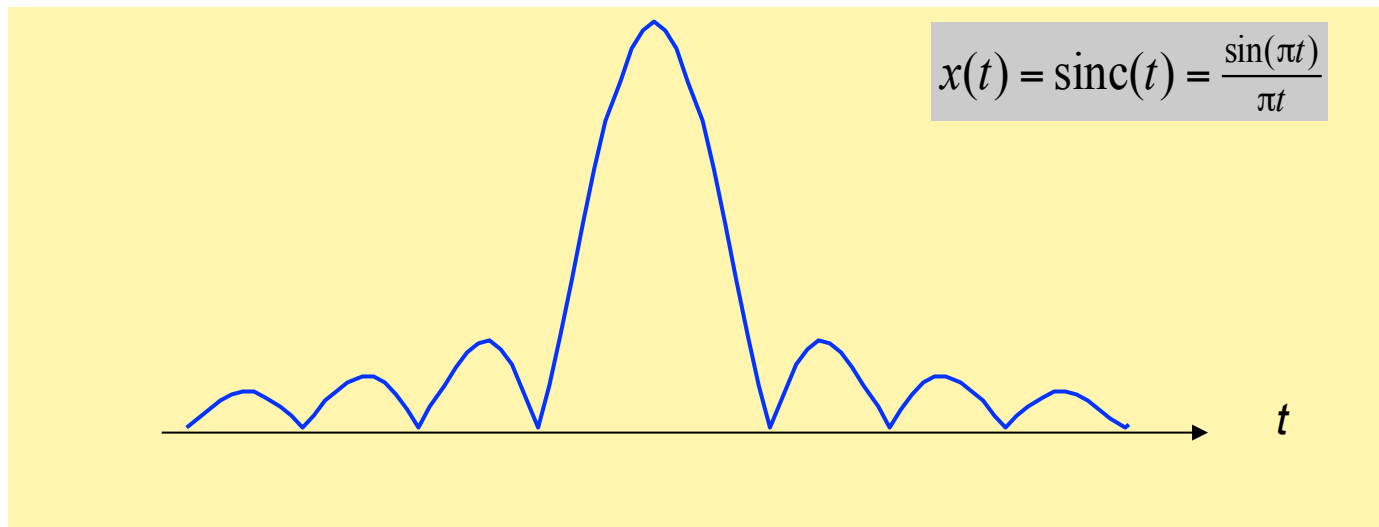


Activity 1

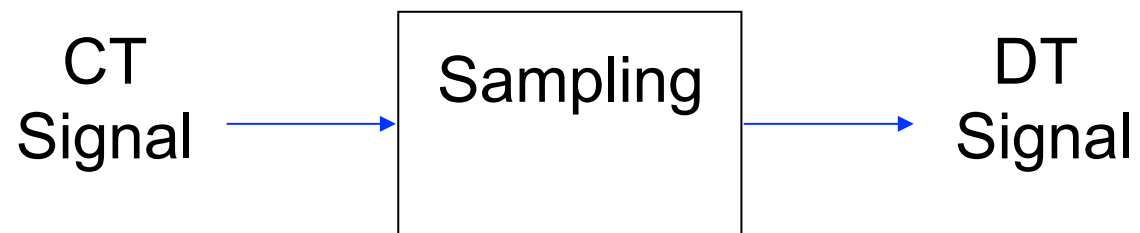
Plot the CT signal $x(t) = \sin(5\pi t + 30^\circ)$.
Discretize the CT signal with a uniform sampling period of $T_s = 0.25\text{s}$. Sketch the resulting waveforms.

