EEE336 Signal Processing and Digital Filtering

Lecture 1 Introduction

1_1 Basic Information

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Room EE322

Module Information

- Module Code: EEE336
- Module Title: Signal Processing and Digital Filtering
- Module Credit: 5 credits
- Module Leader: Zhao Wang
  - My office: EE322
  - Office hour: 13:00 – 15:00 p.m. everyday
  - Teaching Assistant: Zhenzhen Jiang

Module Information

- Time tabling:
  - The first 6 weeks:
    - Video watching: 3-4 hours / week
    - Practicing: about 2 hours / week
  - Weeks 7-16:
    - Video watching: 0-4 hours / week
    - Practicing: about 2 hours / week
    - In-class teaching: 4 hours
  - Formal Lab (3 hours, 15%):
    - Extra time to complete the programming and lab report: about 10-20 hours.

Learning Process

- What's new about this module: flipped classroom!
  - Most teaching content will be presented as short video clips on ICE
    - Watch them beforehand, and answer the quizzes after each video;
    - Practices
      - Typical problems;
      - Programming practices;
    - If you find something not clear:
      - Watch the video again;
      - Read the complementary documents / reference materials;
      - Inform the lecturer (by email or face to face) about your confusion.
  - In-class lecture
    - Quick test, summary and review, discussion, tutorial.

Resources

- On ICE:
  - Video clips on theoretical contents and programming demo, quizzes and problems, discussion topics in forum, …

- Reference books
  - 1. S. K. Mitra, Digital Signal Processing: A Computer-Based Approach, 4th., McGraw-Hill, 2006.
  - 2. S. J. Orfanidis, Introduction to Signal Processing, Prentice Hall, 2003.
  - 3. A.V.Oppenheim, Discrete Time Signal Processing, Prentice Hall, 1999.
  - 4. J.G.Proakis, Digital Signal Processing, Principles, Algorithms and Applications, 3rd., Prentice Hall, 1996.

More resources

- Online courses:
  - "Digital Signal Processing" on Coursera
    - Provided by École Polytechnique Fédérale de Lausanne
    - https://www.coursera.org/learn/dsp/home/info
  - "Digital Signal Processing" on OCW
    - Provided by MIT
    - https://ocw.mit.edu/resources/res-6-008-digital-signal-processing-spring-2011/index.htm
- Softwares
  - Matlab (vR2016a)
    - Signal Processing Toolbox, DSP System Toolbox, Audio System Toolbox, …
  - Audacity, Sonic Visualiser, etc.

More resources

- CD content of Ref.1, “Digital Signal Processing: A Computer-Based Approach, 4th.” by Sanjit K. Mitra
  - http://www.cems.uvm.edu/~gmirchan/classes/EE275/Mitra_4/
- “Introduction to Digital Filters with Audio Applications” by Julius O. Smith III
  - https://ccrma.stanford.edu/~jos/filters/
- “Digital Signal Processors” by TI (Texas Instrument)
  - http://www.ti.com/processors/digital-signal-processors/overview.html
- “科学计算 – 使用Matlab” by 张智星
  - https://www.camdemy.com/media/3308#cmt1

EEE336 Digital Signal Processing

Lecture 1 Introduction

1_2 What is SIGNAL?

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What's this module about?

Digital Signal Processing	+	Digital Filtering	=	Signal Processing and Digital Filtering

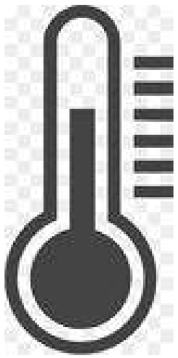
Digital Signal Processing

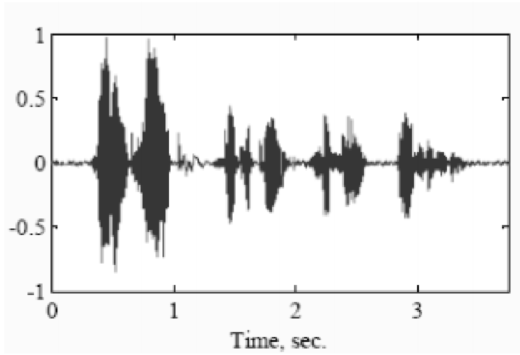
- What is "Signal"? Section 1_2
- What is "Signal Processing"? Section 1_3
- What is "Digital Signal Processing"? Section 1_4
- Why do we want Digital Signal Processing? Section 1_4
- Where is Digital Signal Processing used? Section 1_5

Digital Signal Processing

- Signal – physical quantity that is represented as a function of *independent variables.*

  – Some examples:
    - Temperature
    - Sound
    - Photograph
    - Video





Digital Signal Processing

- Every signal carries information.

Digital Signal Processing

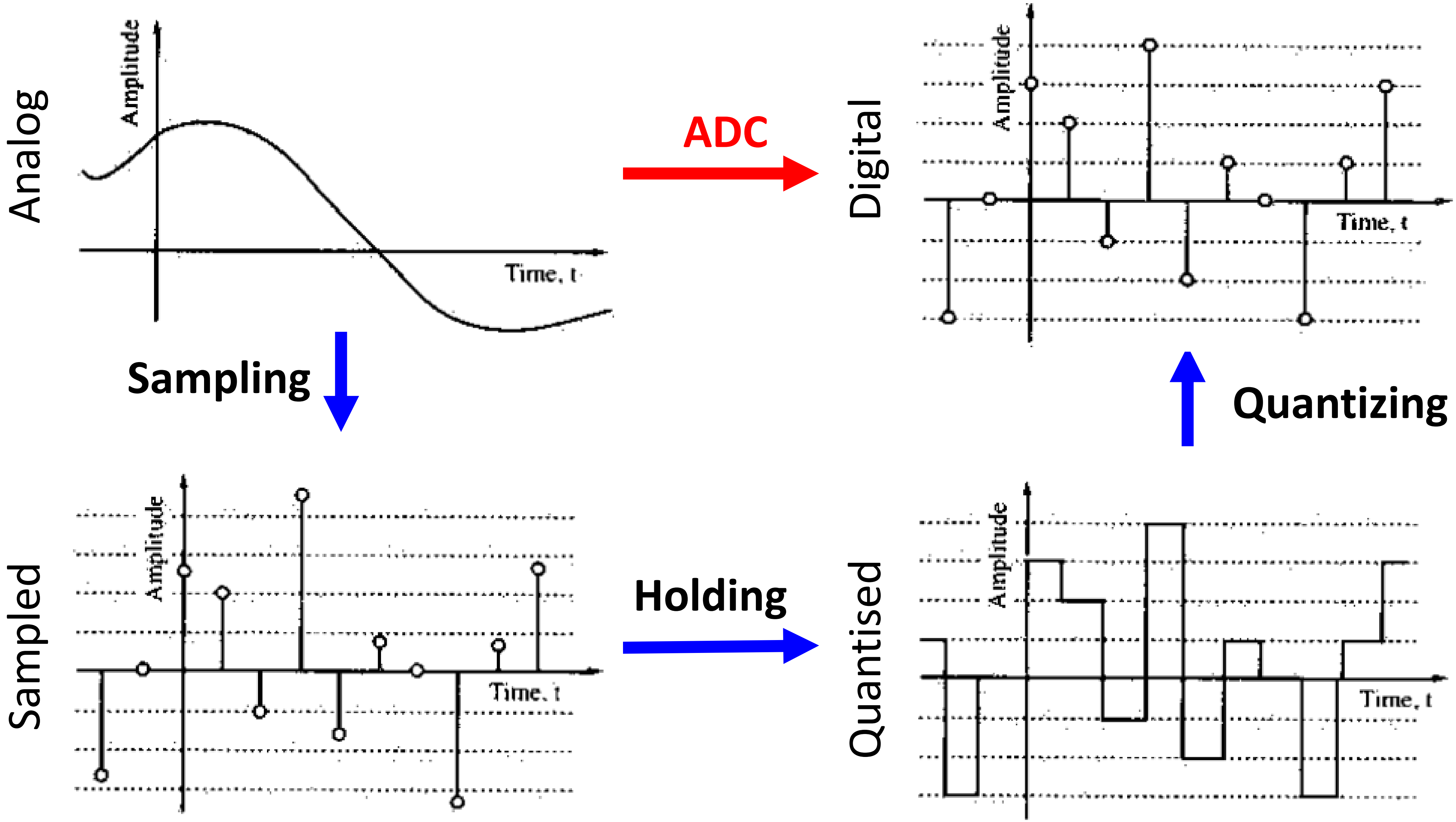
- Signal Processing
  - Analyze – understanding the information carried by the signal
  - Synthesize – creating a signal to contain the given information

- System: “something” that can manipulate, change, record, or transmit input signals.
  - Example: CD/DVD player, digital thermalmeter, etc.

