CSE4214 Digital Communications

Chapter 1

Signals and Spectra

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CSE4214 Digital Communications

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  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

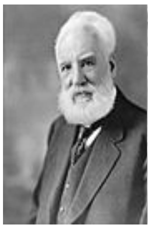
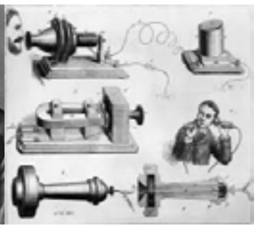
Milestones

- 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

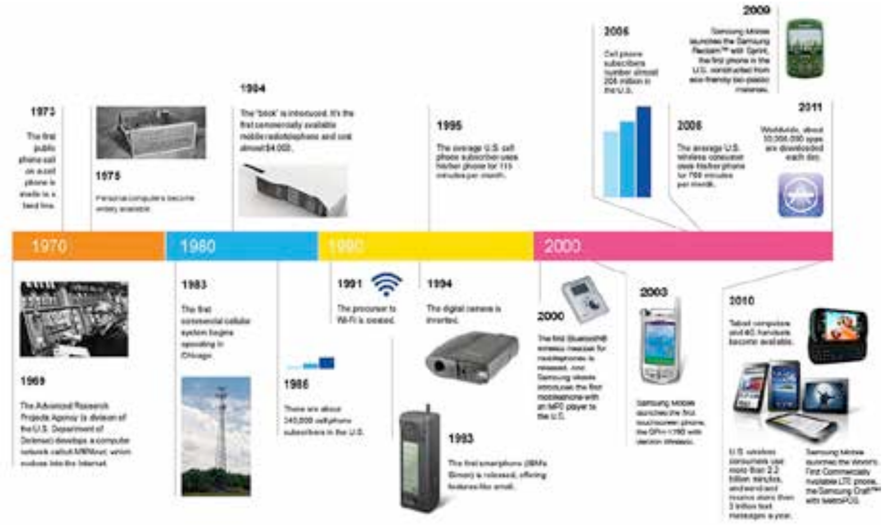



Milestones

- 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



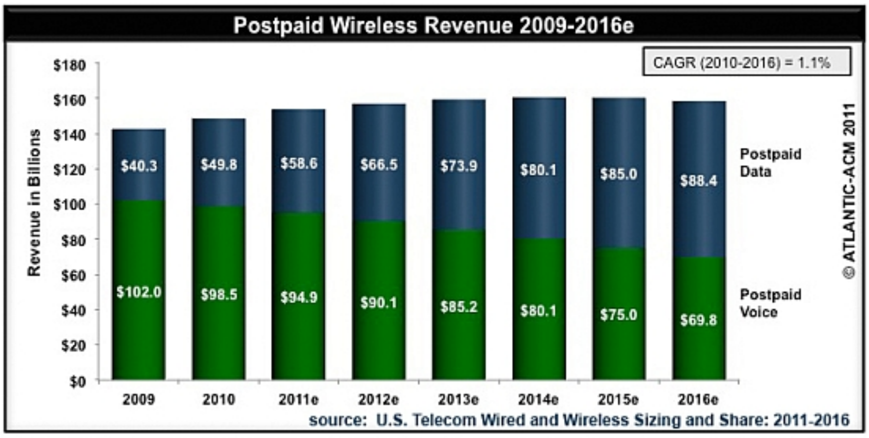
Source: http://www.samsung.com/us/wow/wireless.html

Internet Traffic Trend

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

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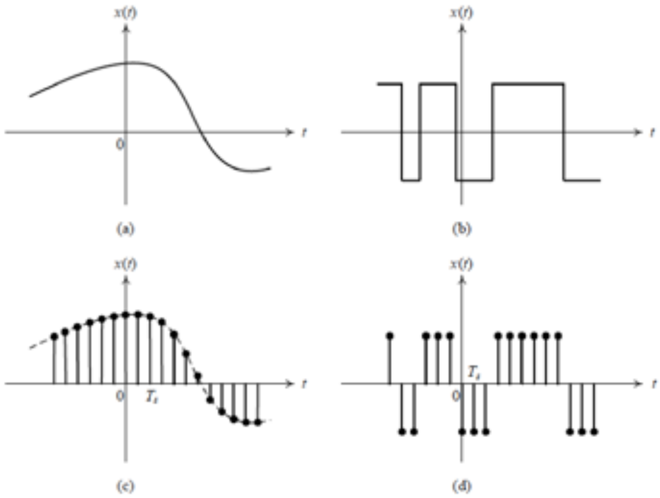
Why digital ?

