BLM2041 Signals and Systems

Syllabus

The Instructors:

Doç. Dr. Ali Can Karaca

ackaraca@yildiz.edu.tr

Dr. Ahmet Elbir

aelbir@yildiz.edu.tr

Information Systems:

Fundamentals

DEFINITION(S) OF SYSTEM

A system can be broadly defined as an integrated set of elements that accomplish a defined objective.

People from different engineering disciplines have different perspectives of what a "system" is.

For example,

- software engineers often refer to an integrated set of computer programs as a "system"
- electrical engineers might refer to complex integrated circuits or an integrated set of electrical units as a "system"

As can be seen, "system" depends on one's perspective, and the "integrated set of elements that accomplish a defined objective" is an appropriate definition.

Definition(s) of system

- A system is an assembly of parts where:
  - The parts or components are connected together in an organized way.
  - The parts or components are affected by being in the system (and are changed by leaving it).
  - The assembly does something.
  - The assembly has been identified by a person as being of special interest.
- Any arrangement which involves the handling, processing or manipulation of resources of whatever type can be represented as a system.
- Some definitions on online dictionaries
  - http://en.wikipedia.org/wiki/System
  - http://dictionary.reference.com/browse/systems
  - http://www.businessdictionary.com/definition/system.html

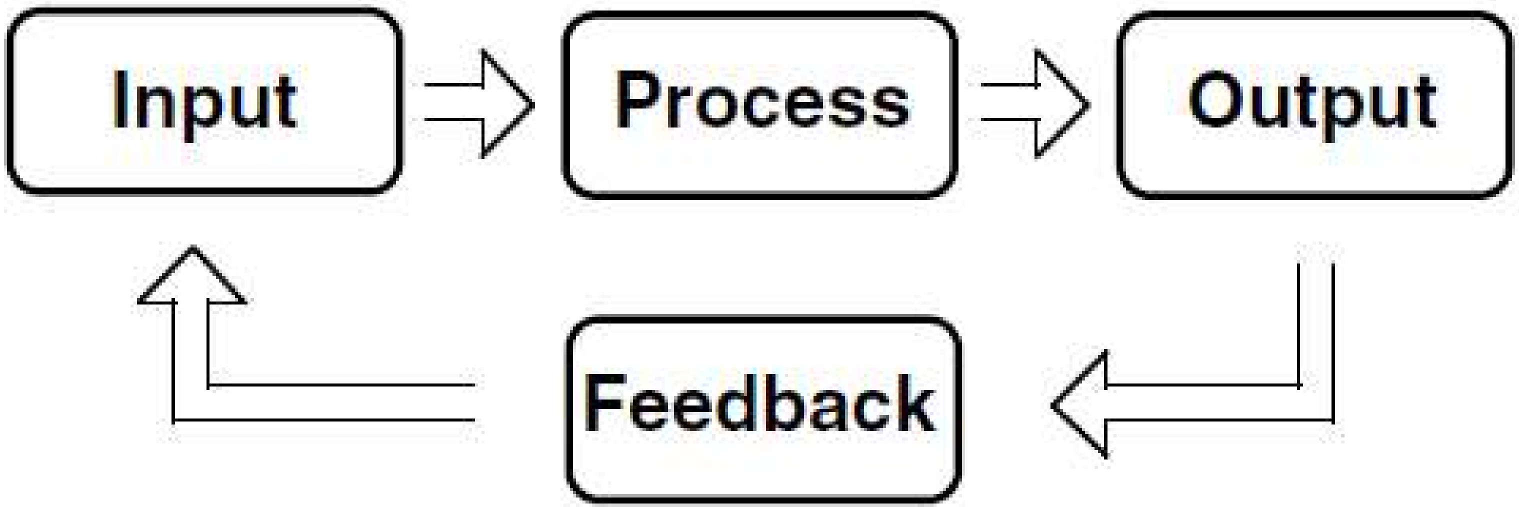
Definition(s) of system

- A system is defined as multiple parts working together for a common purpose or goal.
- Systems can be large and complex
  - such as the air traffic control system or our global telecommunication network.
- Small devices can also be considered as systems
  - such as a pocket calculator, alarm clock, or 10-speed bicycle.

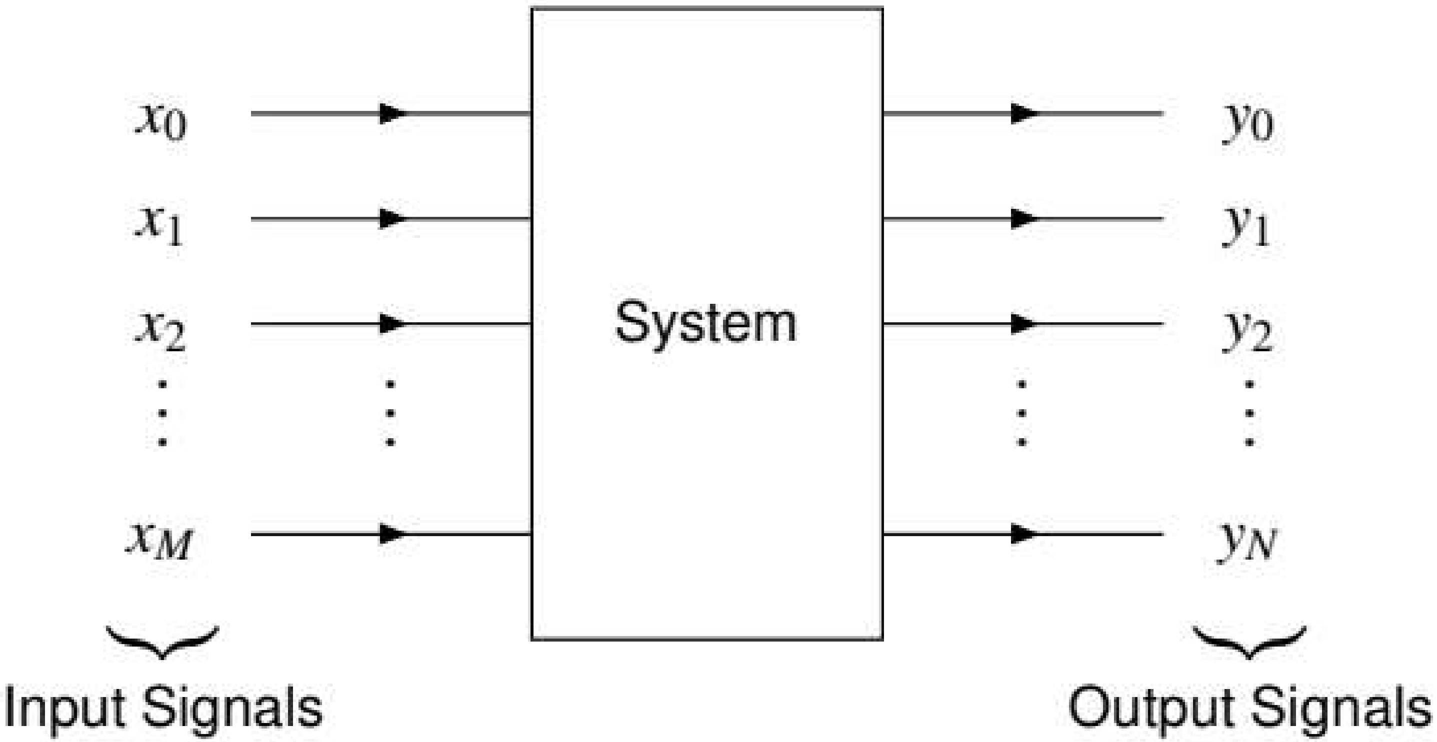
Definition(s) of system

- Systems have inputs, processes, and outputs.
- When feedback (direct or indirect) is involved, that component is also important to the operation of the system.
- To explain all this, systems are usually explained using a model.
- A model helps to illustrate the major elements and their relationship, as illustrated in the next slide

