PDS0101

Introduction to Digital Systems

Introduction to Digital Concepts

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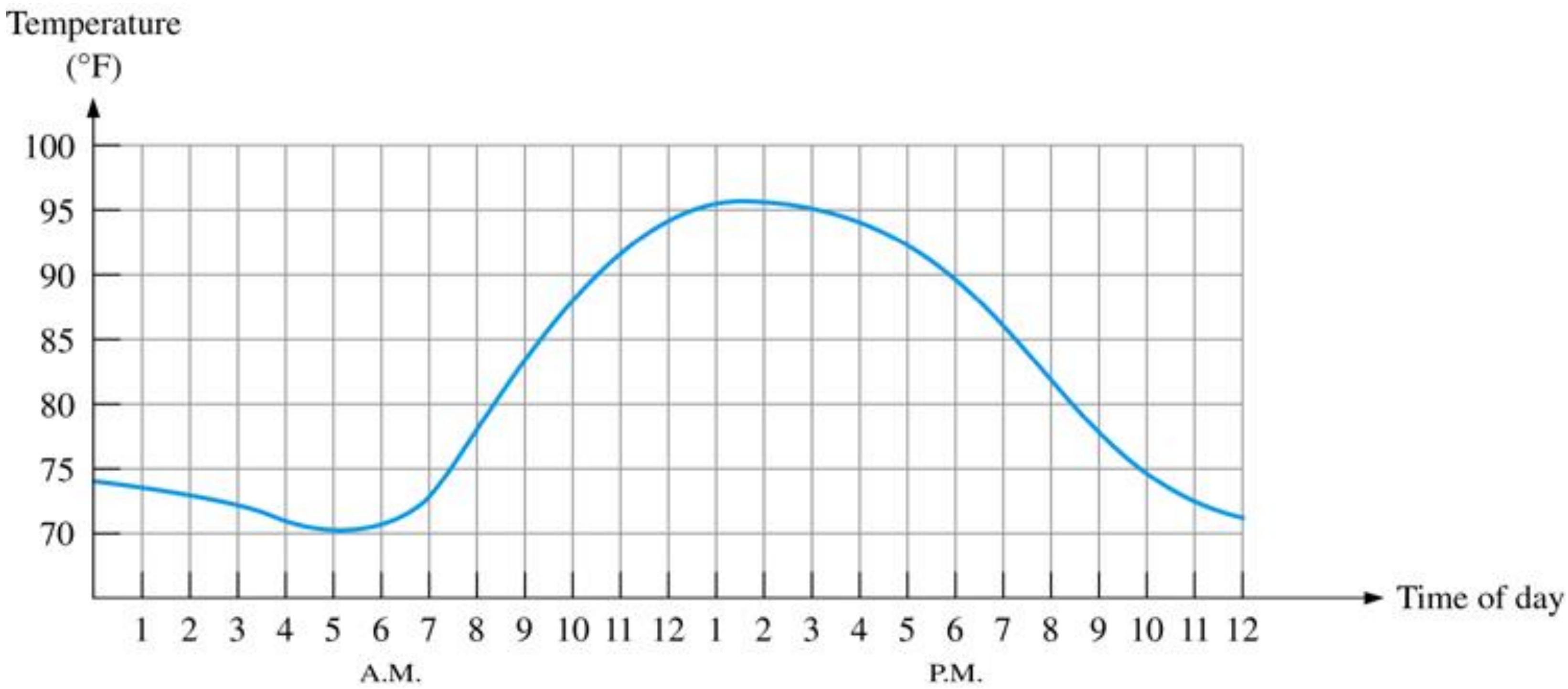
Lecture outcome

- By the end of today's lecture you should know
  - Analog vs. Digital Quantities
  - Examples of analog and digital electronic systems
  - Advantages and limitations of Digital Systems
  - Hybrid Systems
  - Logic levels – Positive and Negative Logic
  - Digital Waveforms – Period, Frequency, Duty cycle
  - Timing Diagram
  - Types of Data Transfer – Serial vs. Parallel

