CSE4214 Digital Communications

Chapter 1

Signals and Spectra

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CSE4214 Digital Communications

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- Couse 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%

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

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Introduction

Introduction

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

Evolution of Communications

Source: http://www.dmacc.edu/ci/images/timeline-telecom.jpg

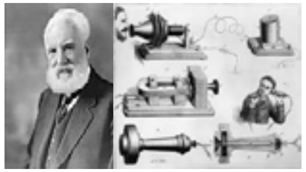
Milestones

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

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

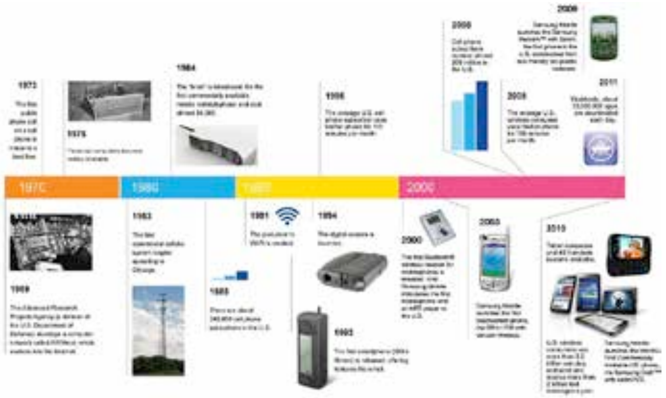


Milestones

- 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.

Source: http://www.ieeeghn.org/wiki/index.php/Wireless_Telegraphy

Wireless Communications

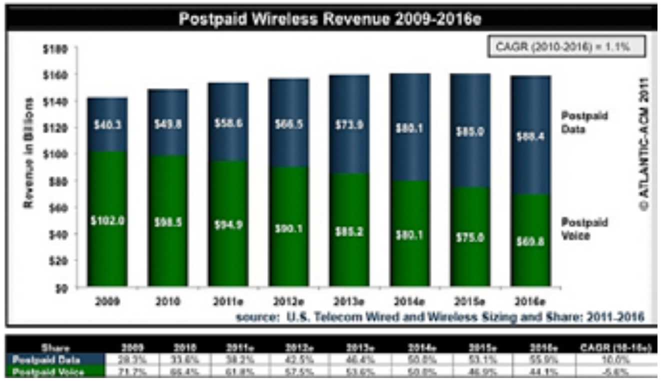


Source: http://www.samsung.com/us/wow/wireless.html

Internet Traffic Trend

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

Wireless Revenue



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

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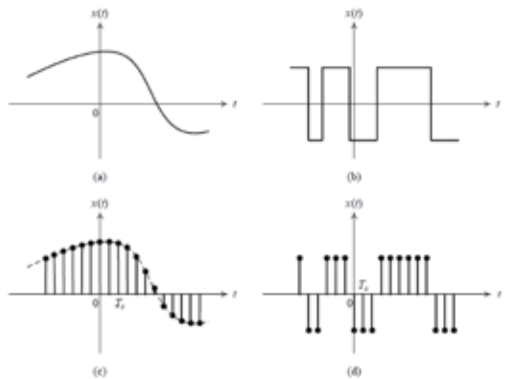
Why digital ?