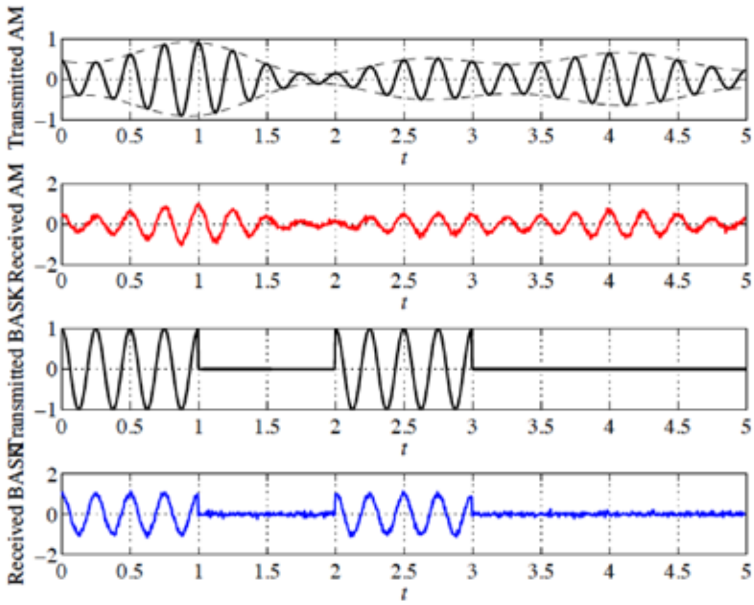
Analog and Digital Signals



Analog versus Digital

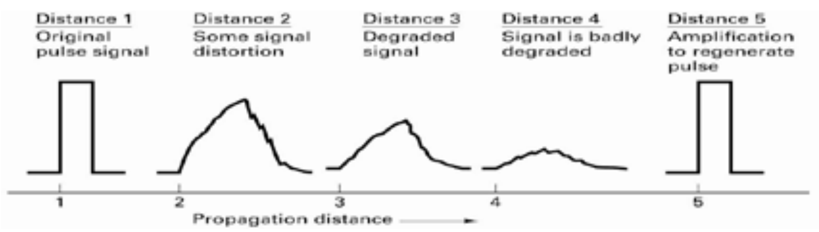
Analog	Digital
Compute on a continuous set, e.g. real numbers	Compute on a discrete set, e.g. 0,1
Difficult to implement arbitrary nonlinear operations	Can implement arbitrary nonlinear operations
Noise prone	Less sensitive to variations in environment
Graceful degradation	No-graceful degradation
Generally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

Analog versus Digital

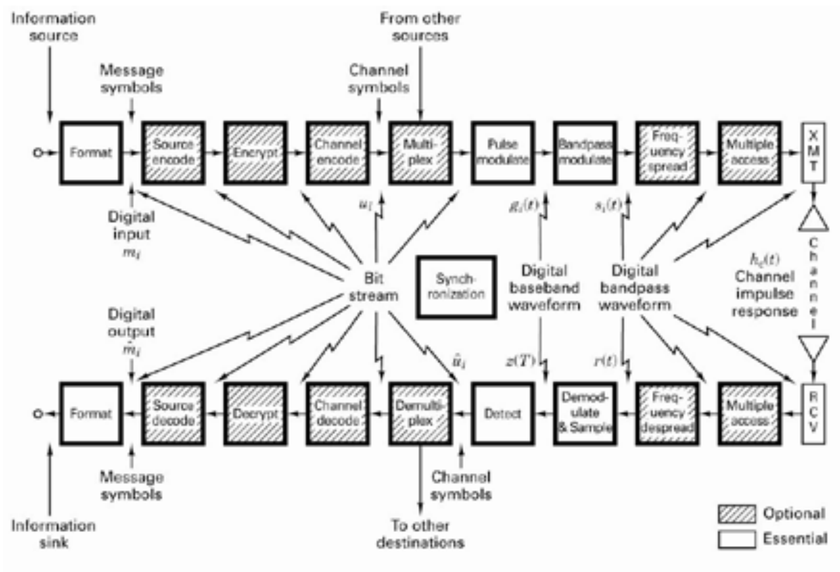


Why Digital?

- 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

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

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Classification of Signals

Classification of Signals

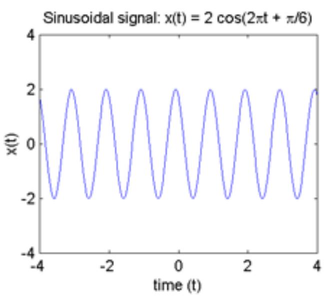
- Deterministic versus Random Signals.
- Continuous-time (CT) versus Discrete-time (DT) Signals.
- Analog versus Digital Signals.
- Periodic versus Aperiodic Signals
- Odd and Even Signals.
- Energy versus Power Signals.