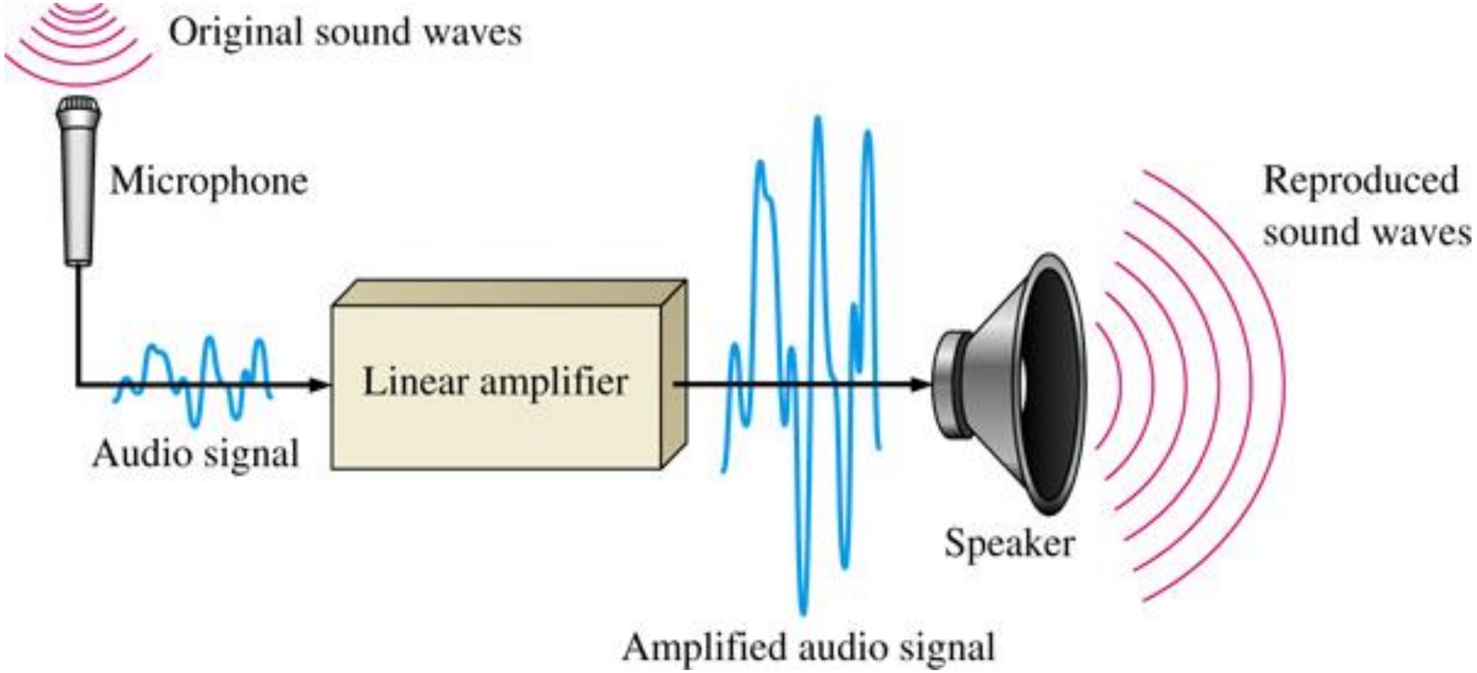
Analog quantities

- An analog quantity (or analog signal) refers to a continuous signal in which the time varying feature (measured variable) of the signal is a representation of some other time varying quantity
- Values change smoothly from one value to the next
- Examples: Temperature, Pressure, Level, Position, Volume, Voltage, Current etc.