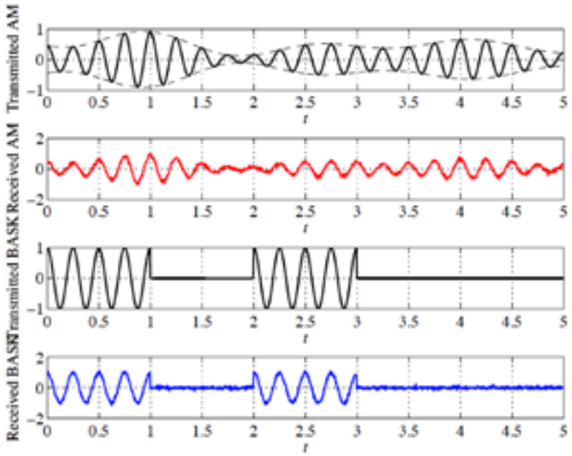
Analog and Digital Signals



Analog versus Digital

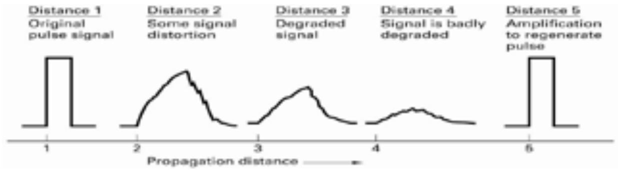
Analog	Digital
Compute on a continuous set, e.g. real numbers	Compute on a discrete set, e.g. 0,1
Difficult to implement arbitrary nonlinear operations	Can implement arbitrary nonlinear operations
Noise prone	Less sensitive to variations in environment
Graceful degradation	No-graceful degradation
Generally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

Analog versus Digital

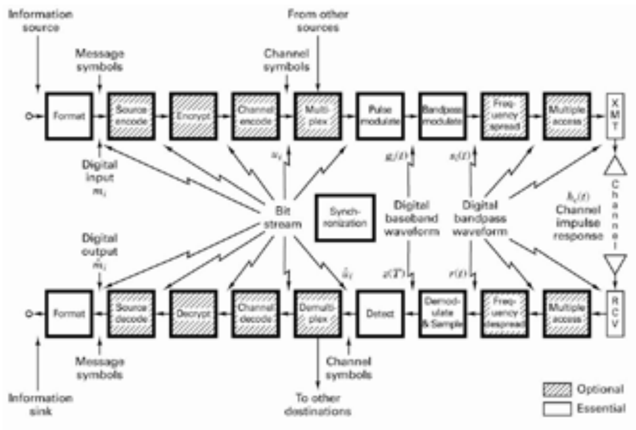


Why Digital?

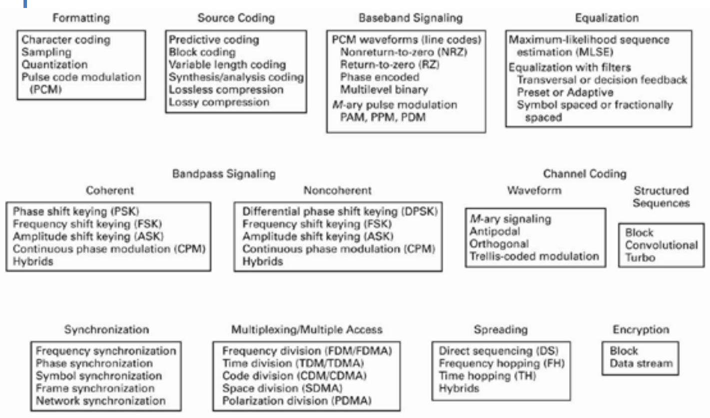
- Less subject to distortion and interference
- Digital signal processing is more reliable and less expensive than analog signal processing
- Digital communication techniques lend themselves naturally to channel coding for:
  - Protection against jamming and interference
  - Secure transmission



Digital Communication System



Transformation in Digital Communications



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Classification of Signals

Classification of Signals

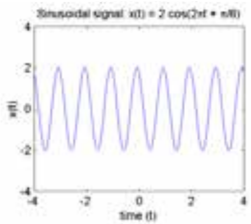
- Deterministic versus Random Signals.
- Continuous-time (CT) versus Discrete-time (DT) Signals.
- Analog versus Digital Signals.
- Periodic versus Aperiodic Signals
- Odd and Even Signals.
- Energy versus Power Signals.