Classification of Signals

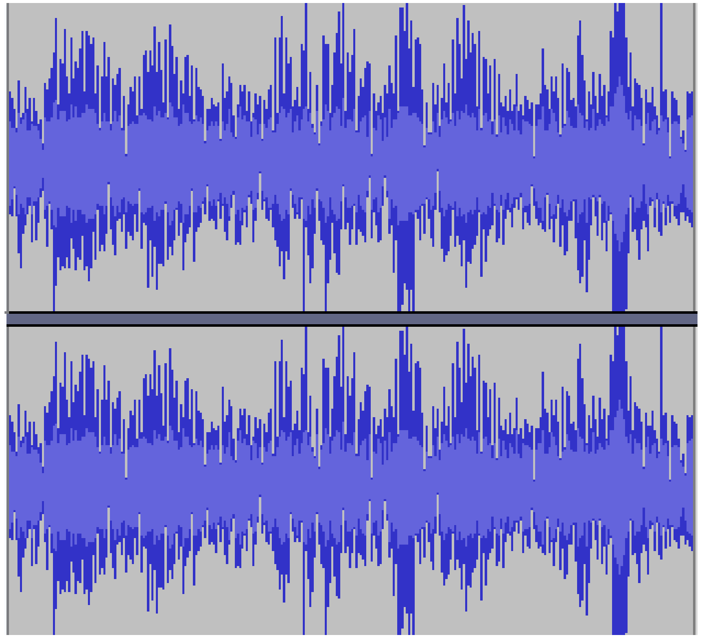
- Continuity in time:
  - Continuous time signals vs. discrete time signals
- Continuity in value:
  - Continuous valued signals vs. digital signals
- Value of the signals:
  - Real valued signals vs. complex valued signals
- Number of channels:
  - Single channel signals vs. multichannel signals
- Certainty:
  - Deterministic vs. random signal
- Number of dimensions:
  - One-dimensional vs. two dimensional vs. multidimensional signals

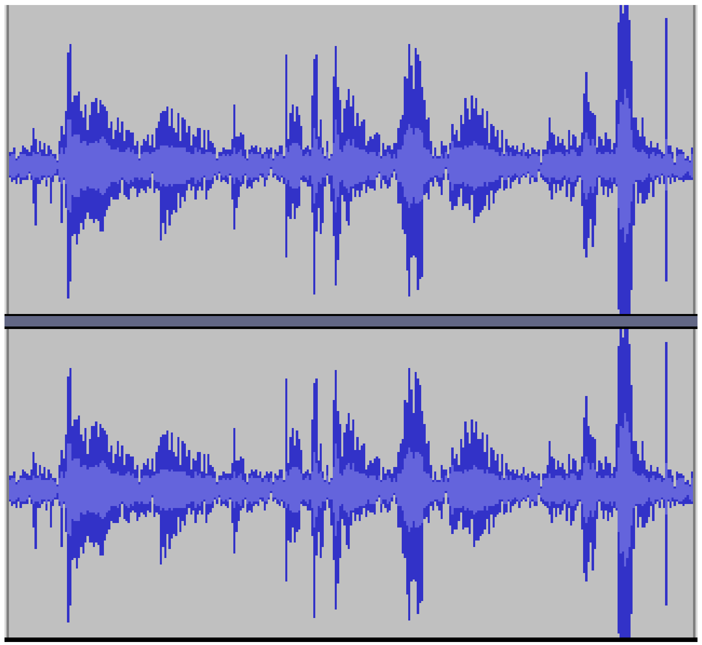
Characterization of Signals



Example of Typical Signals (1/5)

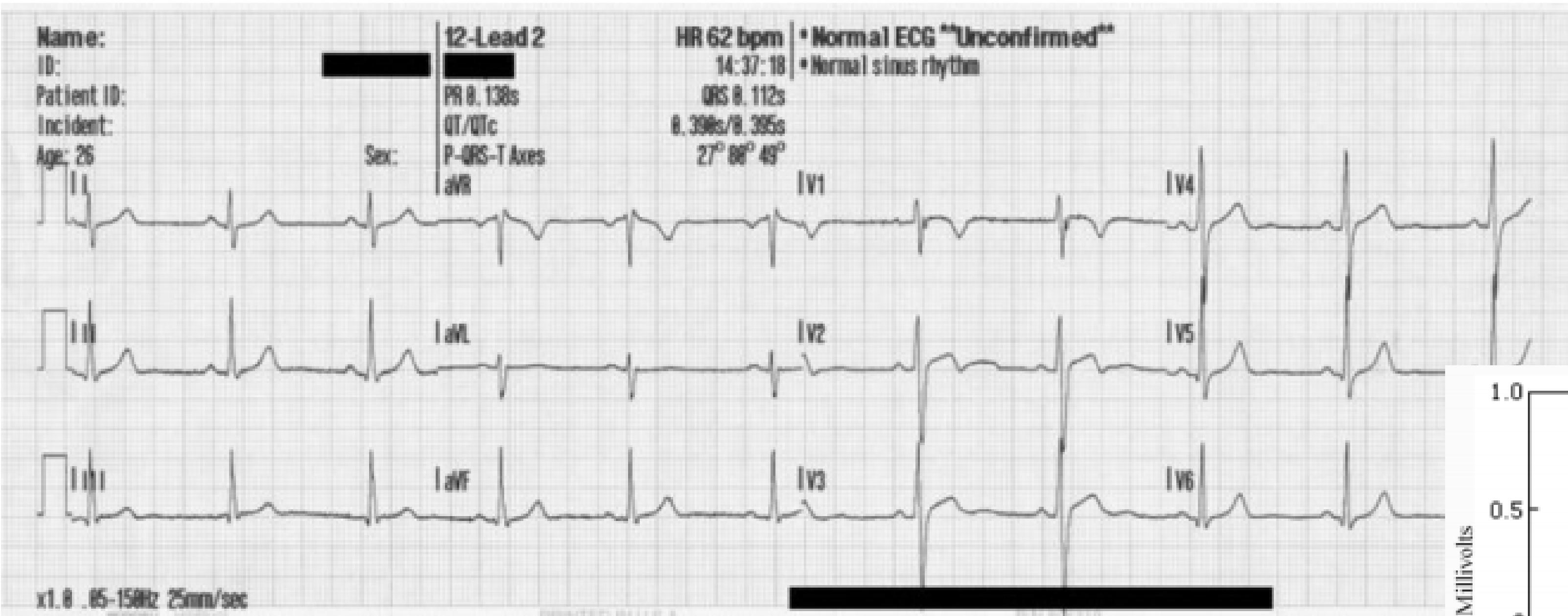
- **Speech and music signals** - Represent air pressure as a function of time at a point in space
  - "I like digital signal processing":
  - Which one sounds better?
  - What has been done to it?

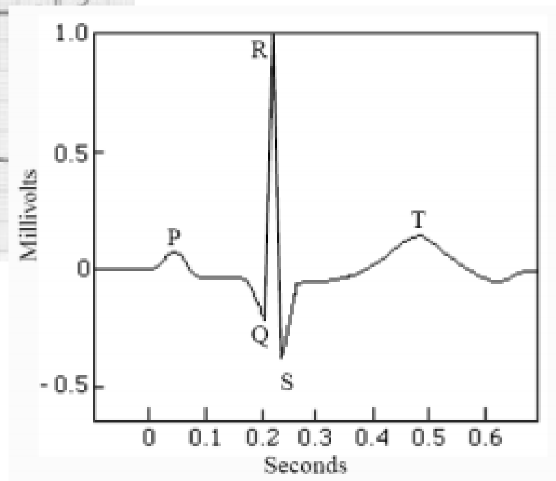




Example of Typical Signals (2/5)

- **Electrocardiography (ECG) Signal** - Represents the electrical activity of heart





One period of the waveform

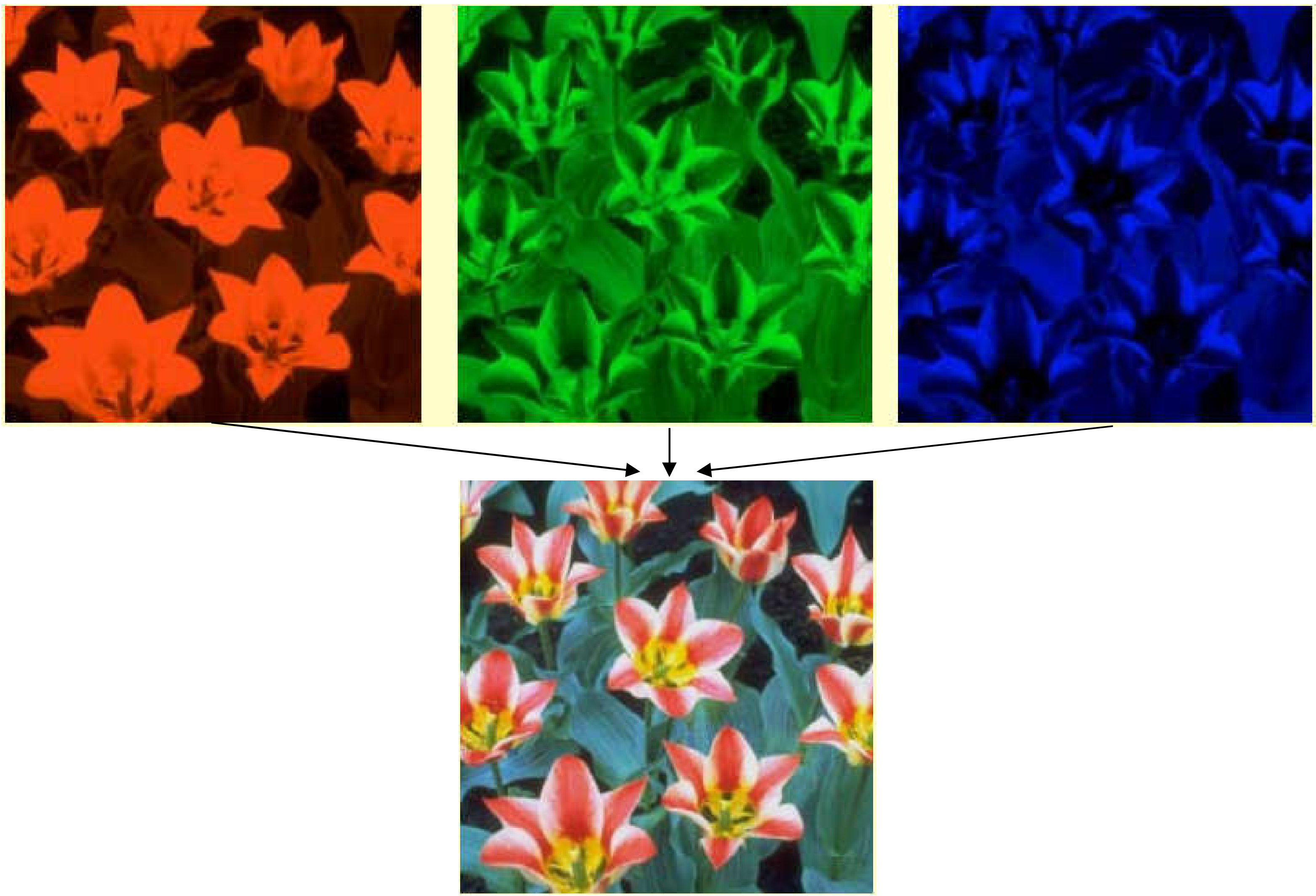
Example of Typical Signals (3/5)

- **Black-and-white picture** - Represents light intensity as a function of two spatial coordinates

$I(x, y)$

Example of Typical Signals (4/5)

- **Color Image** – Consists of Red, Green, and Blue (RGB) components



Example of Typical Signals (5/5)

- **Video signals** - Consists of a sequence of images, called frames, and is a function of 3 variables: 2 spatial coordinates and time

Frame 1

Frame 3

Frame 5

1_2 Wrap up

- What is “Signal”?
- Classification of signals
- Example of typical signals
  - Audio: speech and music
  - ECG and EEG
  - Pictures: black and white, color
  - Video

EEE336 Digital Signal Processing

Lecture 1 Introduction

1_3 What is Signal Processing?