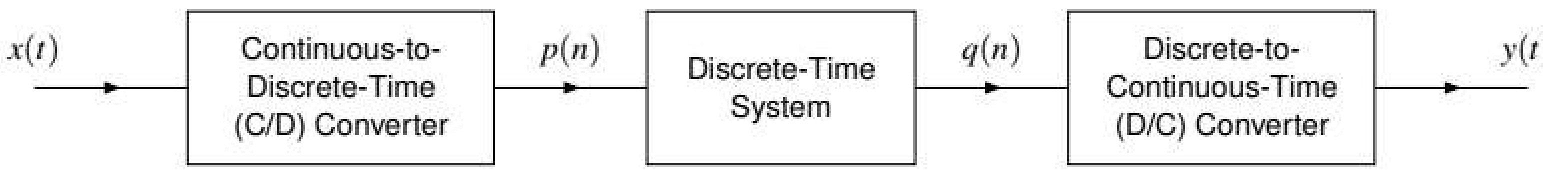
A systems model



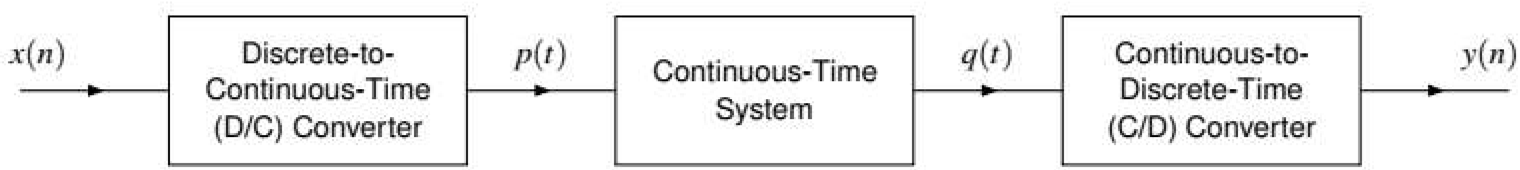
A systems model



Signal Processing System



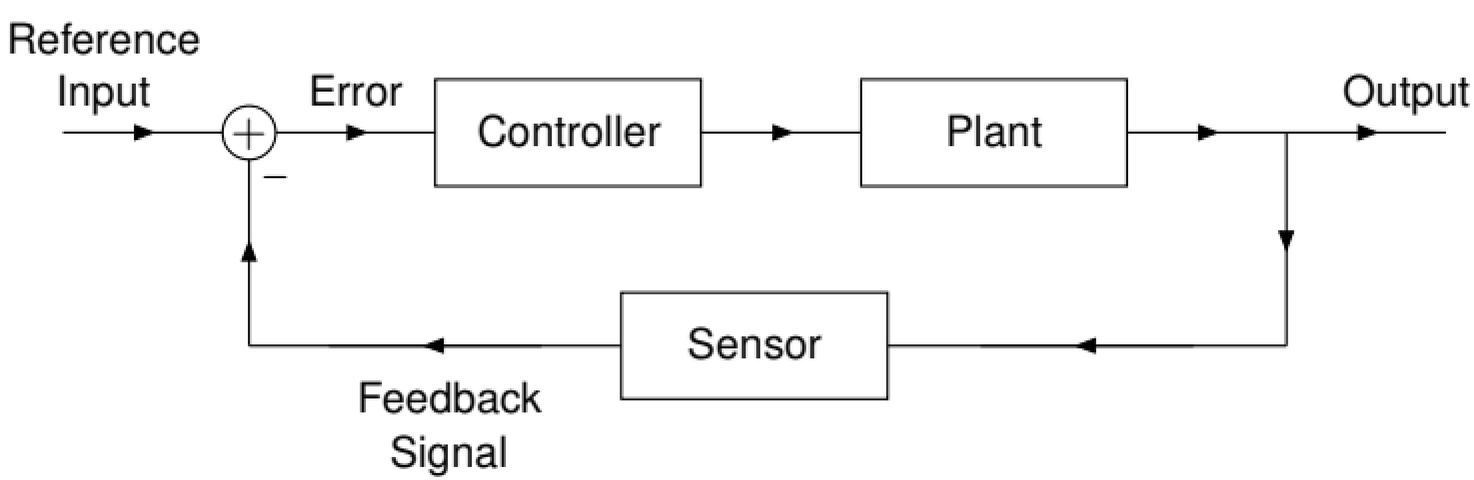
Processing a Continuous-Time Signal With a Discrete-Time System