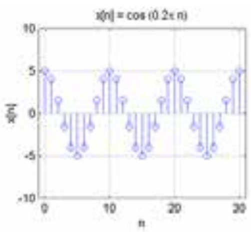
Deterministic vs Random Signals

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



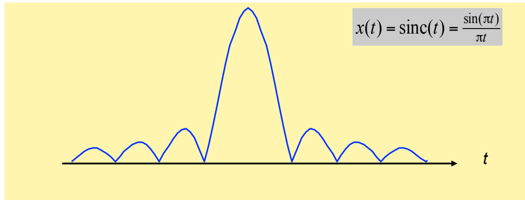


Activity 1

Plot the CT signal $x(t)$ = sin($5\pi t$ + 30°). Discretize the CT signal with an uniform sampling period of T_s = 0.25s. Sketch the resulting waveforms.

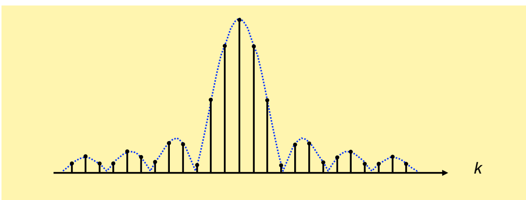
Analog vs Digital Signals

- 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.

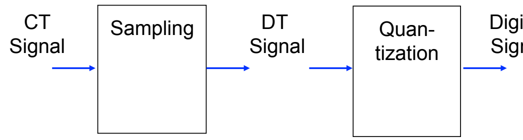


Analog vs Digital Signals

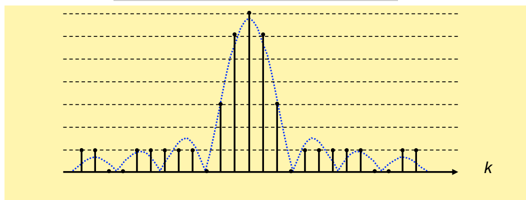
$$x[k] = x(t)\big|_{t=kT_s} = \text{sinc}(kT_s) = \frac{\sin(\pi k T_s)}{\pi k T_s}$$



Analog vs Digital Signals

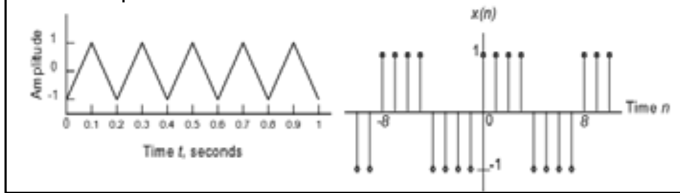


$$x_q[k] = \left[x[k]\right]_q = \left[\frac{\sin(\pi k T_s)}{\pi k T_s}\right]_q$$



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

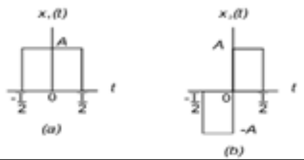
(a) $x[k] = \sin(5\pi k)$

(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:

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

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:

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

Energy vs Power Signals

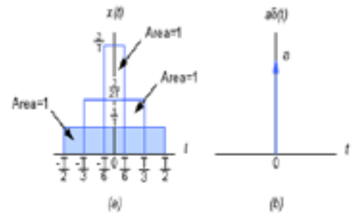
1. Energy Signals: have finite total energy for the entire duration of the signal. As a consequence, total power in an energy signal is 0.
2. Power Signals: have non-zero power over the entire duration of the signal. As a consequence, the total energy in a power signal is infinite.
3. Periodic signals 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. $\delta(t) = \begin{cases} \text{undefined} & t = 0 \\ 0 & t \neq 0 \end{cases}$
2. $\int_{-\infty}^{\infty} \delta(t)dt = 1$
3. $\delta(at) = \frac{1}{|a|}\delta(t)$
4. $x(t)\delta(t - t_o) = x(t_o)\delta(t - t_o)$
5. $\int_{-\infty}^{\infty} x(t)\delta(t - t_o)dt = x(t_o)$



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

$$x(t) = \sum_{n=-\infty}^{\infty} c_n e^{-j2\pi nf_0 t} \text{ where } c_n = \frac{1}{T_0}\int_{\langle T_0\rangle} x(t)e^{j2\pi nf_0 t}dt$$

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

$$G_x(f) = \sum_{n=-\infty}^{\infty} |c_n|^2 \delta(f - nf_0)$$

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