Analog vs Digital Signals

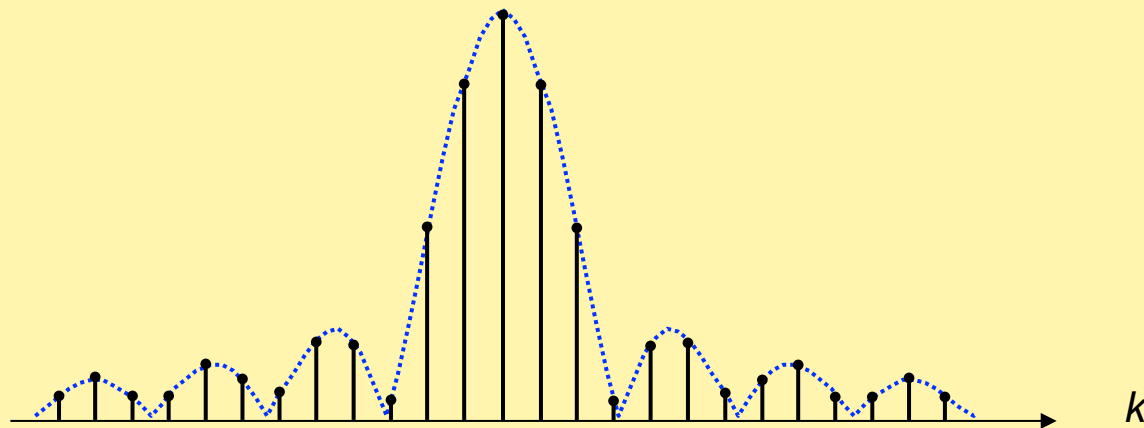
- Analog Signals:
 - Defined for all instants of time. Amplitude can take on any value.
- Digital Signals:
 - Defined at discrete values of time. Amplitude is restricted to finite set of values.