Processing a Discrete-Time Signal With a Continuous-Time System

Communication & Control Systems

General Structure of a Communication System

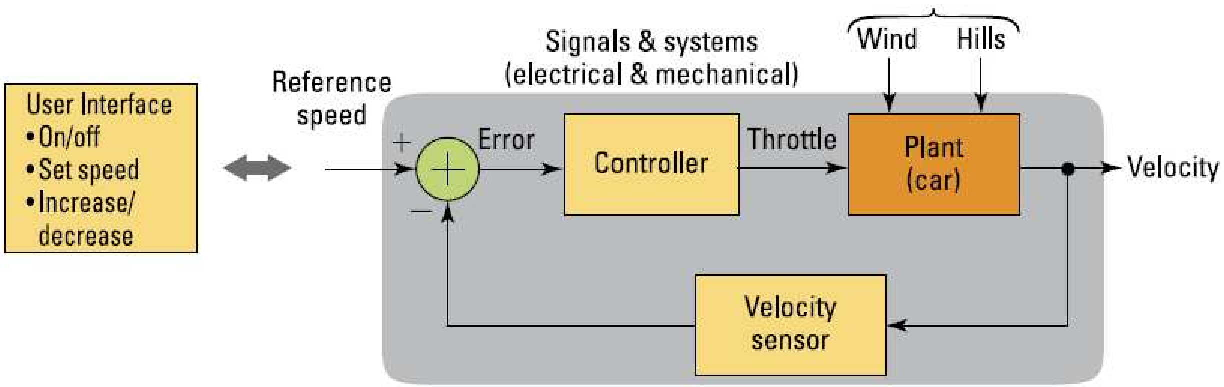


General Structure of a Feedback Control System

Arabalardaki Hız Sabitleme Sistemi

Giriş işareti: Referans hız, rüzgar ve yokuş olma durumu

Çıkış işareti: Arabanın hızı

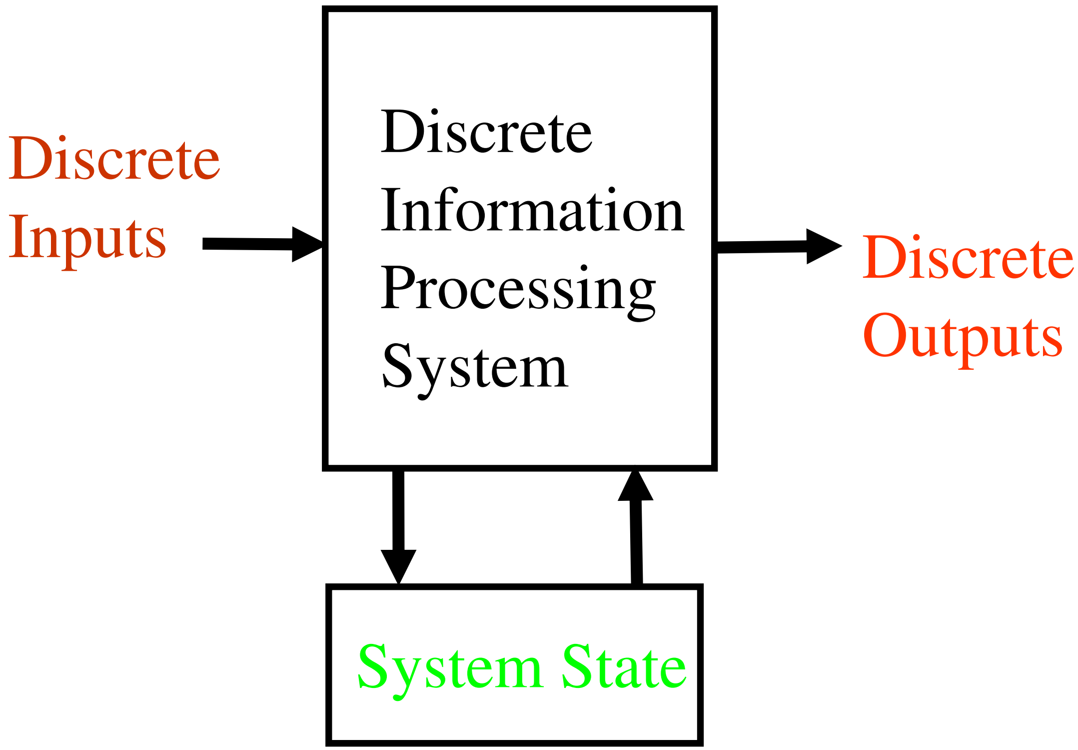


Sistem

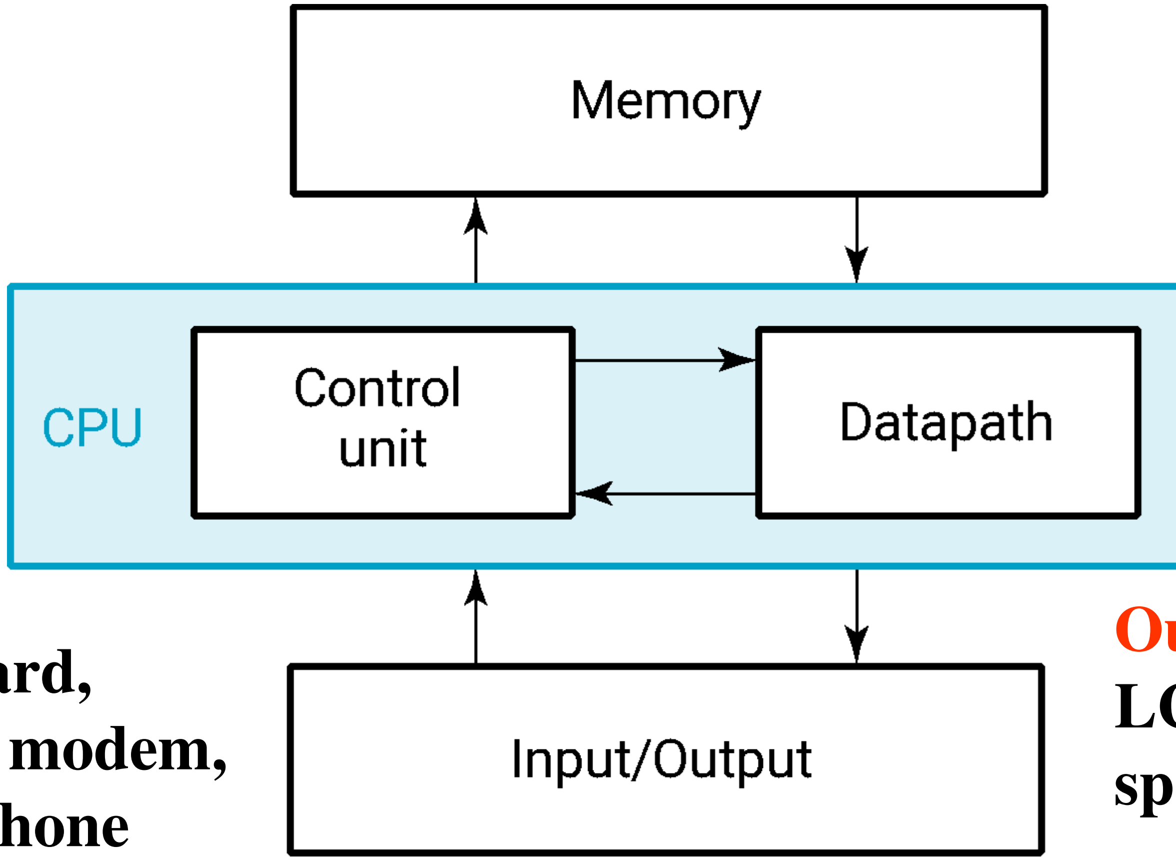
Ref: *Signals and Systems for Dummies*

Digital System

- **Takes a set of discrete information (inputs) and discrete internal information (system state) and generates a set of discrete information (outputs).**



A Digital Computer Example



Inputs: Keyboard, mouse, modem, microphone

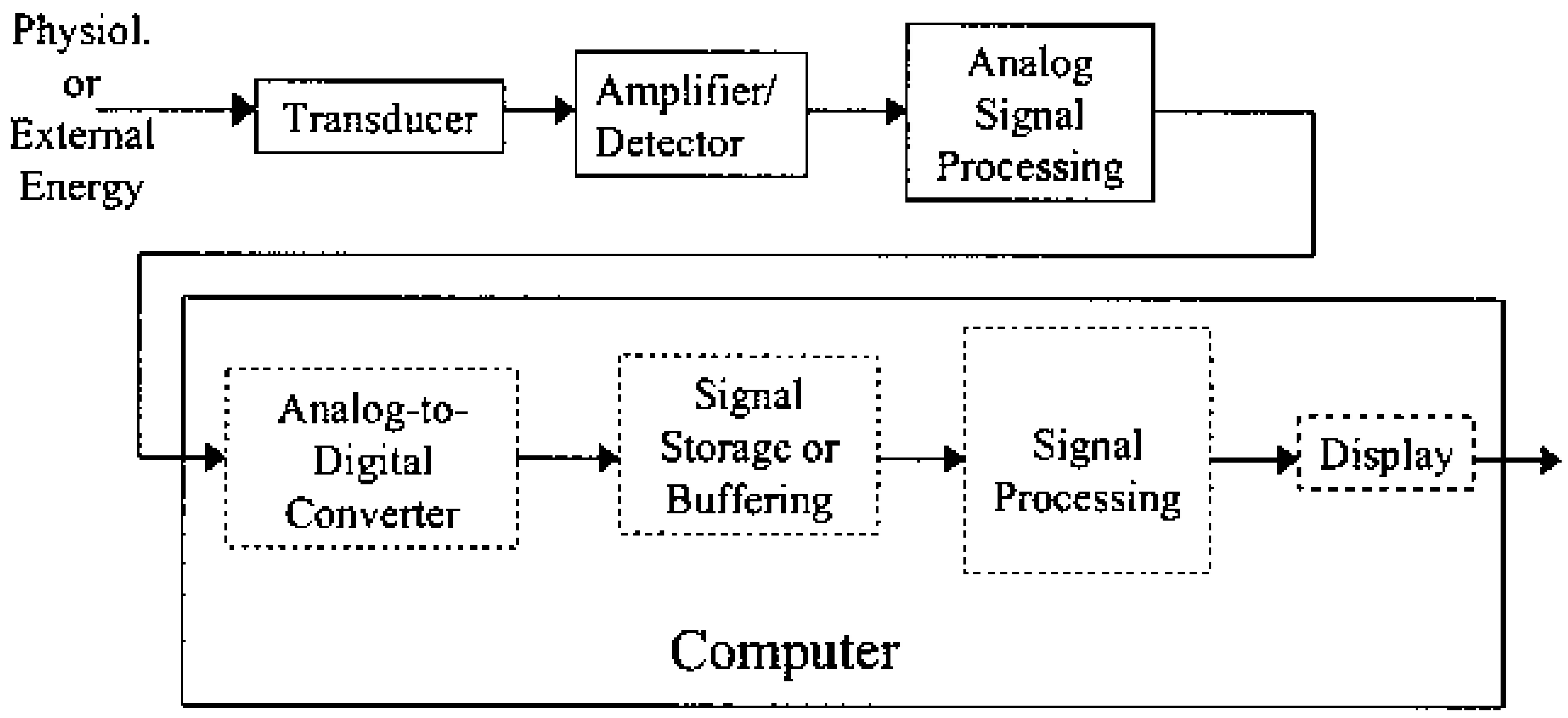
Outputs: CRT, LCD, modem, speakers

Synchronous or Asynchronous?

Signal

- An information variable represented by physical quantity.
- For digital systems, the variable takes on discrete values.
- Two level, or binary values are the most prevalent values in digital systems.
- Binary values are represented abstractly by:
  - digits 0 and 1
  - words (symbols) False (F) and True (T)
  - words (symbols) Low (L) and High (H)
  - and words On and Off.
- Binary values are represented by values or ranges of values of physical quantities

A typical measurement system



Transducers

- A “transducer” is a device that converts energy from one form to another.
- In signal processing applications, the purpose of energy conversion is to transfer information, not to transform energy.
- In physiological measurement systems, transducers may be
  - input transducers (or sensors)
    - they convert a non-electrical energy into an electrical signal.
    - for example, a microphone.
  - output transducers (or actuators)
    - they convert an electrical signal into a non-electrical energy.
    - For example, a speaker.

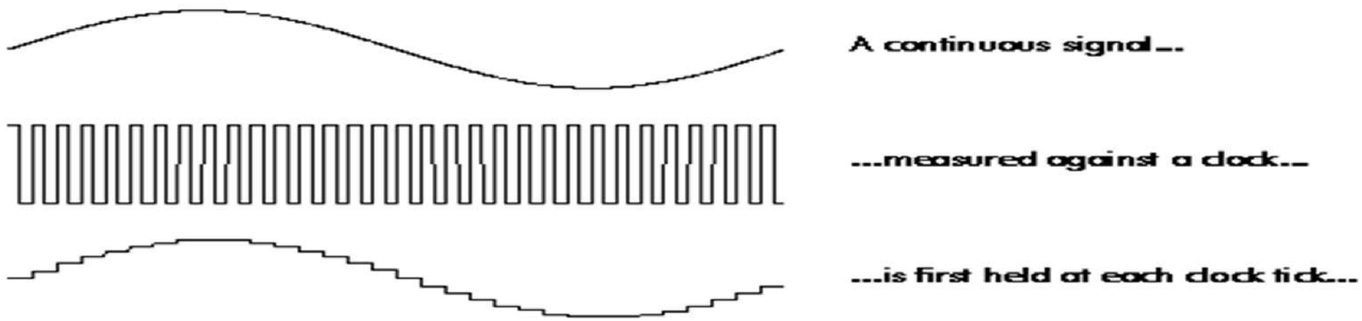
Analogue signal

- The analogue signal
  - a continuous variable defined with infinite precision

  is converted to a discrete sequence of measured values which are represented digitally
- Information is lost in converting from analogue to digital, due to:
  - inaccuracies in the measurement
  - uncertainty in timing
  - limits on the duration of the measurement
- These effects are called quantisation errors