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Signal Processing

- ***A signal carries information.***
- ***The objective of signal processing is to extract the information carried by the signal***

- Signal processing is concerned with the mathematical representation of the signal and the algorithmic operation carried out to extract the information.
  – DSP: signal processing in the digital domain

Typical Signal Processing Operations

- Most signal processing operations of analog signals are carried out in the ***time-domain***;
- In the case of discrete-time signals, both ***time-domain*** or ***frequency-domain*** operations are usually employed.

- Examples of typical signal processing operations:
  - Time domain operations
    - Elementary operations: scaling, delay, arithmetic operations
  - Frequency domain operations
    - Filtering
    - Modulation (Amplitude modulation)
    - Multiplexing and demultiplexing

Elementary Time-domain Operations (1/3)

- ***Scaling*** – the multiplication of a signal by a positive or negative constant.
- If $x(t)$ is an analog signal that is scaled by a constant α, then the scaling operation generates:

$$y(t) = \alpha x(t)$$

  - If $|\alpha|>1$, the operation is called *amplification*;
    - Where the constant α is called “gain”.
  - If $|\alpha|<1$, the operation is called *attenuation*.

Elementary Time-domain Operations (2/3)

- ***Delay*** – the delay operation generates a delayed replica of the original signal.
- For an analog signal $x(t)$,

$$y(t) = x(t - t_0)$$

is the signal obtained by delaying $x(t)$ by the amount of time t_0, which is assumed to be a positive value.

  – If t_0 is negative, then it is an ***advance*** operation.

Elementary Time-domain Operations (3/3)

- Most applications require operations involving two or more signals to generate a new signal

- ***Addition***

  $y(t) = x_1(t) + x_2(t)$

- ***Subtraction***

  $y(t) = x_1(t) - x_2(t)$

- ***Production***

  $y(t) = x_1(t) \cdot x_2(t)$

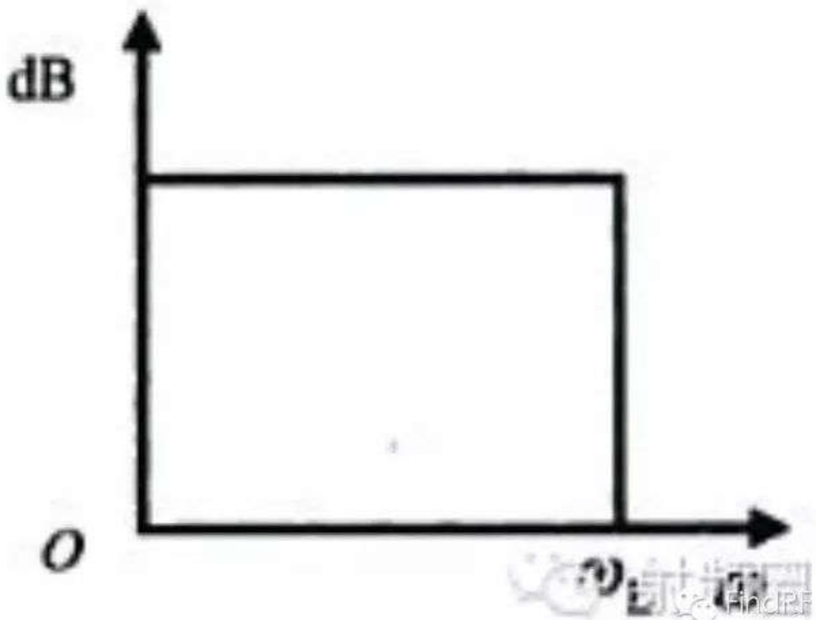
- ***Division***

  $y(t) = x_1(t)/x_2(t)$

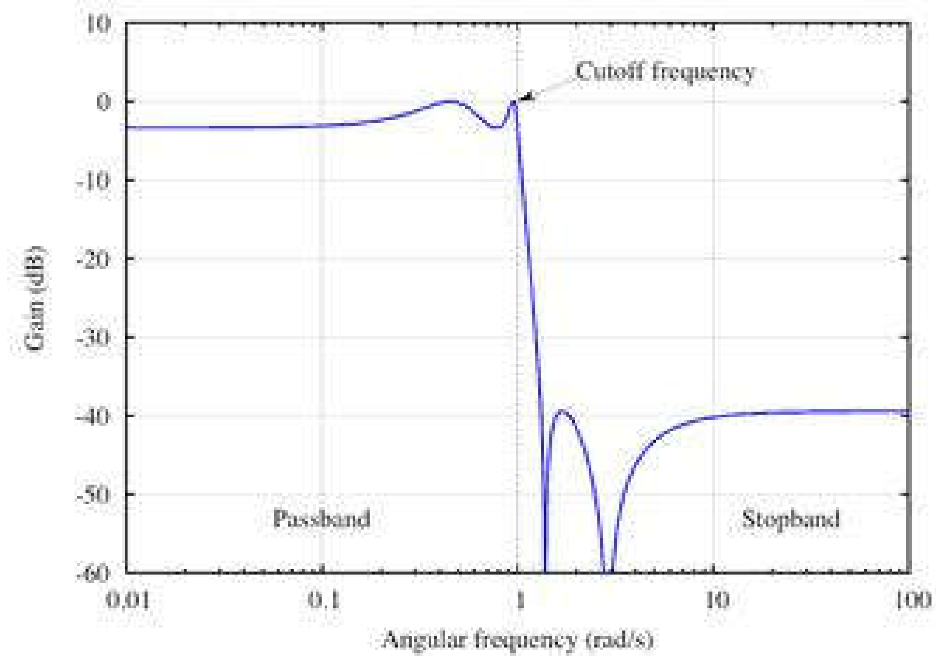
- Most complex operations are implemented by combining two or more elementary operations.

Filtering (1/4)

- Filtering – deliberately changing the frequency content of the signal.
- An ideal filter passes certain frequency components without distortion and blocks other frequency components.