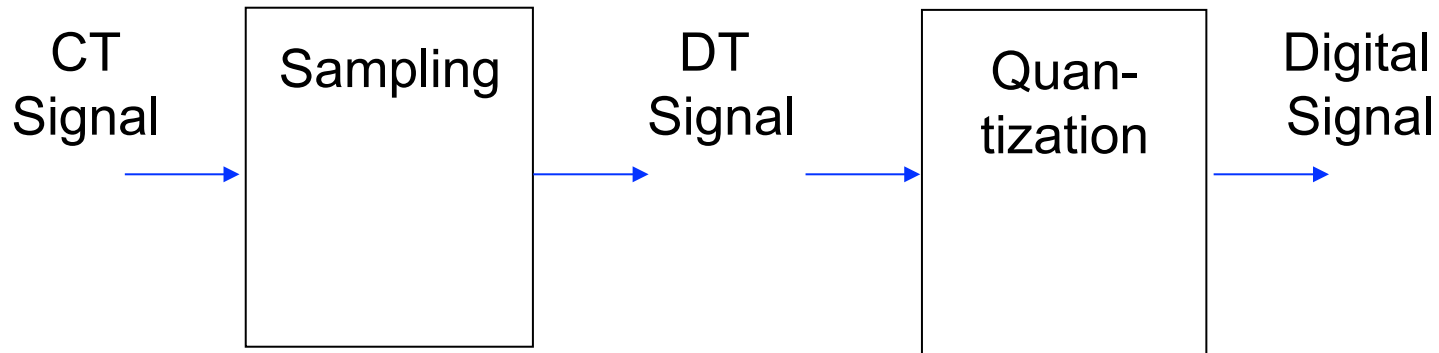
Analog vs Digital Signals



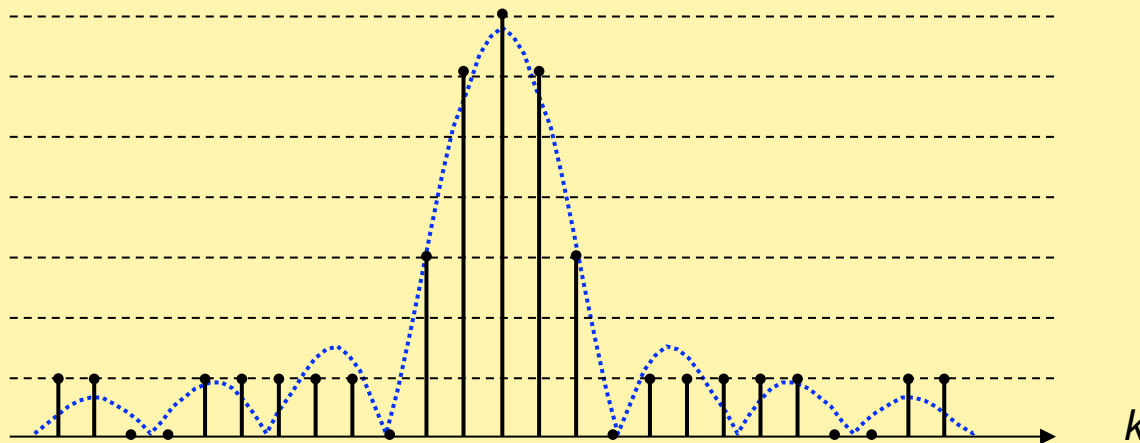
$$x[k] = x(t) \Big|_{t=kT_s} = \text{sinc}(kT_s) = \frac{\sin(\pi kT_s)}{\pi kT_s}$$



Analog vs Digital Signals



$$x_q[k] = [x[k]]_q = \left[\frac{\sin(\pi k T_s)}{\pi k T_s} \right]_q$$



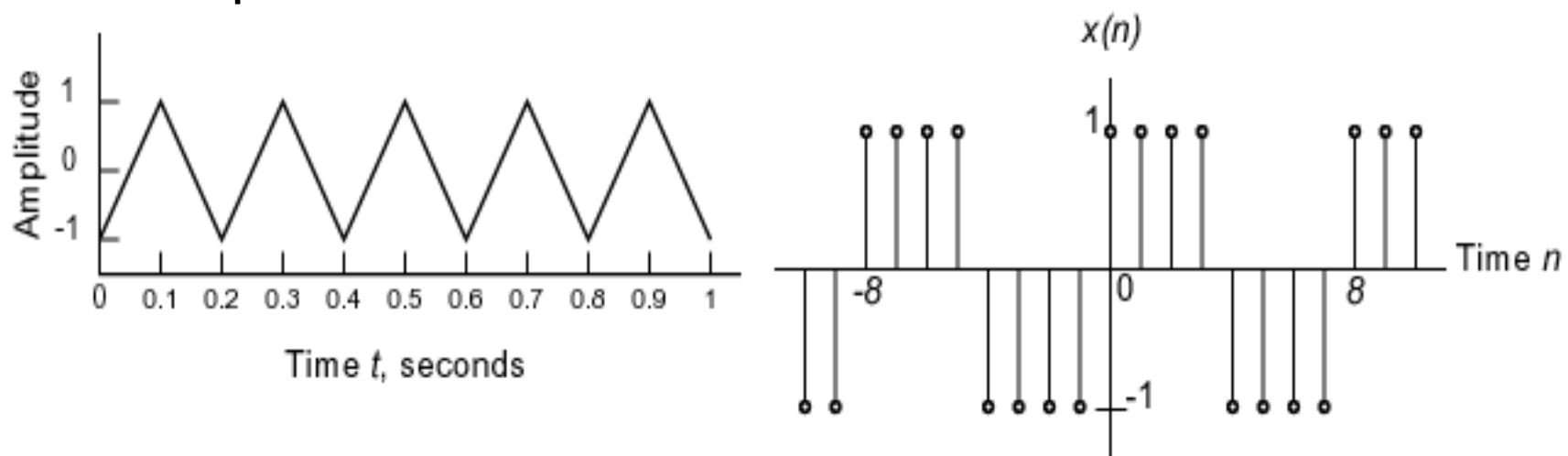
Periodic vs Aperiodic Signals

- Periodic signals: A periodic signal $x(t)$ is a function of time that satisfies the condition

$$x(t) = x(t + T_0) \text{ for all } t$$

where T_0 is a positive constant number and is referred to as the fundamental period of the signal.