Digital signal

- The continuous analogue signal has to be held before it can be sampled

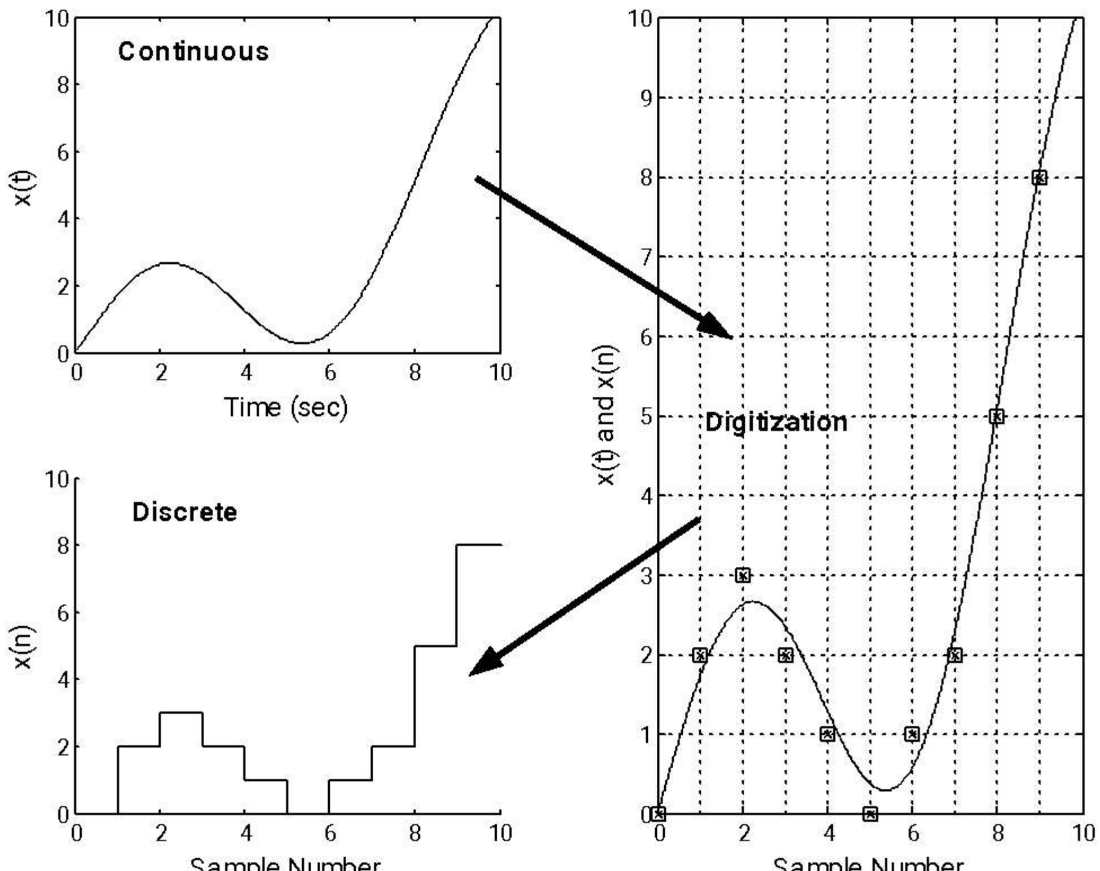


- Otherwise, the signal would be changing during the measurement
- Only after it has been held can the signal be measured, and the measurement converted to a digital valu

Signal Encoding: Analog-to Digital Conversion

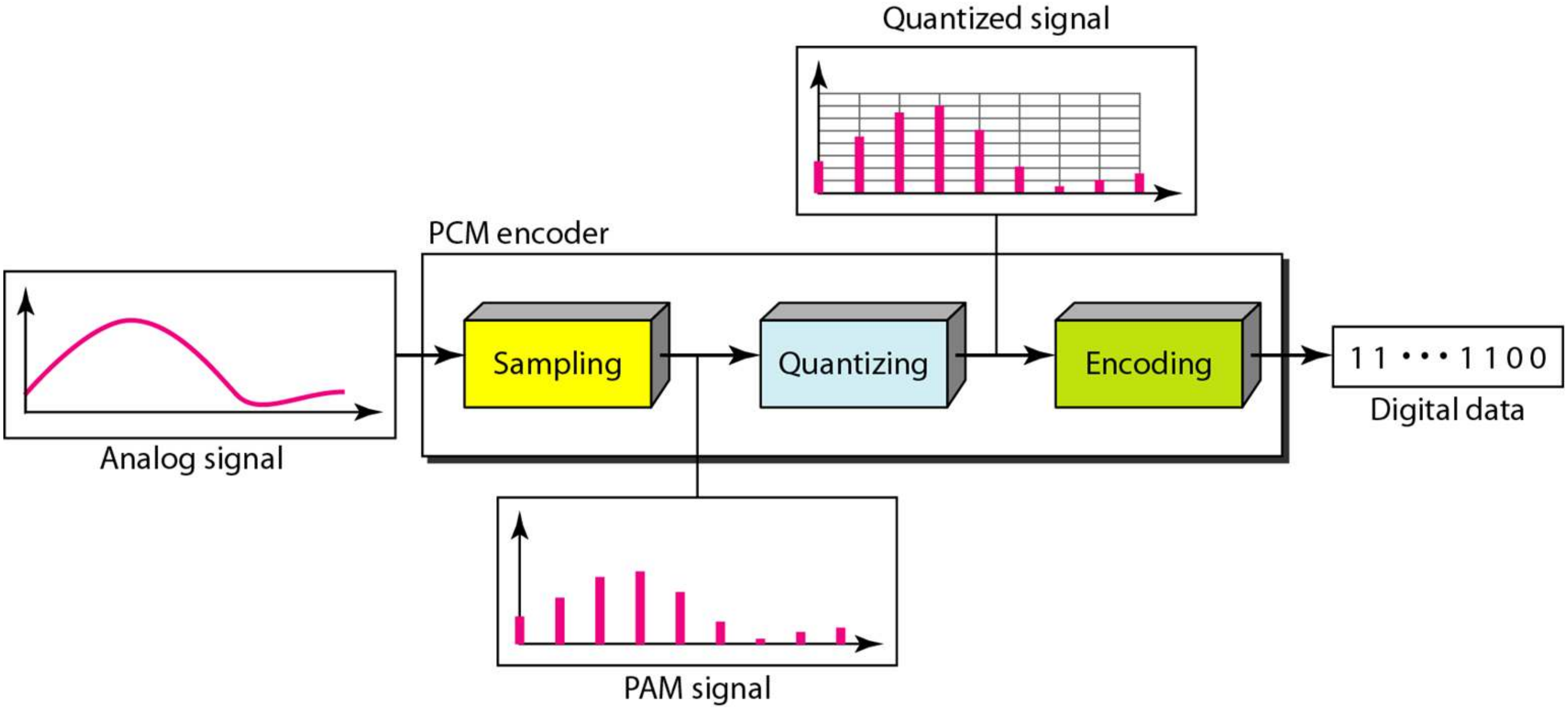
Continuous (analog) signal $\leftrightarrow$ Discrete signal

x(t) = f(t) $\leftrightarrow$ Analog to digital conversion $\leftrightarrow$ x[n] = x [1], x [2], x [3], ... x[n]



Analog-to Digital Conversion

- ADC consists of four steps to digitize an analog signal:
  1. Filtering
  2. Sampling
  3. Quantization
  4. Binary encoding
- Before we sample, we have to filter the signal to limit the maximum frequency of the signal as it affects the sampling rate.
- Filtering should ensure that we do not distort the signal, ie remove high frequency components that affect the signal shape.

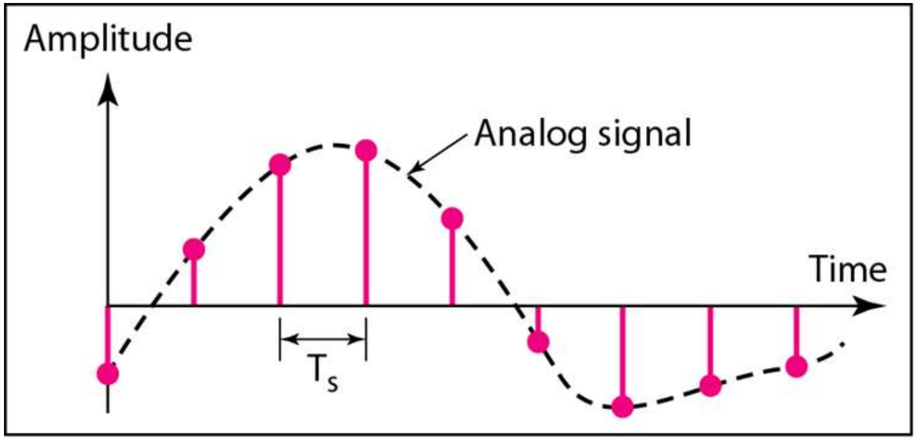

Quantized signal
PCM encoder
Sampling
Quantizing
Encoding
11 ••• 1100
Digital data
Analog signal
PAM signal