Ideal Lowpass Filter

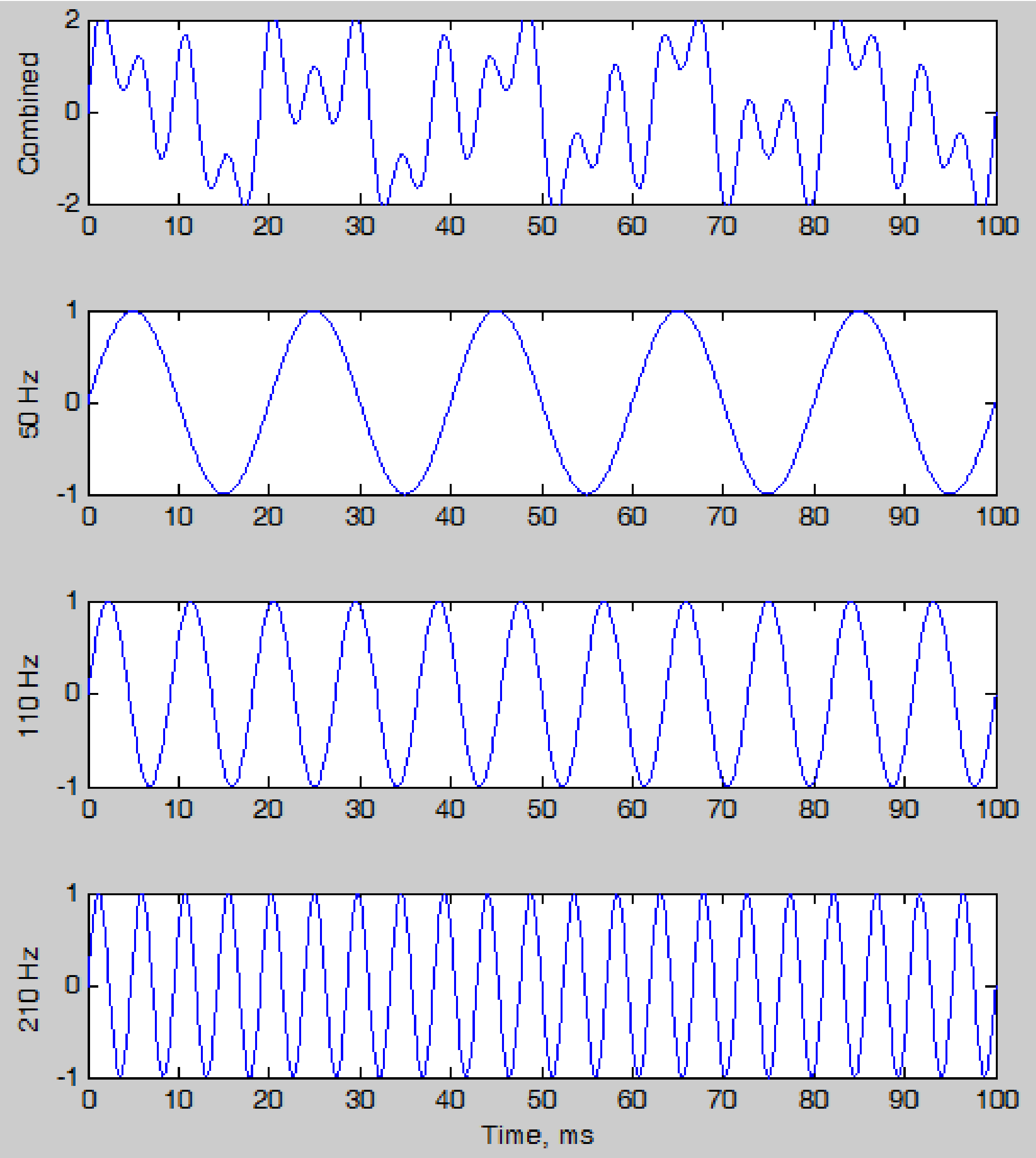


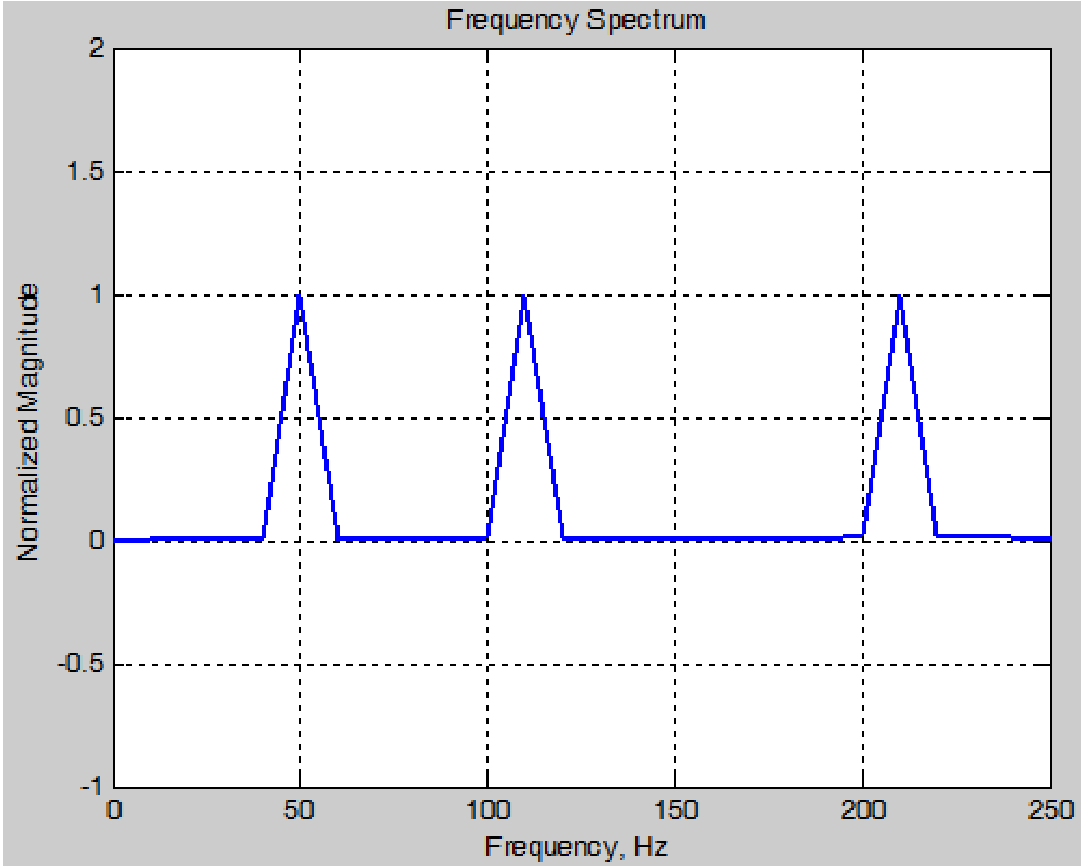
Practical Lowpass Filter

Filtering (2/4)

- Typical types of filters
  - Lowpass (LPF) – removes high freqs, and retains low freqs
  - Highpass (HPF) – removes low freqs, and retains high freqs
  - Bandpass (BPF) – retains an interval of freqs within a band, removes others
  - Bandstop(BSF) – removes an interval of freqs within a band, retains others
  - Notch filter – removes a specific frequency
  - Comb filter – removes a series of frequencies (integral multiples of a low frequency)

1.2.2 Filtering (3/4)

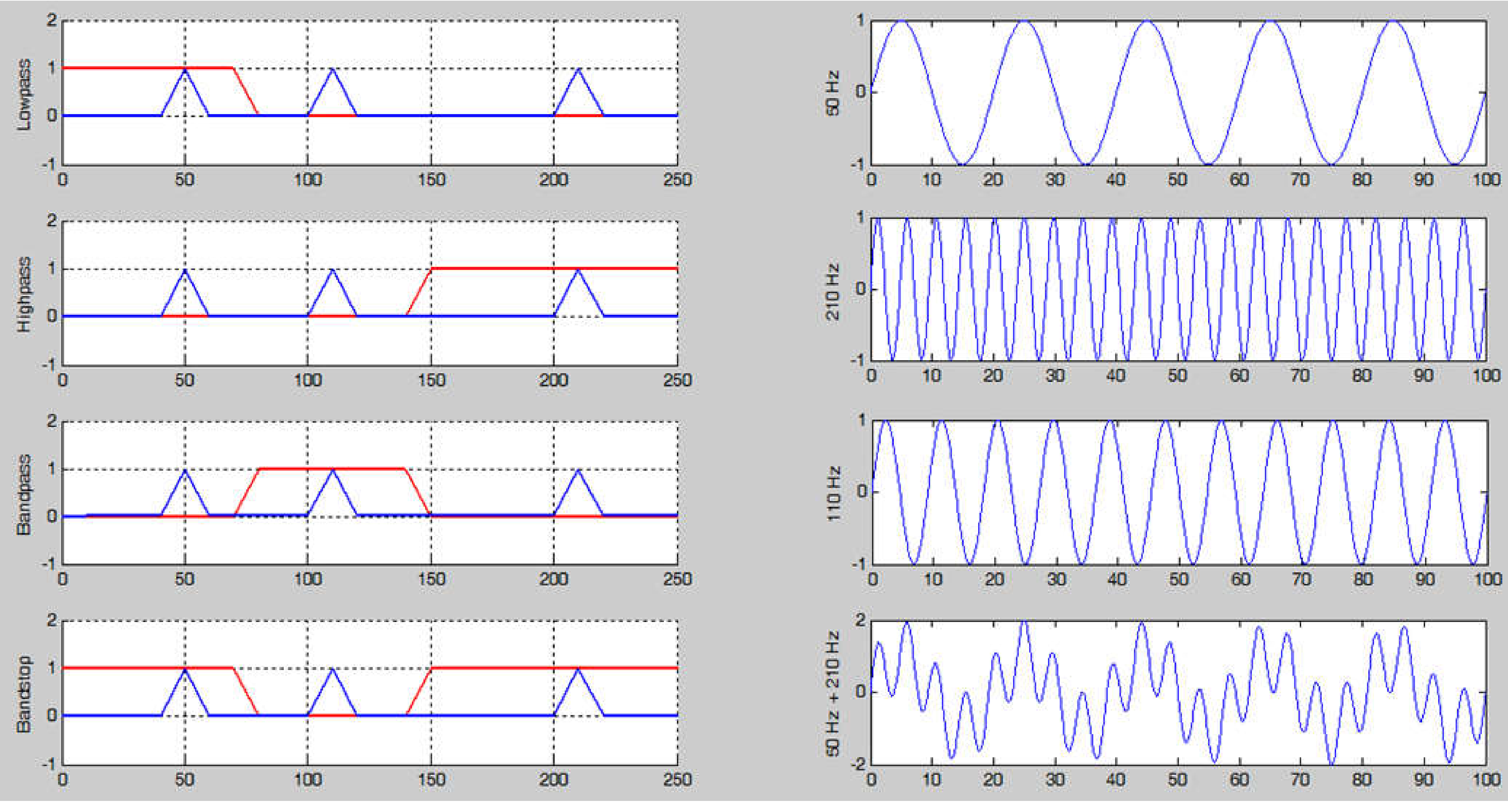




$$y(t) = x_1(t) + x_2(t) + x_3(t)$$

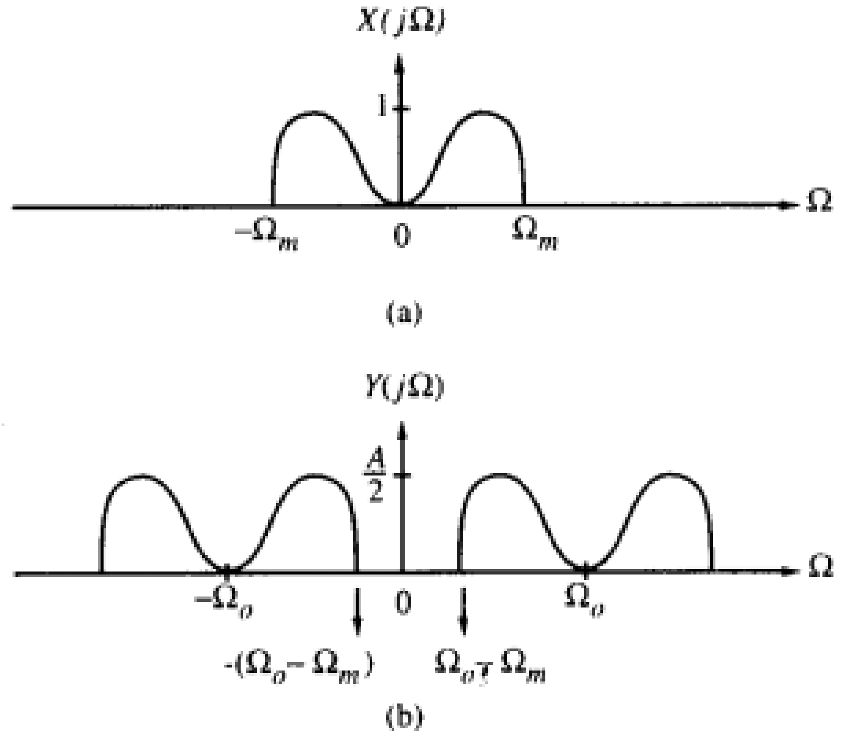
Filtering (4/4)