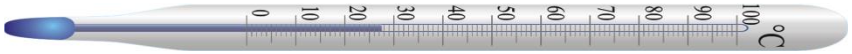
An analog electonic system example

- Analog system
  - A combination of devices that manipulate I/O values represented in analog form
  - Here the variable is allowed to take any value in a specified range
  - Example: A basic audio public address system
    Sound through a microphone causes voltage changes in proportion to the amplitude of the sound waves

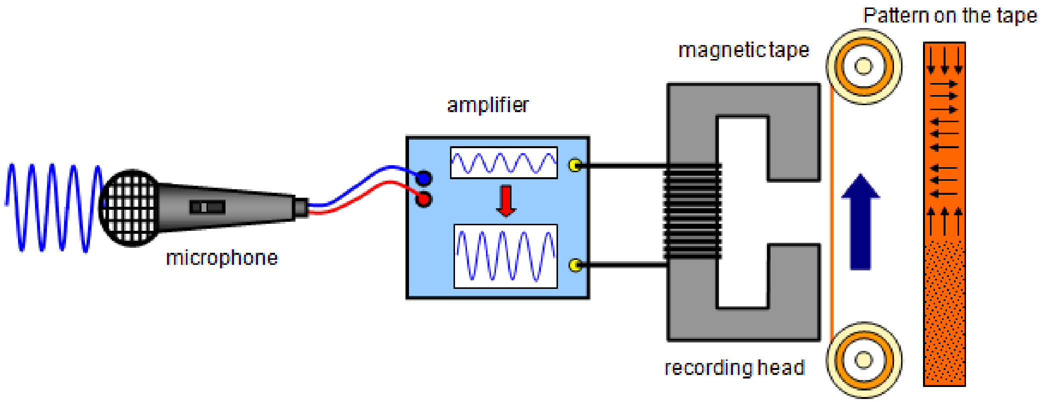


More analog system examples

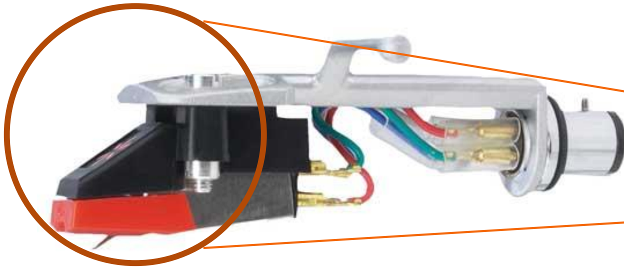
- Automobile speedometer changes with speed
  - It can have any value between zero and say, 120 mph
- Mercury thermometer varies over a range of values with temperature.
  - Height of the column of mercury is proportional to the temperature - Level of the mercury represents the value of the temperature