Sampling

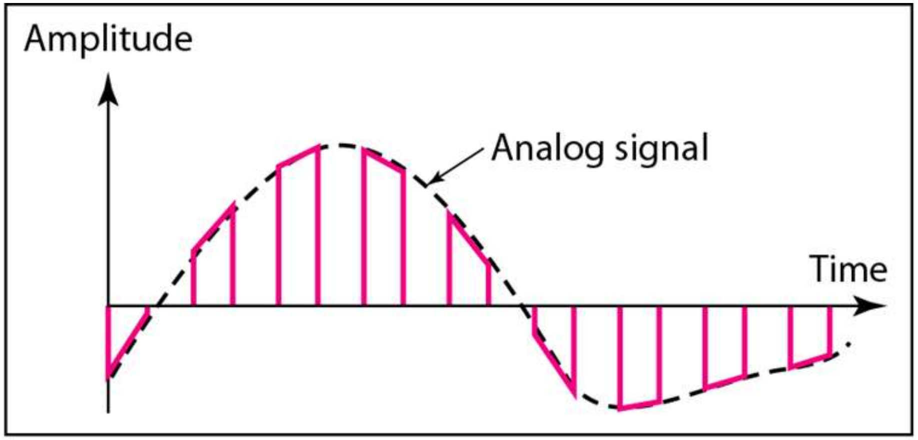
- The sampling results in a discrete set of digital numbers that represent measurements of the signal
  - usually taken at equal intervals of time
- Sampling takes place after the hold
  - The hold circuit must be fast enough that the signal is not changing during the time the circuit is acquiring the signal value
- We don't know what we don't measure
- In the process of measuring the signal, some information is lost

Sampling

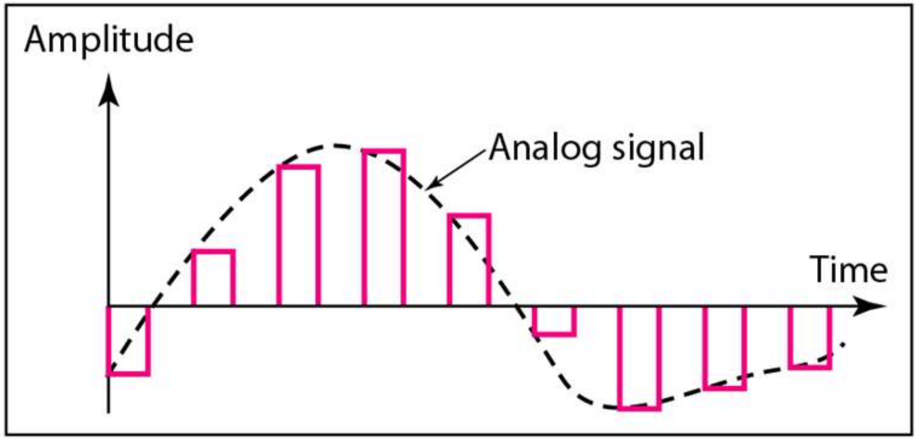
- Analog signal is sampled every T_S secs.
- T_s is referred to as the sampling interval.
- $f_s = 1/T_s$ is called the sampling rate or sampling frequency.
- There are 3 sampling methods:
  - Ideal - an impulse at each sampling instant
  - Natural - a pulse of short width with varying amplitude
  - Flattop - sample and hold, like natural but with single amplitude value
- The process is referred to as pulse amplitude modulation PAM and the outcome is a signal with analog (non integer) values



a. Ideal sampling

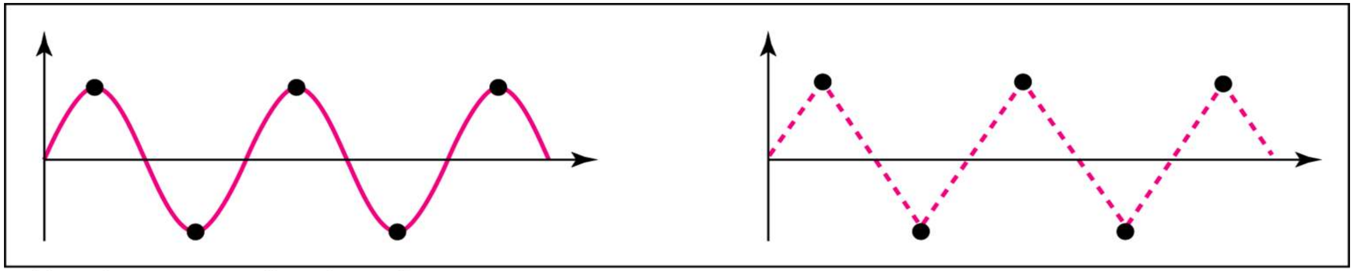


b. Natural sampling

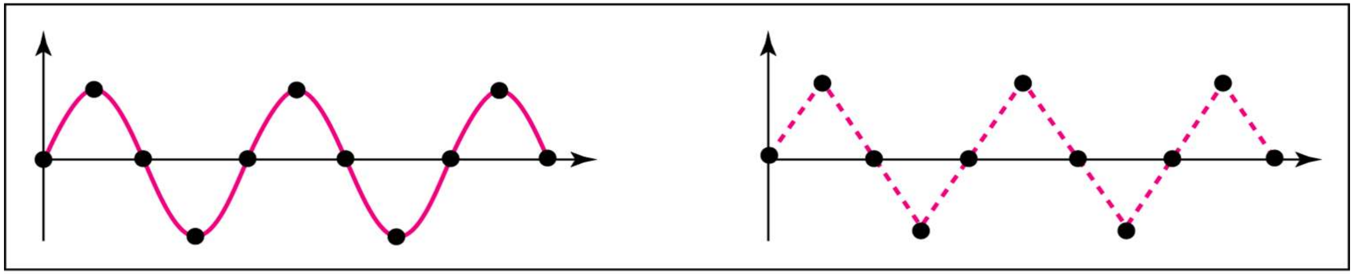


c. Flat-top sampling

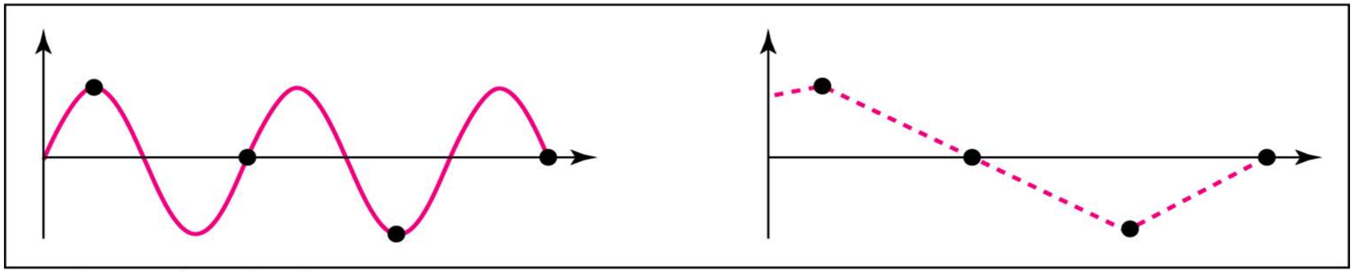
Recovery of a sampled sine wave for different sampling rates