Frequency domain | Time domain



Modulation and Demodulation (1/2)

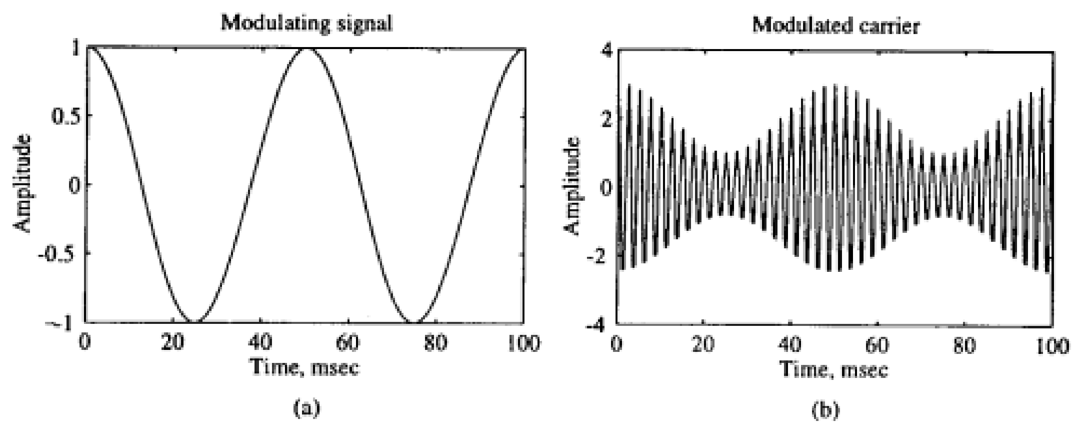
- In ***Amplitude Modulation***:
  - Carrier signal $c(t) = A\cos(\Omega_0 t)$
  - Modulating signal $x(t) = \cos(\Omega_0 t)$
  - Modulated signal $y(t) = \mathrm{c(t)} \cdot x(t)$



$$y(t) = \frac{A}{2}\cos\big((\Omega_0 + \Omega_1)t\big) + \frac{A}{2}\cos\big((\Omega_0 - \Omega_1)t\big)$$

$$\Downarrow$$

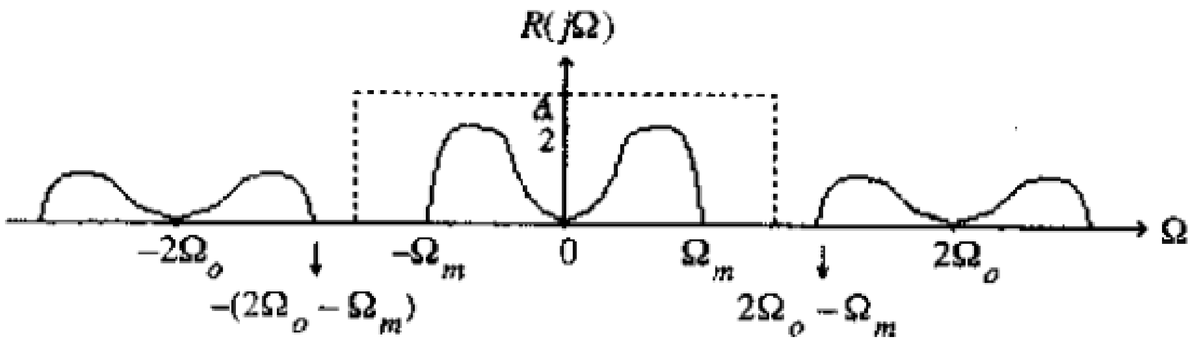
$$Y(j\Omega) = \frac{A}{2}X\big(j(\Omega_0 + \Omega_1)\big) + \frac{A}{2}X\big(j(\Omega_0 - \Omega_1)\big)$$



Modulation and Demodulation (2/2)

- Demodulation is carried out in two stages:
  - Multiply the modulated signal y(t) with a sinusoidal signal of the same frequency as the carrier:

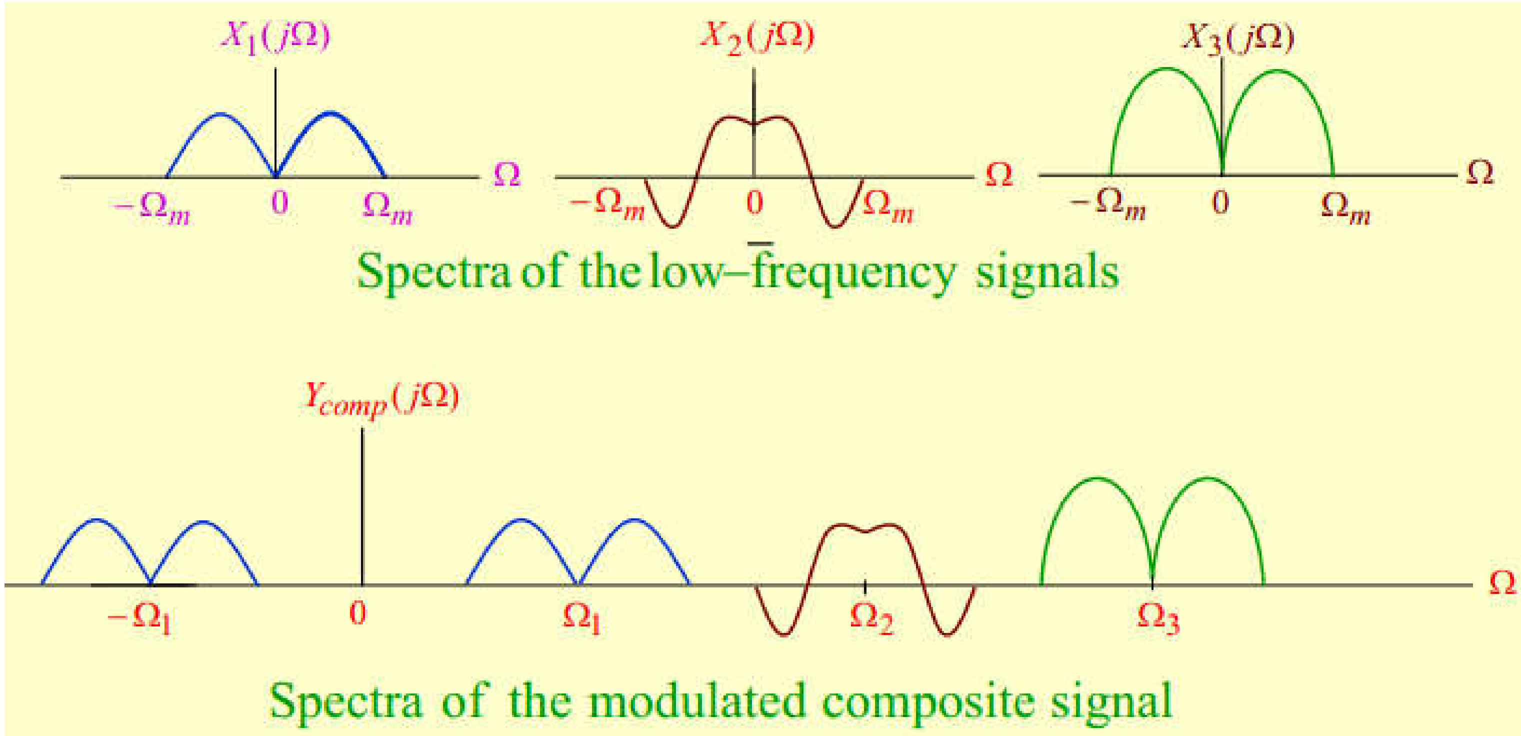
$$r(t) = y(t)\cos(\Omega_0 t) = Ax(t)\,cos^2(\Omega_0 t)$$
$$= \frac{A}{2}x(t) + \frac{A}{2}x(t)\cos(2\Omega_0 t)$$



  - Use a lowpass filter to recover the original modulated signal. The cut-off frequency of this lowpass filter should be Ω_0

Multiplexing and Demultiplexing

- Multiplexing - to efficiently utilize a wideband transmission channel, many narrowband low-frequency signals are combined for a composite wideband signal that is transmitted as a single signal.



1_3 Wrap up

- What is “Signal Processing”?

- Typical Signal Processing Operations
  - Time domain operations
    - Elementary operations: scaling, delay, arithmetic operations
  - Frequency domain operations
    - Filtering
    - Modulation (Amplitude modulation)
    - Multiplexing and demultiplexing

EEE336 Digital Signal Processing

Lecture 1 Introduction

1_4 What is DSP?