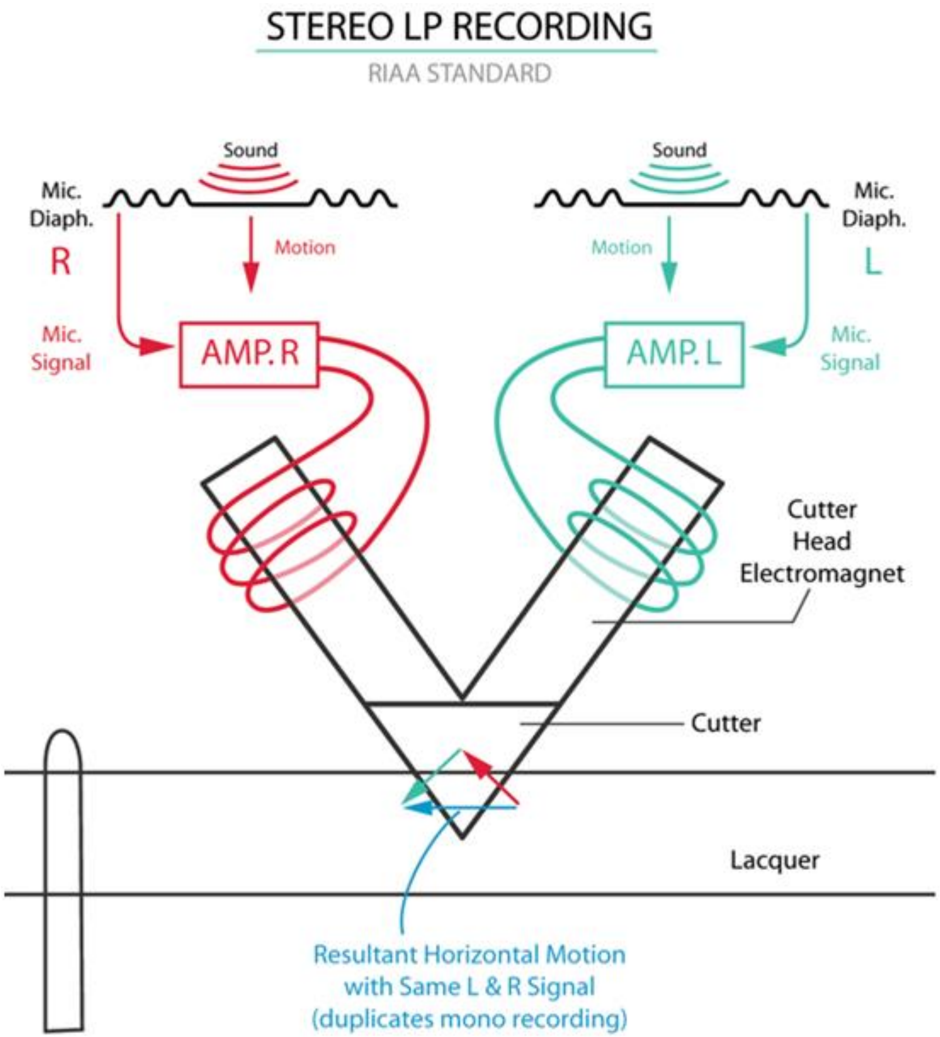


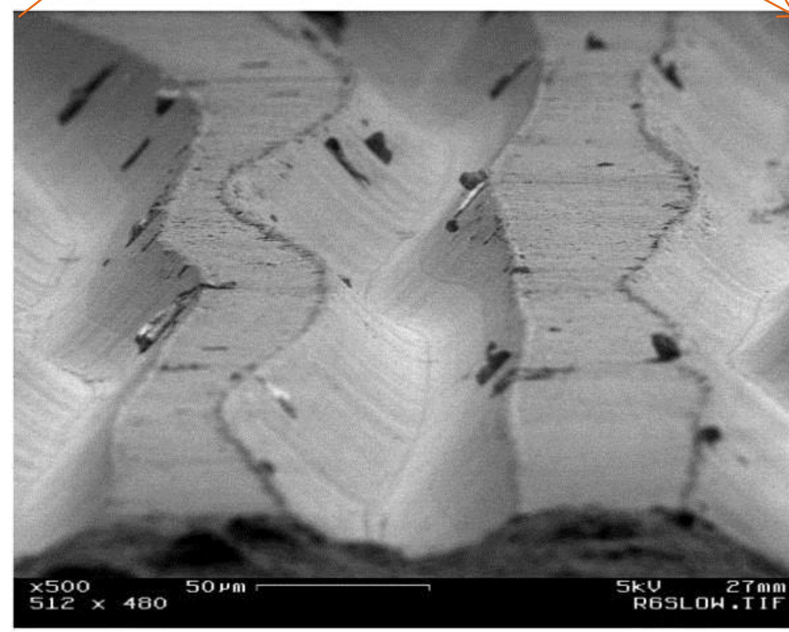
- Magnetic tape recording and playback equipment



- Vinyl record for audio playback (see next slide)