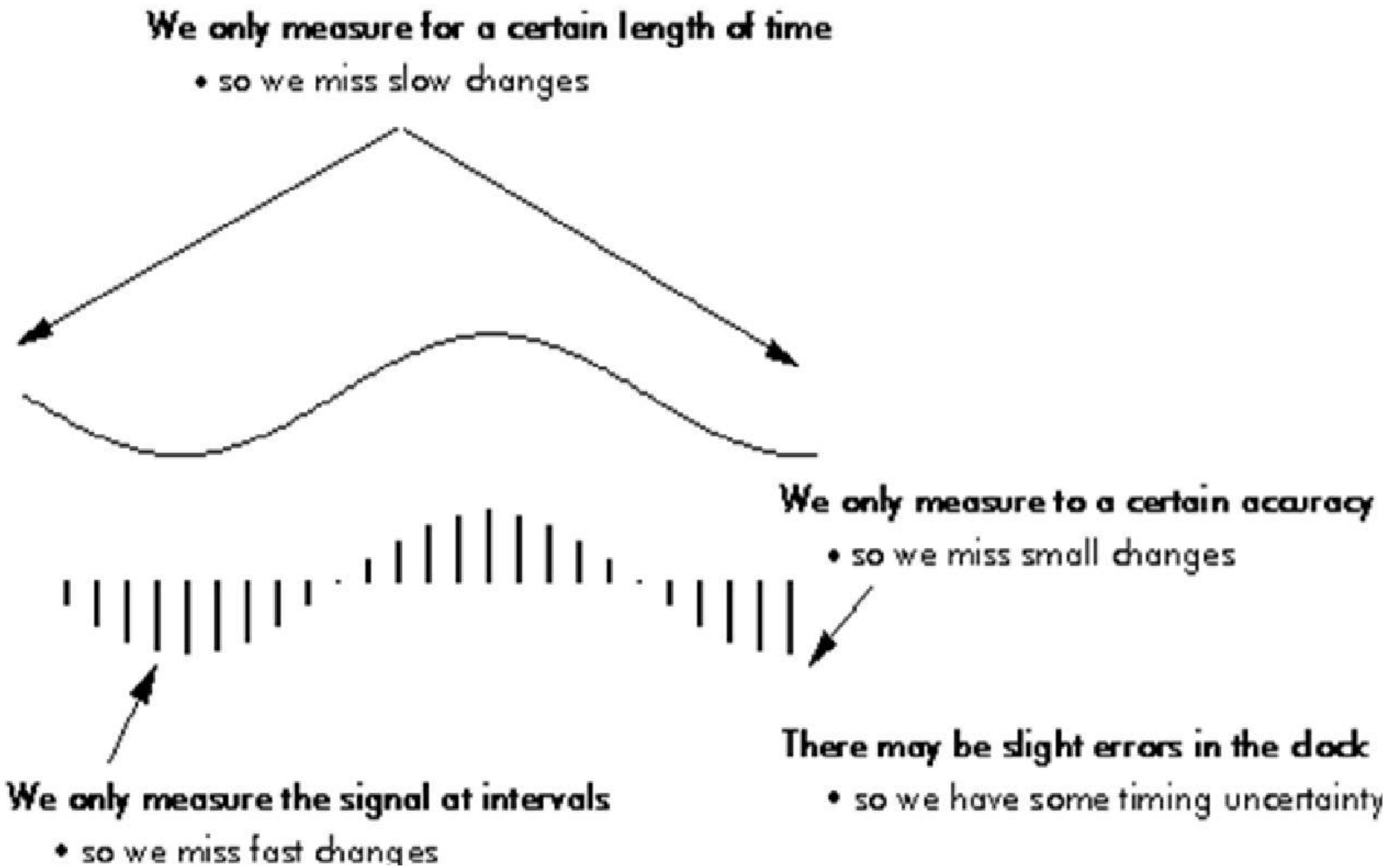
a. Nyquist rate sampling: $f_s = 2\ f$

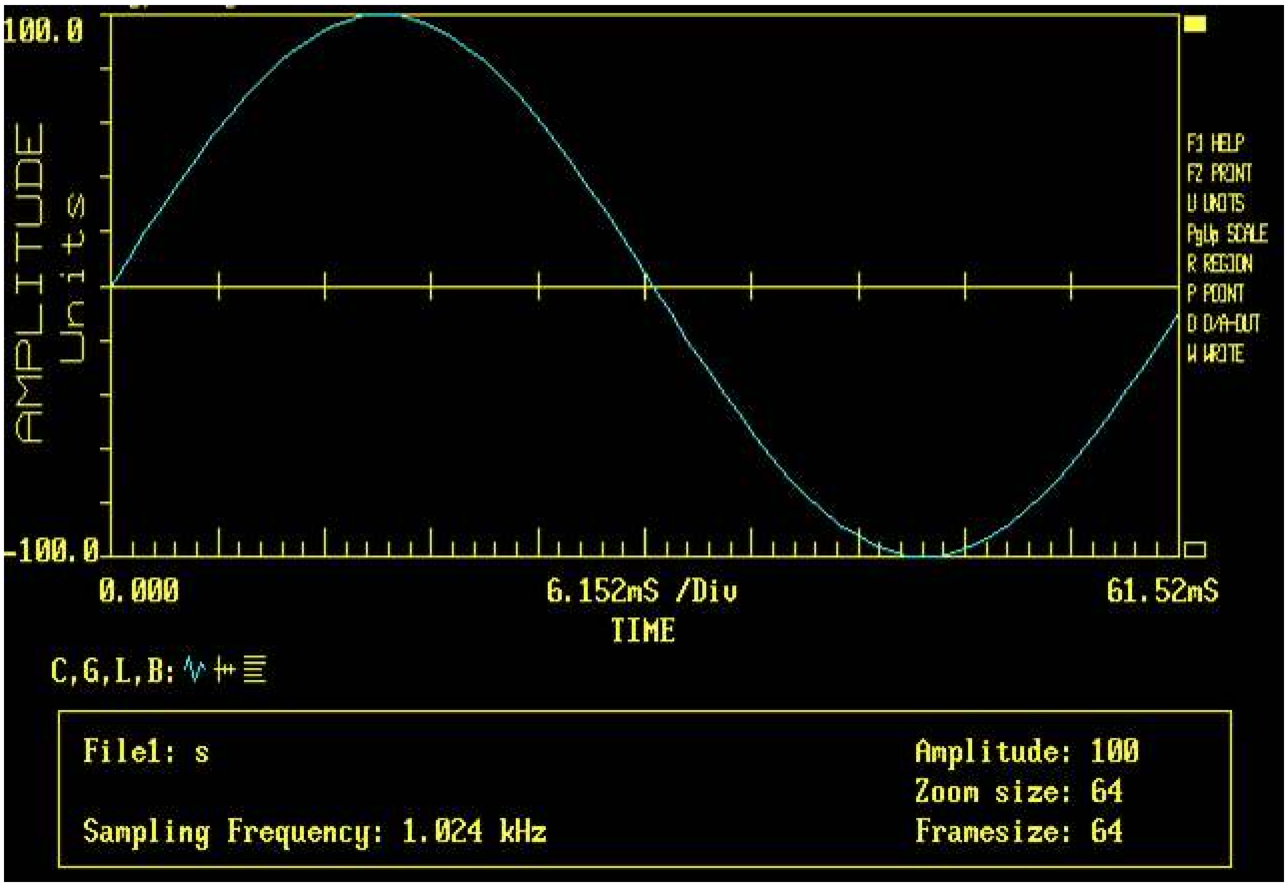


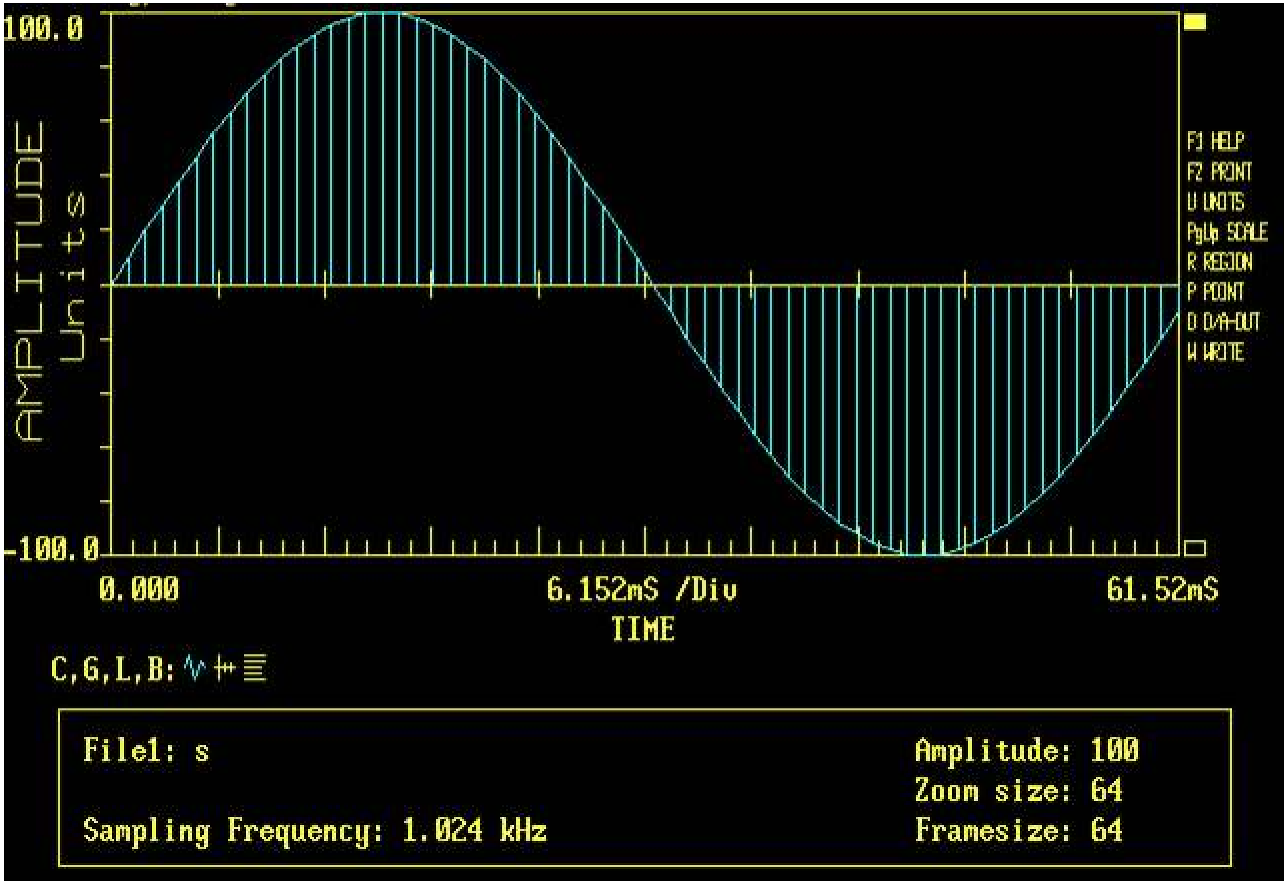
b. Oversampling: $f_s = 4\ f$

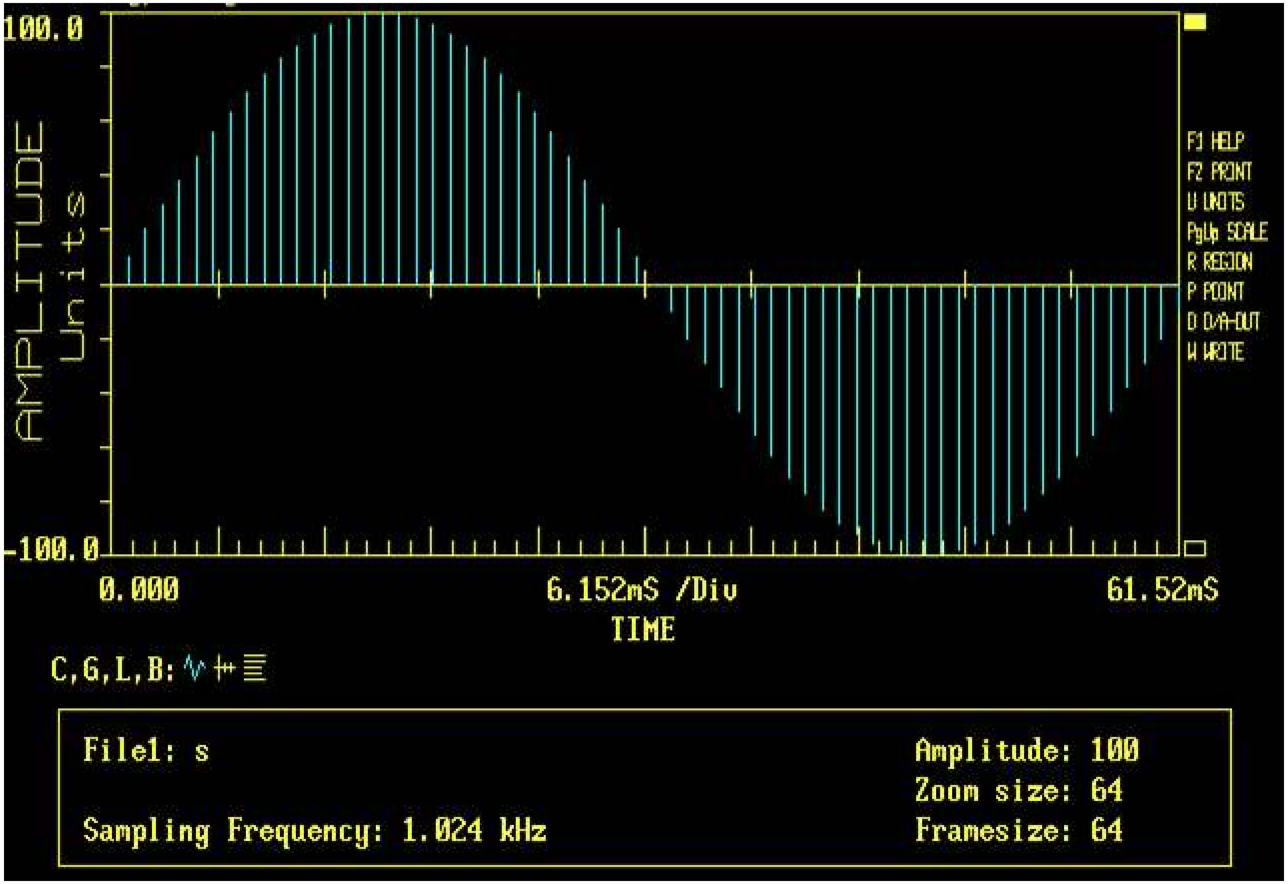


c. Undersampling: $f_s = f$


We only measure for a certain length of time
• so we miss slow changes
We only measure to a certain accuracy
• so we miss small changes
There may be slight errors in the clock
• so we have some timing uncertainty
We only measure the signal at intervals
• so we miss fast changes


100.0
-100.0
AMPLITUDE
Units
F1 HELP
F2 PRINT
U UNITS
PgUp SCALE
R REGION
P POINT
D D/A-OUT
W WRITE
0.000
6.152mS /Div
61.52mS
TIME
C,G,L,B:
File1: s