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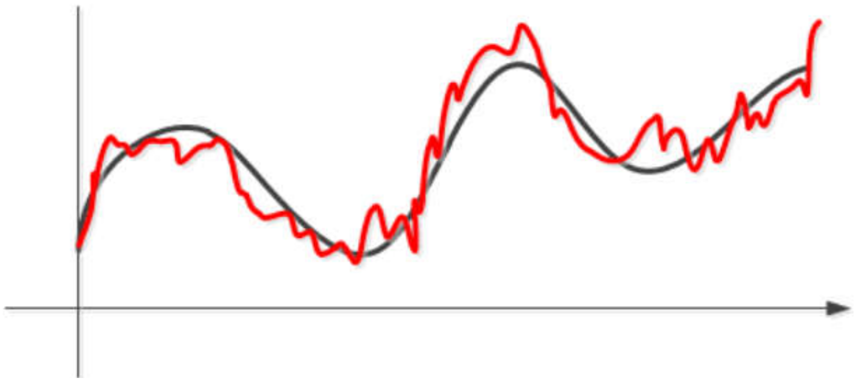
Analogue Signal Processing

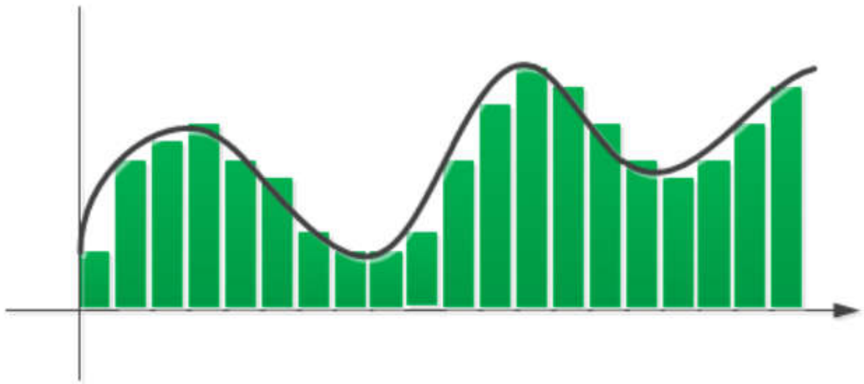
- Most real-world signals are analogue
  - They are continuous in time and amplitude
- Analogue circuits process these signals using
  - Resistors, Capacitors, Inductors, Amplifiers,...
- Limitations of Analogue Signal Processing
  - Low anti-interference;
  - Unstable;
  - Unsecure;
  - Complexity;
  - Inflexibility.

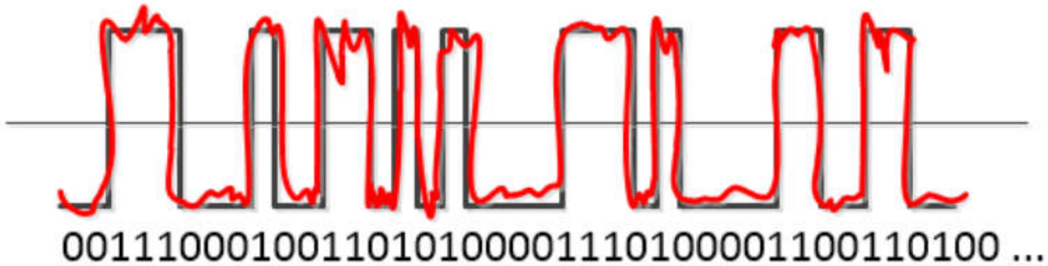
Digital Signal Processing - Advantages

- Anti-interference and high precision



Analogue signal is jammed by the external noise.





Digital signal is jammed by the external noise.

Digital Signal Processing - Advantages

- Stability

Old picture

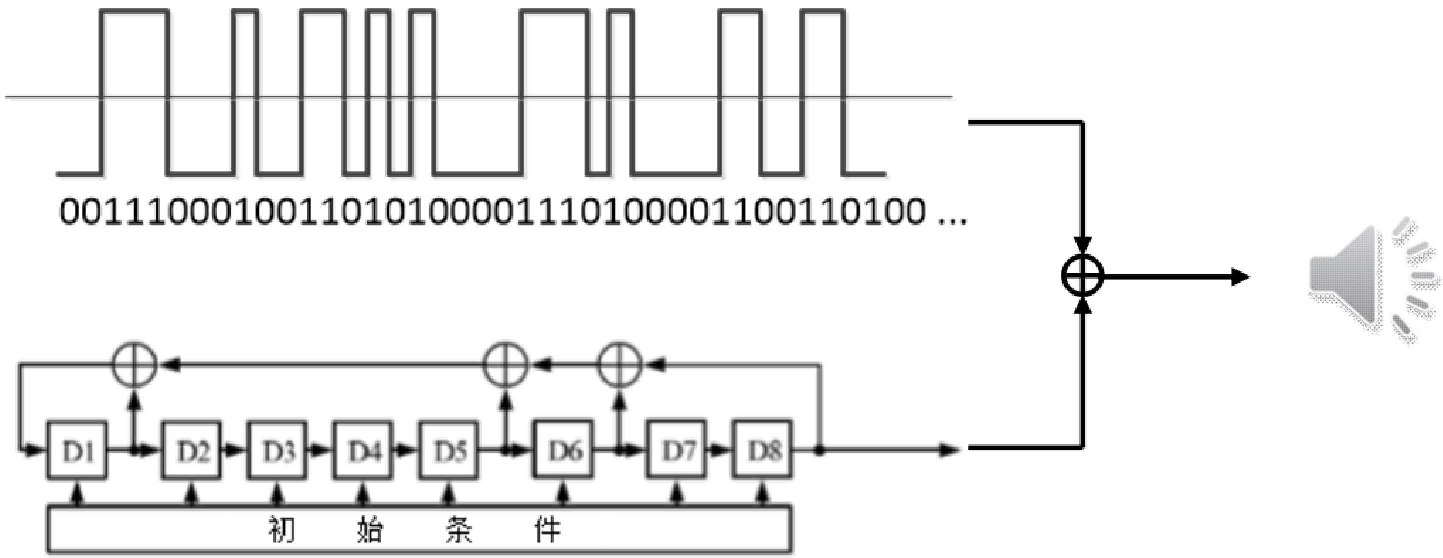
Tape recorder quality

Digital picture

CD quality

Digital Signal Processing - Advantages

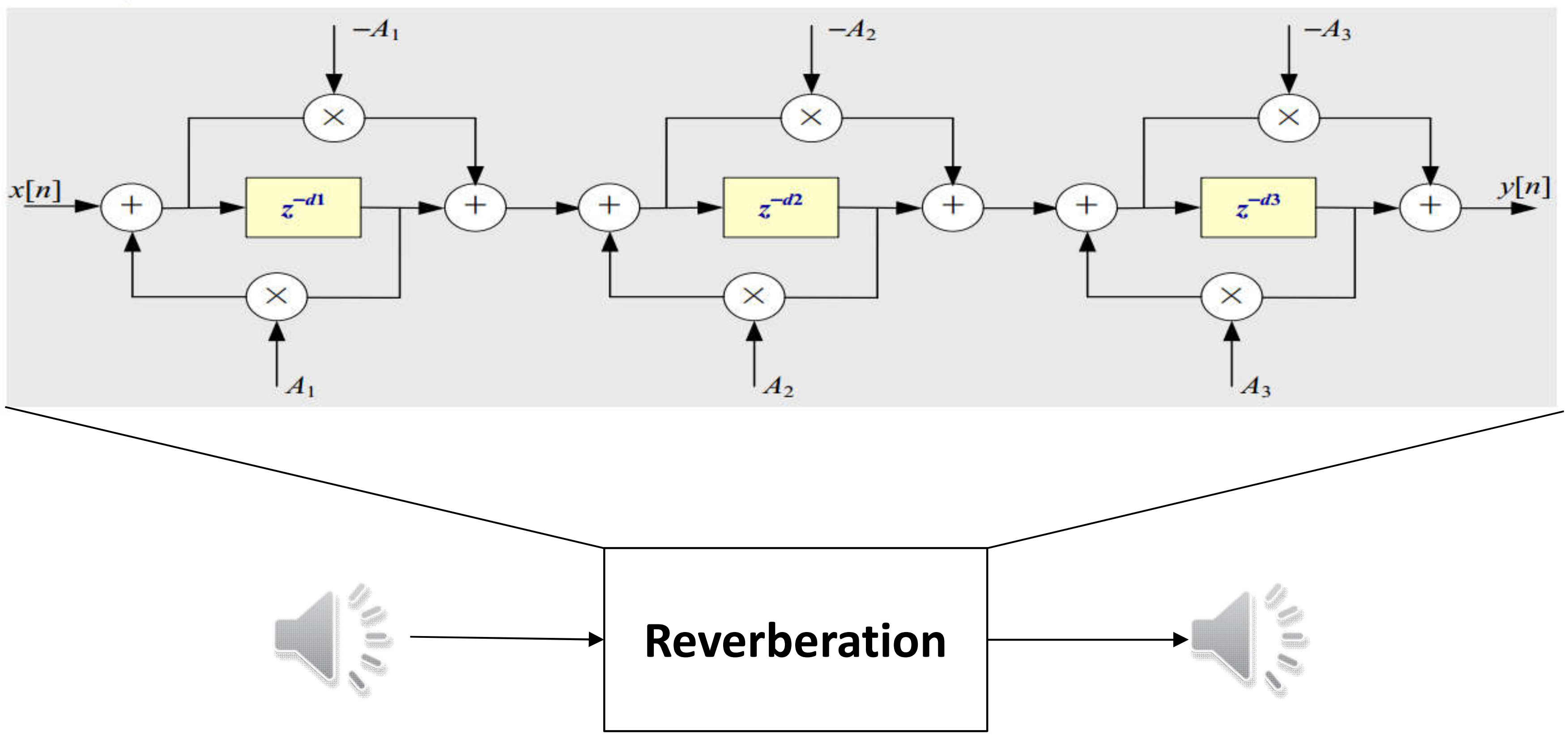
- Security



pseudo-random code

Digital Signal Processing - Advantages

- Easy processing



Original track

After reverberation

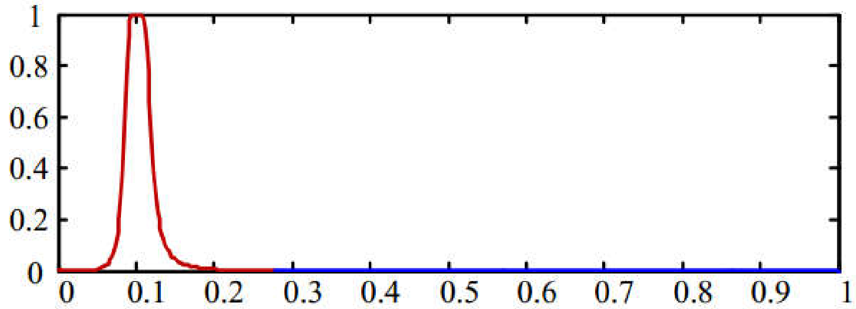
Digital Signal Processing - Advantages

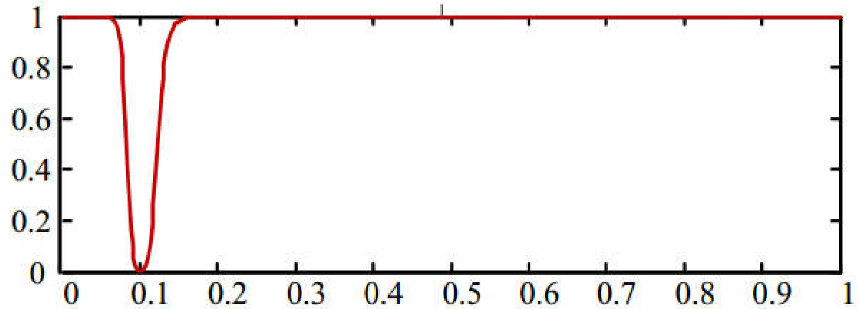
- Flexibility

$$H_1(z) = \frac{(0.0943 - 0.2828z^{-2} + 0.2828z^{-4} - 0.0943z^{-6}) \times 10^{-3}}{1 - 5.5242z^{-1} + 12.9897z^{-2} - 16.6206z^{-3} + 12.2014z^{-4} - 4.8741z^{-5} + 0.8288z^{-6}}$$