- Fundamental frequency (f_0) is the inverse of the period of the signal. It is measured in Hertz (Hz = 1/s).
- Nonperiodic (Aperiodic) signals: are those that do not repeat themselves.



Activity 2

For the following sinusoidal signals

(a) $x[k] = \sin(5\pi k)$

(b) $y[k] = \cos(k/3)$

Determine the fundamental period K_0 of the DT signals.

Even vs Odd Signals

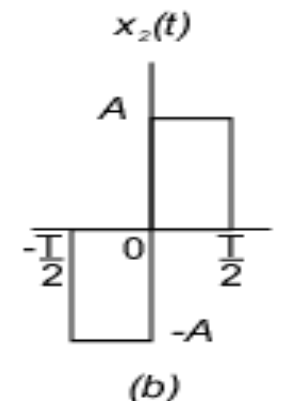
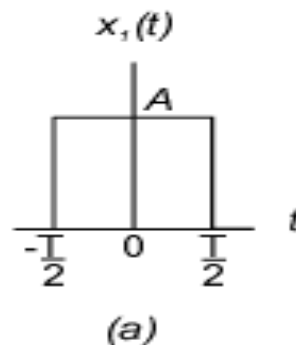
1. Even Signal: A CT signal $x(t)$ is said to be an even signal if it satisfies the condition :

$$x(-t) = x(t) \text{ for all } t.$$

1. Odd Signal: The CT signal $x(t)$ is said to be an odd signal if it satisfies the condition

$$x(-t) = -x(t) \text{ for all } t.$$

2. Even signals are symmetric about the vertical axis or time origin.
3. Odd signals are antisymmetric (or asymmetric) about the time origin.



Even vs Odd Signals

5. Signals that satisfy neither the even property nor the odd property can be divided into even and odd components based on the following equations:

$$\text{Even component of } x(t) = 1/2 [x(t) + x(-t)]$$

$$\text{Odd component of } x(t) = 1/2 [x(t) - x(-t)]$$

Activity 3

For the signal

$$Y=1-|x-1|$$

do the following:

- (a) sketch the signal
- (b) evaluate the odd part of the signal
- (c) evaluate the even part of the signal.

Energy vs Power Signals

Energy:

$$E_{\infty} = \begin{cases} \int_{-\infty}^{\infty} |x^2(t)| dt & \text{for CT Signals} \\ \sum_{-\infty}^{\infty} |x[k]|^2 & \text{for DT Signals} \end{cases}$$

Power:

$$P_{\infty} = \begin{cases} \lim_{T \rightarrow \infty} \frac{1}{T} \int_{-T/2}^{T/2} |x(t)|^2 dt & \text{for CT Signals} \\ \lim_{N \rightarrow \infty} \frac{1}{N+1} \sum_{-N/2}^{N/2} |x[k]|^2 & \text{for DT Signals} \end{cases}$$

Energy vs Power Signals

1. Energy Signals: have finite total energy for the entire duration of the signal. As a consequence, total power in an energy signal is 0.
2. Power Signals: have non-zero power over the entire duration of the signal. As a consequence, the total energy in a power signal is infinite.
3. Periodic signals are always power signals with power given by

$$P_{\infty} = \begin{cases} \frac{1}{T_0} \int_{\langle T_0 \rangle} |x(t)|^2 & \text{for CT Signals} \\ \frac{1}{N_0} \sum_{\langle -N_0 \rangle} |x[k]|^2 & \text{for DT Signals} \end{cases}$$

Elementary Signal

■ Unit Impulse Function

- Defined from the following properties:

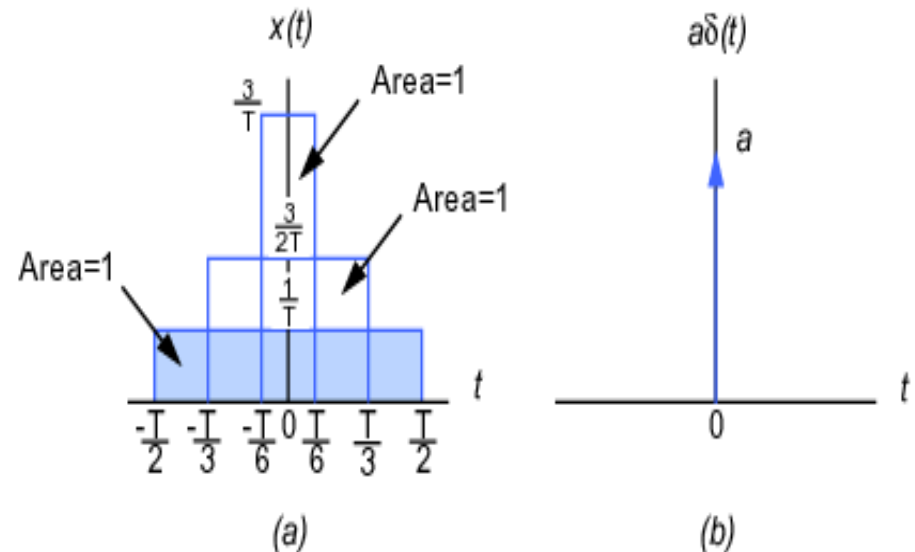
$$1. \quad \delta(t) = \begin{cases} \text{undefined} & t = 0 \\ 0 & t \neq 0 \end{cases}$$

$$2. \quad \int_{-\infty}^{\infty} \delta(t) dt = 1$$

$$3. \quad \delta(at) = \frac{1}{|a|} \delta(t)$$

$$4. \quad x(t)\delta(t - t_0) = x(t_0)\delta(t - t_0)$$

$$5. \quad \int_{-\infty}^{\infty} x(t)\delta(t - t_0) dt = x(t_0)$$



Activity 4

- Solve the integral

$$\int_{-\infty}^{\infty} (t^3 + 5t^2 + 5t + 25)\delta(t + 5)dt = x(t_o)$$

Deterministic Signals

- Energy and Spectral Density

- An energy (aperiodic) signal $x(t)$ can be represented by its **Fourier transform** $X(f)$

$$X(f) = \int_{-\infty}^{\infty} x(t) e^{-j2\pi ft} dt \quad \text{and} \quad x(t) = \int_{-\infty}^{\infty} X(f) e^{j2\pi ft} df$$

- The **energy spectral density** (ESD) of an energy signal is defined as

$$\psi_x(f) = |X(f)|^2$$

Energy and Spectral Density

- A power (periodic) signal $x(t)$ can be represented by its **Fourier Series**

$$x(t) = \sum_{n=-\infty}^{\infty} c_n e^{-j2\pi n f_0 t} \quad \text{where } c_n = \frac{1}{T_0} \int_{\langle T_0 \rangle} x(t) e^{j2\pi n f_0 t} dt$$

- The **power spectral density** (PSD) of a power signal is defined as

$$G_x(f) = \sum_{n=-\infty}^{\infty} |c_n|^2 \delta(f - n f_0)$$

Deterministic Signals

- Autocorrelation
 - The autocorrelation of an energy (aperiodic) signal $x(t)$ is defined as

$$R_x(\tau) = \int_{-\infty}^{\infty} x(t)x(t + \tau)dt$$

Autocorrelation

- The autocorrelation satisfies the following properties

1. $R_x(\tau) = R_x(-\tau)$ Even function w. r. t. τ
2. $R_x(\tau) \leq R_x(0)$ Maximum occurs at $\tau = 0$
3. $R_x(\tau) \xleftrightarrow{FT} \psi_x(f)$ Fourier transform pairs
4. $R_x(0) = \int_{-\infty}^{\infty} x^2(t) dt$ Value at the origin is equal to the energy of the signal