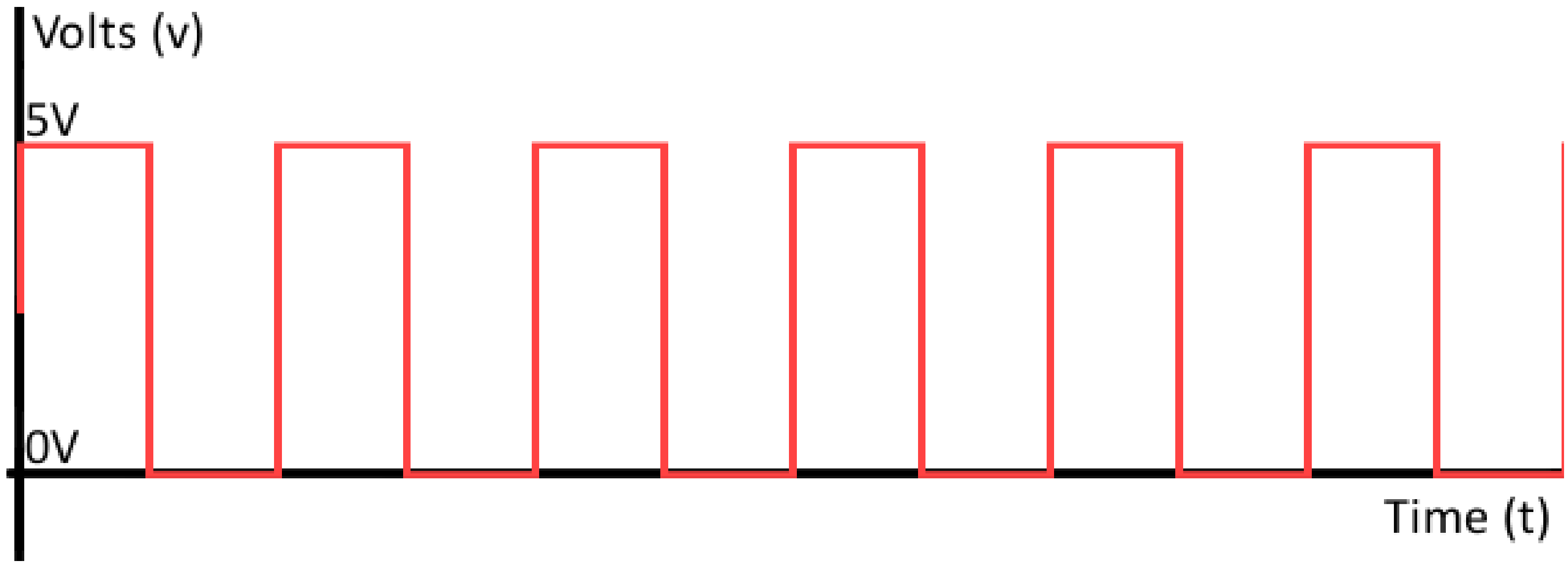




http://www.audiomisc.co.uk/ArchiveMagazine/09/riaa.html

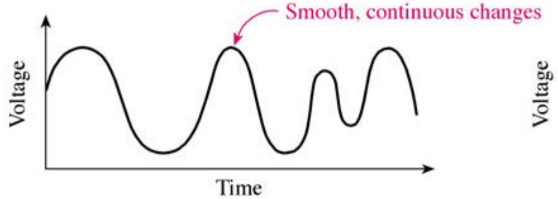
Digital quantities

- The term *digital* means a signal is limited to only a few possible values
- Basic example is using two distinguisable signal voltages on a wire to represent binary 0 and 1 (or low/high and false/true)
- More complicated signals can be constructed by stringing 1s and 0s

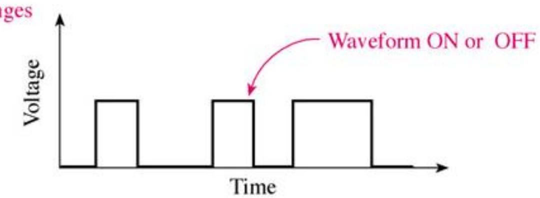


Digital system examples

- Digital systems
  - A combination of devices that manipulate values represented in digital form.
  - Examples: Digital Computer, Handheld Calculator, Digital Watch, Digital audio and video equipment



(a)



(b)