$$H_2(z) = \frac{0.8588 - 4.8975z^{-1} + 11.8861z^{-2} - 15.6940z^{-3} + 11.8861z^{-4} - 4.8975z^{-5} + 0.8588z^{-6}}{1 - 5.4139z^{-1} + 12.4787z^{-2} - 15.6561z^{-3} + 11.2736z^{-4} - 4.4190z^{-5} + 0.7375z^{-6}}$$

Original scale signal





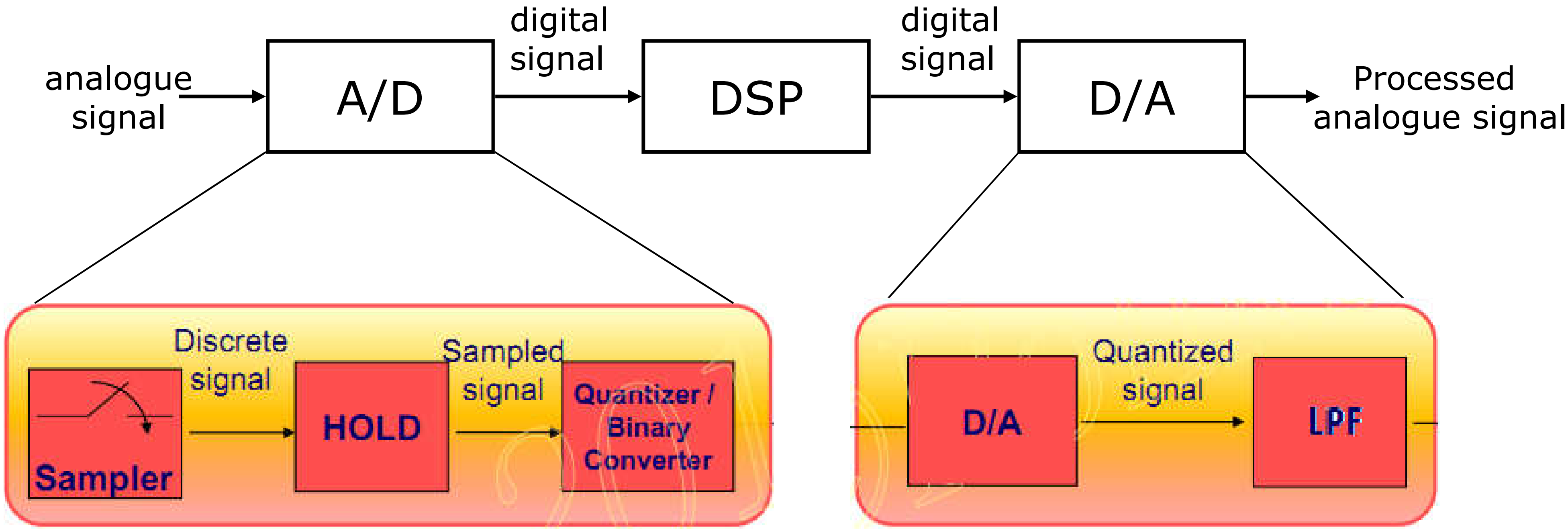
Bandpass

Bandstop

Digital Signal Processing - Disadvantages

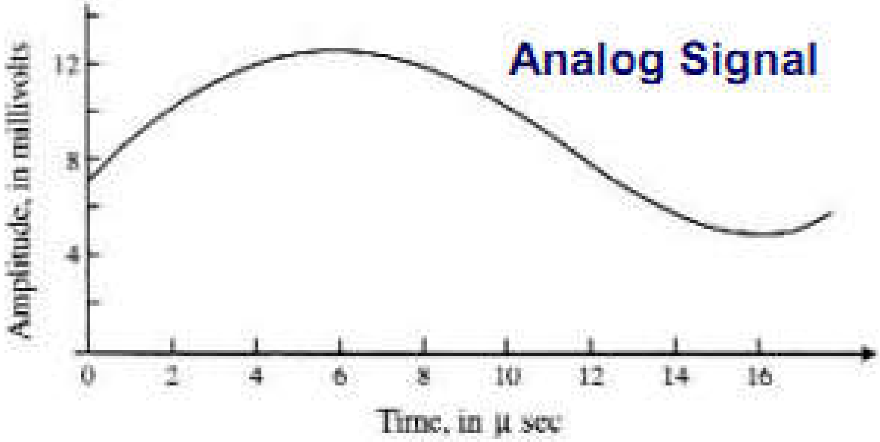
- Limited Frequency Range of Operation
  - Frequency range technologically limited to values corresponding to maximum computing capacities (e.g., A/D converter) that can be developed and exploited
- Digital systems are active devices, thereby consuming more power and being less reliable
- Additional Complexity in the Processing of Analog Signals
  - A/D and D/A converters must be introduced adding complexity to overall system
- Inaccuracy due to finite precision arithmetic
  - Quantization and round-off errors

What is Digital Signal Processing?

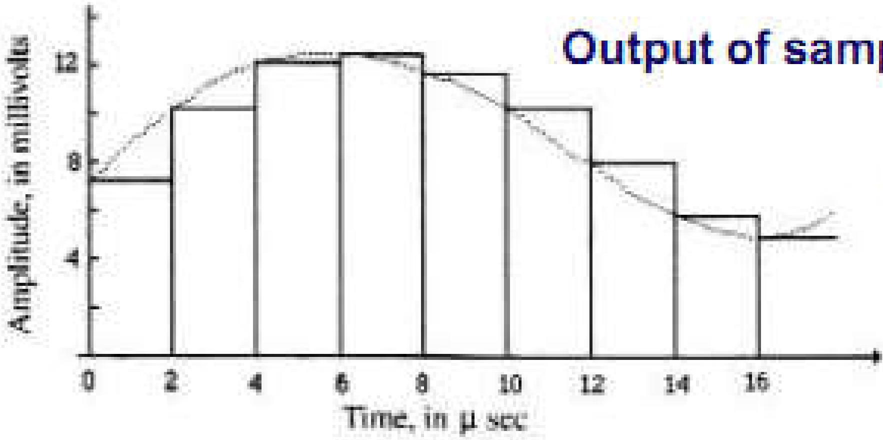


- 1. Represent signals by a sequence of numbers
  - Sampling and analog-to-digital conversions
- 2. Perform processing on these numbers with a digital processor
  - Digital signal processing
- 3. Reconstruct analog signal from processed numbers
  - Reconstruction or digital-to-analog conversion

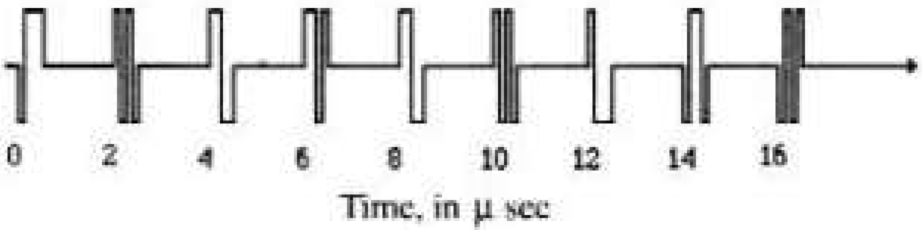
Analog Signal



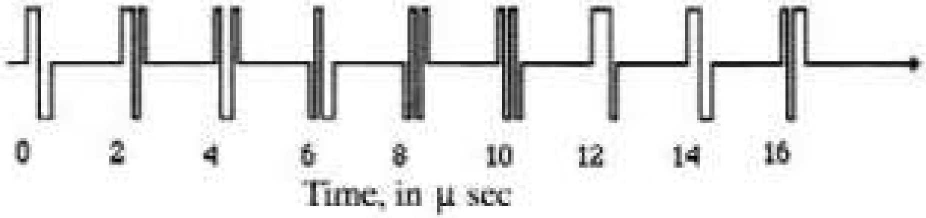
Output of sample & hold



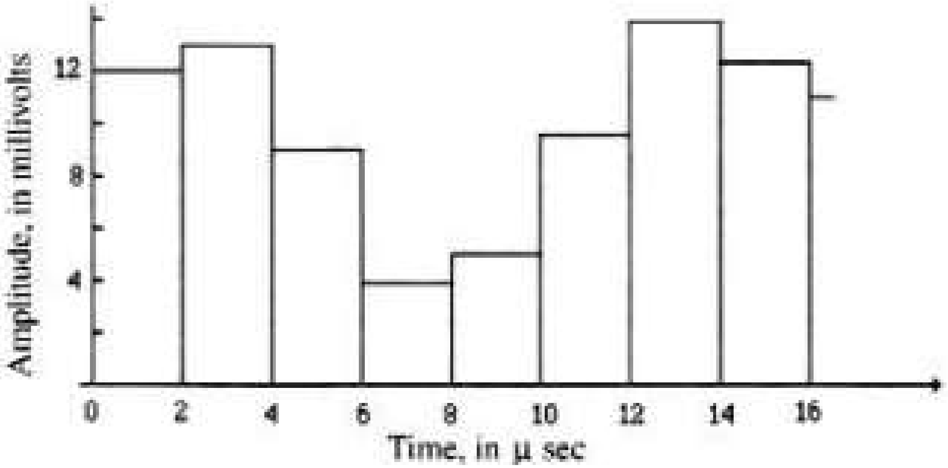
Output of A/D Converter (quantized binary)