Sampling Frequency: 1.024 kHz
Amplitude: 100
Zoom size: 64
Framesize: 64


100.0
-100.0
AMPLITUDE
Units
F1 HELP
F2 PRINT
U UNITS
PgUp SCALE
R REGION
P POINT
D D/A-OUT
W WRITE
0.000
6.152mS /Div
61.52mS
TIME
C,G,L,B:
File1: s
Sampling Frequency: 1.024 kHz
Amplitude: 100
Zoom size: 64
Framesize: 64

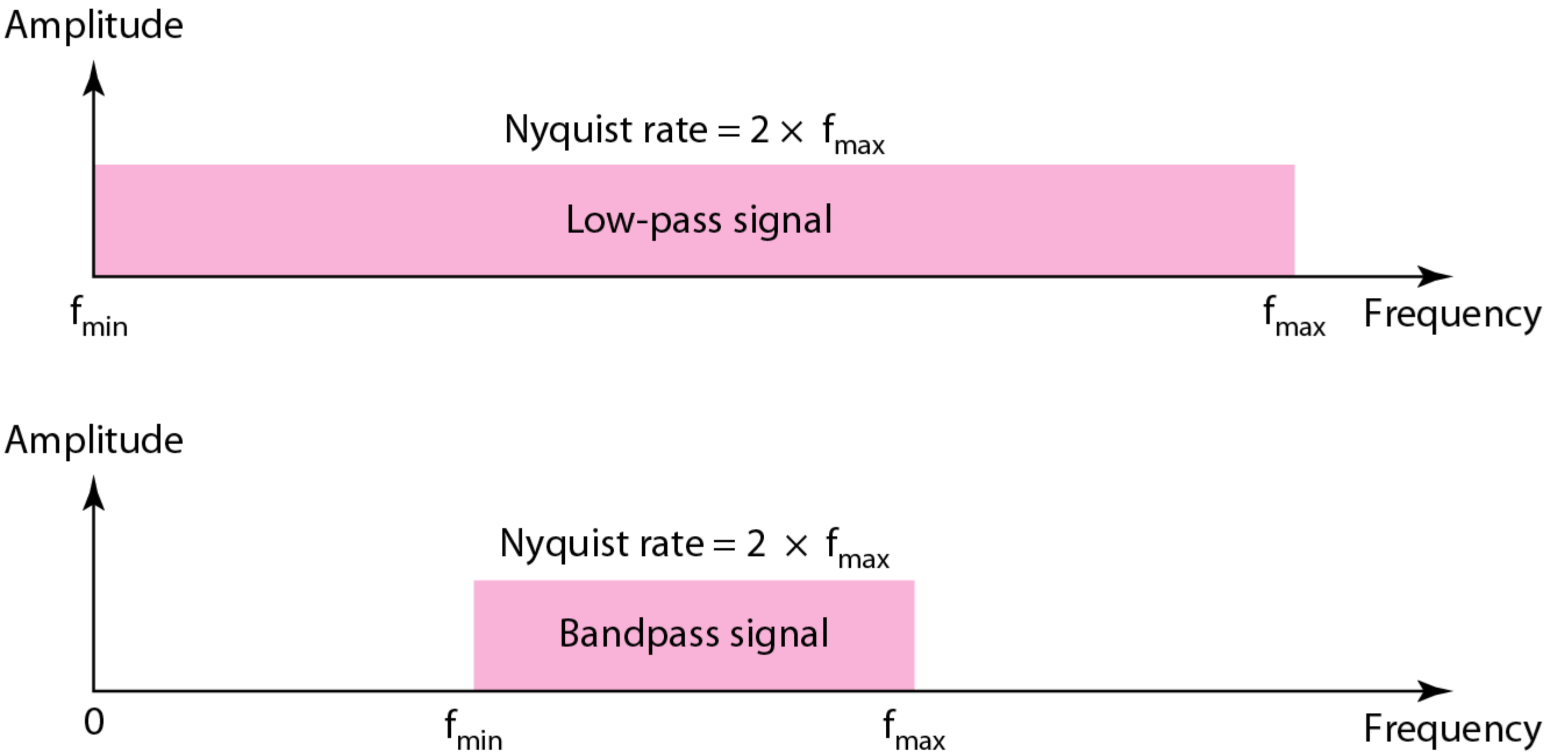

100.0
-100.0
AMPLITUDE
Units
0.000
6.152mS /Div
61.52mS
TIME
F1 HELP
F2 PRINT
U UNITS
PgUp SCALE
R REGION
P POINT
D D/A-OUT
W WRITE
C,G,L,B:
File1: s
Sampling Frequency: 1.024 kHz
Amplitude: 100
Zoom size: 64
Framesize: 64

Sampling Theorem

$$F_s \geq 2f_m$$

According to the Nyquist theorem, the sampling rate must be at least 2 times the highest frequency contained in the signal.