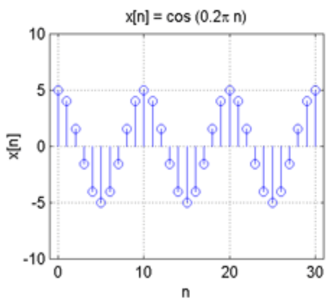
Deterministic vs Random Signals

- 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



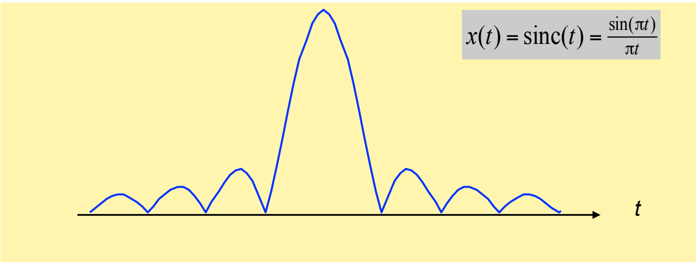


Activity 1

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

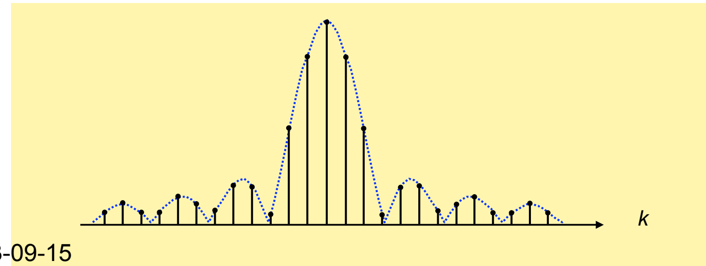
Analog vs Digital Signals

- 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

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



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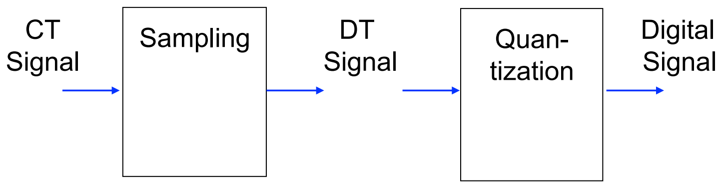
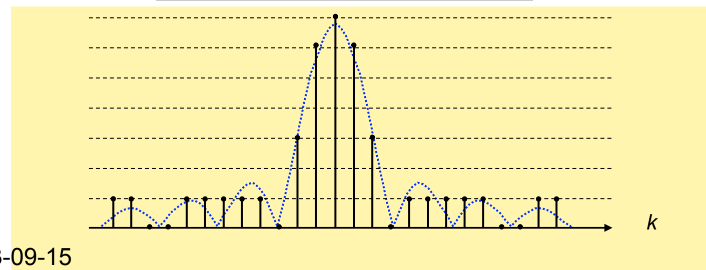
Analog vs Digital Signals



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



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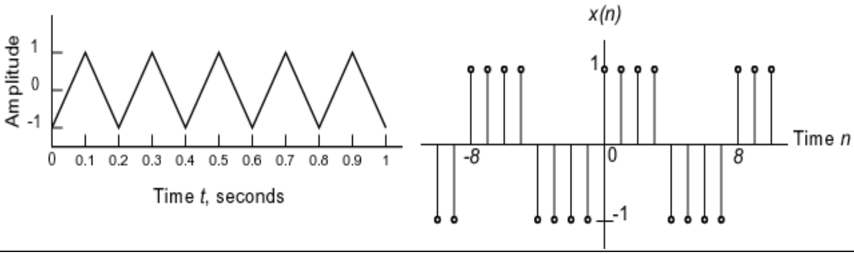
Periodic vs Aperiodic Signals

- 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

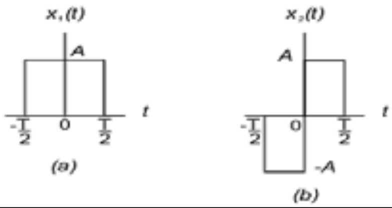
1. Even Signal: A CT signal $x(t)$ is said to be an even signal if it satisfies the condition :

   $x(-t) = x(t)$ for all t.

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

   $x(-t) = -x(t)$ 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.



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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 [$x(t)$ - $x(-t)$]

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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

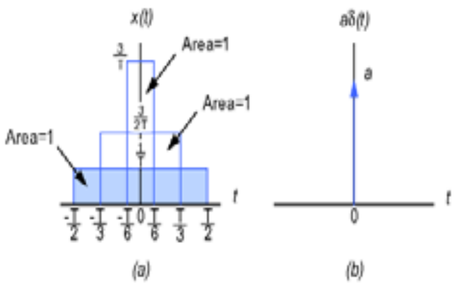
1. Energy Signals: have finite total energy for the entire duration of the signal. As a consequence, total power in an energy signal is 0.
2. Power Signals: have non-zero power over the entire duration of the signal. As a consequence, the total energy in a power signal is infinite.
3. Periodic signals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

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

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

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

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

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

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