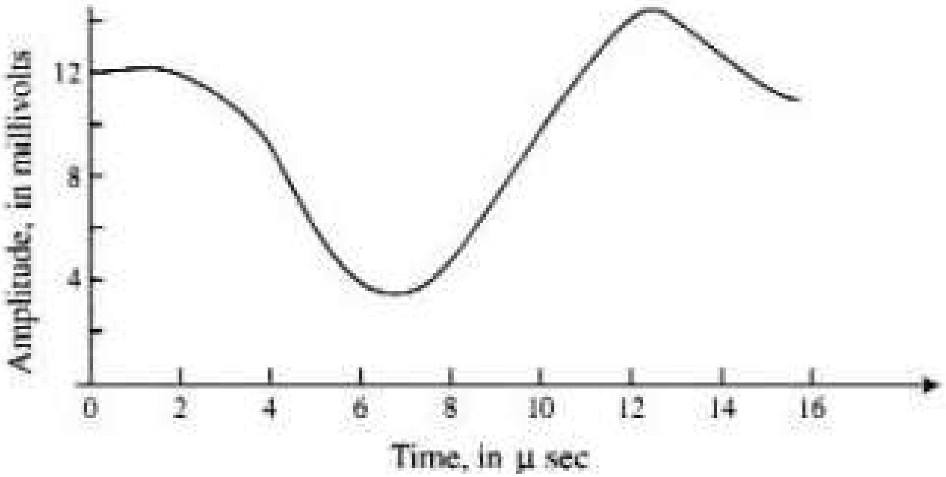
Output of Digital Processor (binary)



Output of D/A Converter (analog)



Output of LPF - Analog Signal



Digital Signal Processor

- A DSP (Digital Signal Processor) is a highly specialized microprocessor that is specifically designed and optimized for DSP (Digital Signal Processing) operations.
- The first successful dedicated DSP chip was the Texas Instruments, TMS 32010 (1983).
  - Separate data and instruction memory
  - Special instruction set for load / multiply / accumulate
  - 16 bits. 390ns for a single multiply-add operation

- TI then built many variations of this chip, with the C2000, C5000, C6000 and DaVinci series. TI is the largest producers of DSP chips today.

1_4 Wrap up

- Why do we use DSP?
  - Analog Signal Processing – limitations
  - Advantages of DSP
    - Anti-interference, stability, security, easy processing, flexibility
  - Disadvantages

- What is DSP?
  - Digital Signal Processing
    - DSP System
  - Digital Signal Processor
    - TI (Texas Instrument)

EEE336 Signal Processing and Digital Filtering

Lecture 1 Introduction

1_5 Applications

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Xi'an Jiaotong-Liverpool University 西交利物浦大學

Where is DSP used?

- Digitalized daily living equipments:

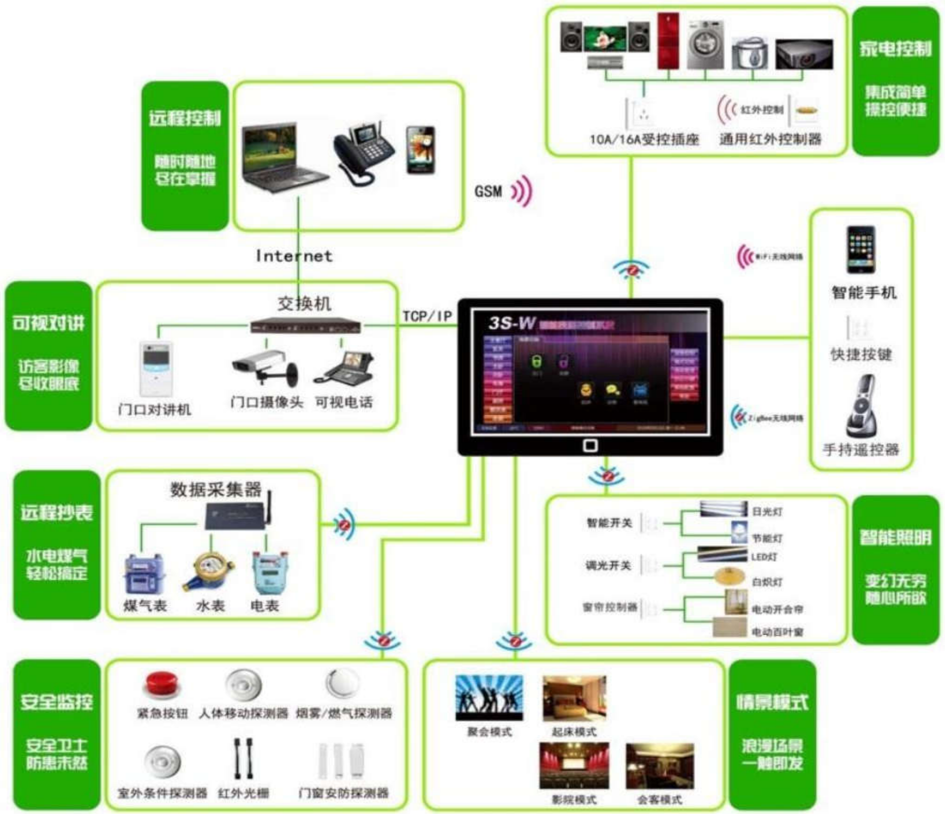


Where is DSP used?

- Digitalized living environment

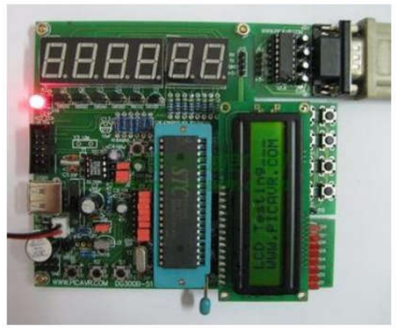
Where is DSP used?

- Digitalized living environment



Digital Home




Embedded system using DSP and MCU

Digital Kitchen

Where is DSP used?

- Digitalized living environment

Digital Hospital

Digital Agriculture

Where is DSP used?

- Digitalized living style

Communication

Transportation

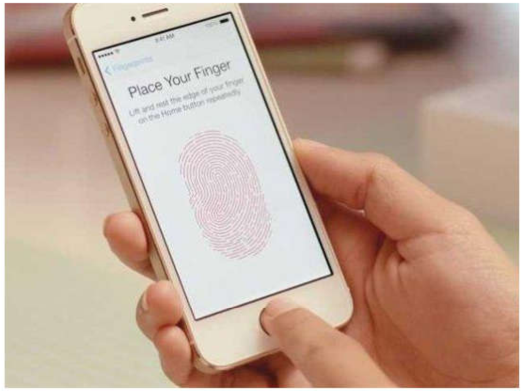
Shopping

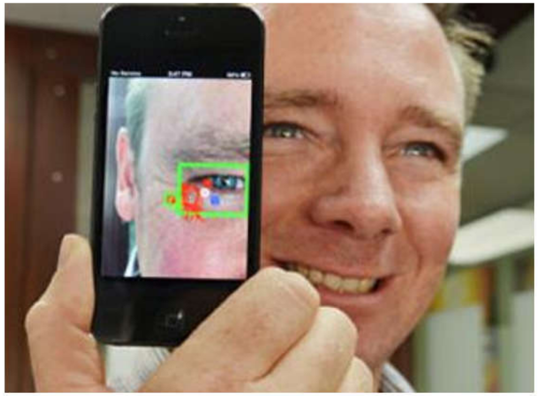
Reading

Teaching

Where is DSP used?

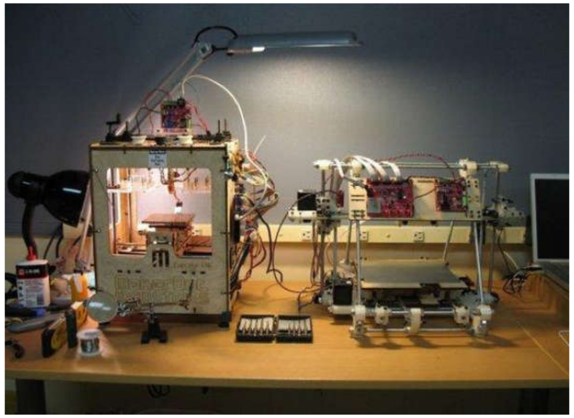
- Digitalized daily techniques





Identity recognition

Music sharing



Digital modelling

1_5 Wrap up

- DSP is Everywhere
  - Signal analysis, noise reduction /removal :
    - biological signals, physical signals, financial data, etc.
    - Audio signal processing, echo cancellation, …
  - Communications
    - analog communications
    - digital and wireless transmission
  - Data encryption, watermarking, fingerprint analysis, speech recognition
  - Image processing and reconstruction, MRI (Magnetic Resonance Imaging), PET (Positron Emission Tomography), CT (Computerized Tomogrphay) scans
  - Signal generation, electronic music synthesis

Chapter 1 Wrap up

- Chapter 1 Introduction
  - Module information
  - What is signal?
  - What is signal Processing?
  - What is DSP (Digital Signal Processing)?
    - Why DSP is so popular?
  - Applications of DSP
- Next:
  - Mathematics revision
  - Introduction to Matlab