Nyquist sampling rate for low-pass and bandpass signals



Quantization

- Sampling results in a series of pulses of varying amplitude values ranging between two limits: a min and a max.
- The amplitude values are infinite between the two limits.
- We need to map the *infinite* amplitude values onto a finite set of known values.
- This is achieved by dividing the distance between min and max into L zones, each of height Δ.

$$\Delta = (\max - \min)/L$$

Quantization Levels

- The midpoint of each zone is assigned a value from 0 to L-1 (resulting in L values)
- Each sample falling in a zone is then approximated to the value of the midpoint.

Quantization Zones

- Assume we have a voltage signal with amplitutes V_{min}=-20V and V_{max}=+20V.
- We want to use L=8 quantization levels.
- Zone width Δ = (20 - -20)/8 = 5
- The 8 zones are: -20 to -15, -15 to -10, -10 to -5, -5 to 0, 0 to +5, +5 to +10, +10 to +15, +15 to +20
- The midpoints are: -17.5, -12.5, -7.5, -2.5, 2.5, 7.5, 12.5, 17.5

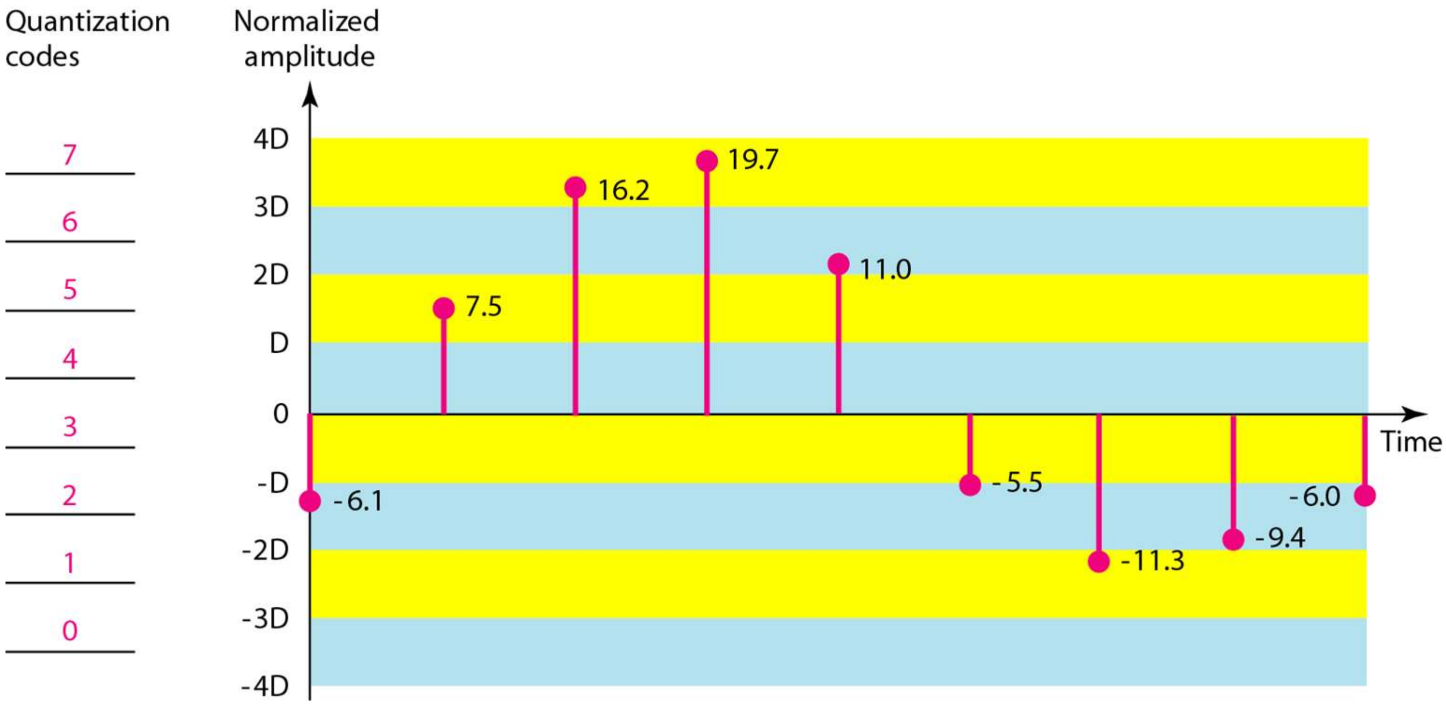
Assigning Codes to Zones

- Each zone is then assigned a binary code.
- The number of bits required to encode the zones, or the number of bits per sample as it is commonly referred to, is obtained as follows:

$$n_b = \log_2 L$$

- Given our example, $n_b = 3$
- The 8 zone (or level) codes are therefore: 000, 001, 010, 011, 100, 101, 110, and 111
- Assigning codes to zones:
  - 000 will refer to zone -20 to -15
  - 001 to zone -15 to -10, etc.

Quantization and encoding of a sampled signal



Normalized PAM values	-1.22	1.50	3.24	3.94	2.20	-1.10	-2.26	-1.88	-1.20
Normalized quantized values	-1.50	1.50	3.50	3.50	2.50	-1.50	-2.50	-1.50	-1.50
Normalized error	-0.38	0	+0.26	-0.44	+0.30	-0.40	-0.24	+0.38	-0.30
Quantization code	2	5	7	7	6	2	1	2	2
Encoded words	010	101	111	111	110	010	001	010	010

Quantization Error

- When a signal is quantized, we introduce an error
  - the coded signal is an approximation of the actual amplitude value.
- The difference between actual and coded value (midpoint) is referred to as the quantization error.
- The more zones, the smaller Δ
  - which results in smaller errors.
- BUT, the more zones the more bits required to encode the samples
  - higher bit rate

Analog-to-digital Conversion

Example An 12-bit analog-to-digital converter (ADC) advertises an accuracy of ± the least significant bit (LSB). If the input range of the ADC is 0 to 10 volts, what is the accuracy of the ADC in analog volts?

Solution:

If the input range is 10 volts then the analog voltage represented by the LSB would be:

$$V_{LSB} = \frac{V_{max}}{2^{\text{Nu bits}}} = \frac{10}{2^{12}} = \frac{10}{4096} = .0024 \text{ volts}$$

Hence the accuracy would be ± 0.0024 volts.

Steps for digitization/reconstruction of a signal

- Band limiting (LPF)
- Sampling / Holding
- Quantization
- Coding

These are basic steps for A/D conversion

- D/A converter
- Sampling / Holding
- Image rejection

These are basic steps for reconstructing a sampled digital signal

Digital data: end product of A/D conversion and related concepts

- Bit: least digital information, binary 1 or 0
- Nibble: 4 bits
- Byte: 8 bits, 2 nibbles
- Word: 16 bits, 2 bytes, 4 nibbles
- Some jargon:
  - integer, signed integer, long integer, 2s complement, hexadecimal, octal, floating point, etc.


MP3 Audio
Recording
ADC
00000
00000
DSP
00000
MEMORY
DAC
00000
00000
Playback

Example

- Hertz = clock cycles per second (frequency)
  - 1MHz = 1,000,000Hz
  - Processor speeds are measured in MHz or GHz.
- Byte = a unit of storage
  - 1KB = 2^{10} = 1024 Bytes
  - 1MB = 2^{20} = 1,048,576 Bytes
  - Main memory (RAM) is measured in MB
  - Disk storage is measured in GB for small systems, TB for large systems.

Number of Bits Required

- Given M elements to be represented by a binary code, the minimum number of bits, n, needed, satisfies the following relationships:

  $2^n \geq M > 2^{(n-1)}$

  $n = \lceil \log_2 M \rceil$ where $\lceil x \rceil$, called the *ceiling function,* is the integer greater than or equal to x.

- Example: How many bits are required to represent decimal digits with a binary code?
  - 4 bits are required ($n = \lceil \log_2 9 \rceil = 4$)

Number of Elements Represented

- Given n digits in radix r, there are r^n distinct elements that can be represented.
- But, you can represent m elements, $m < r^n$
- Examples:
  - You can represent 4 elements in radix $r = 2$ with $n = 2$ digits: (00, 01, 10, 11).
  - You can represent 4 elements in radix $r = 2$ with $n = 4$ digits: (0001, 0010, 0100, 1000).