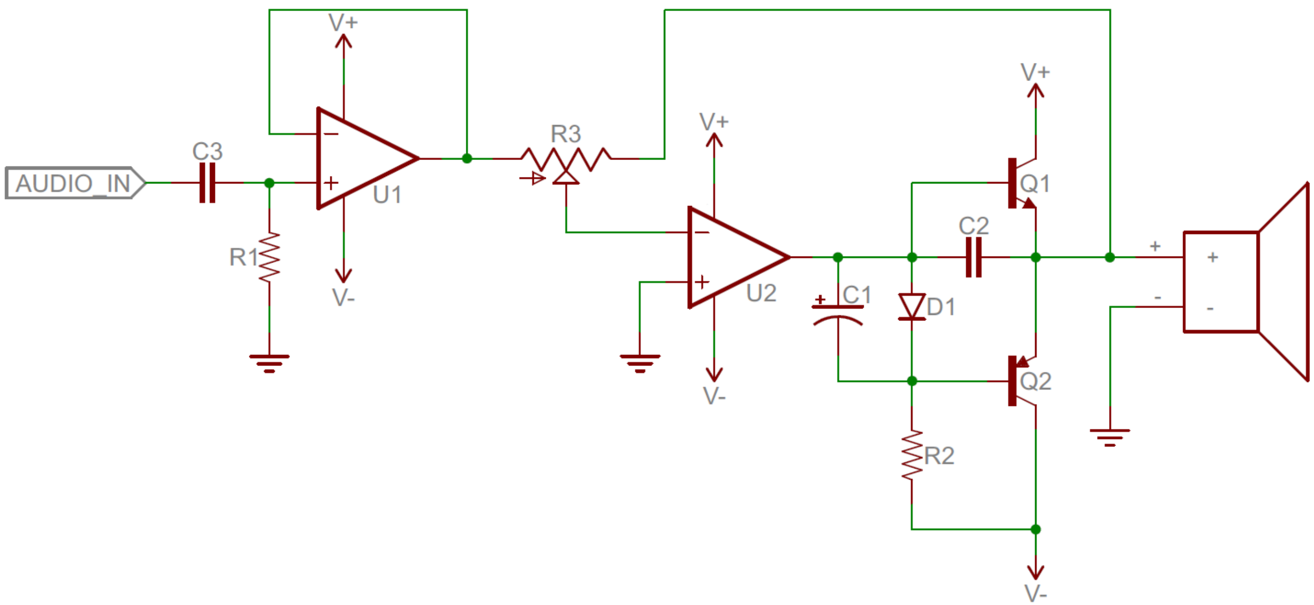
(c)

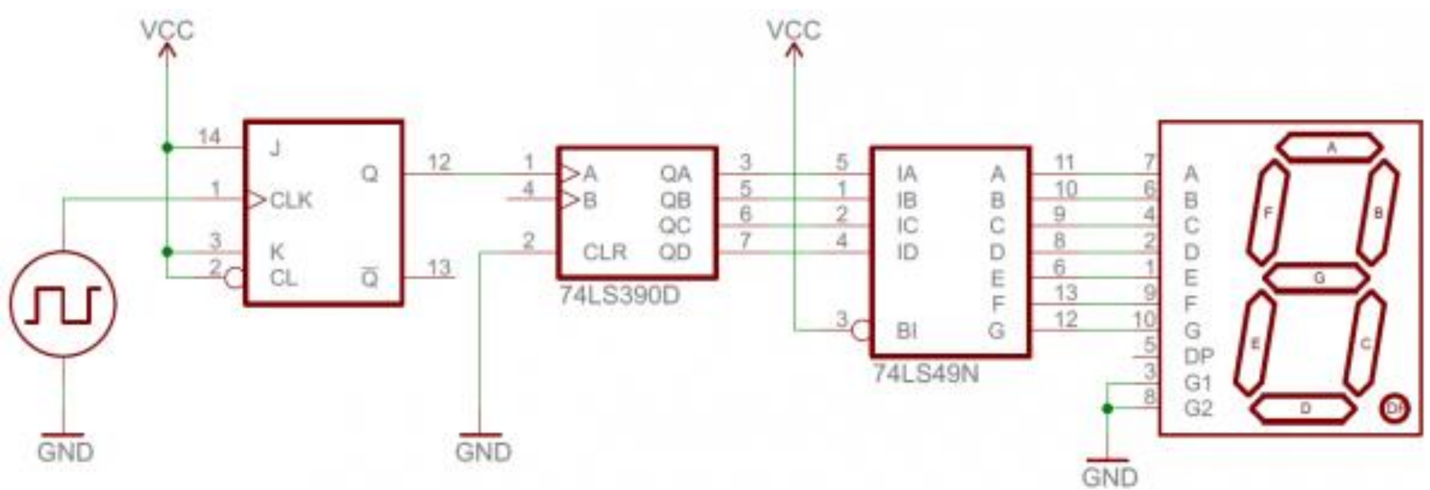
(d)

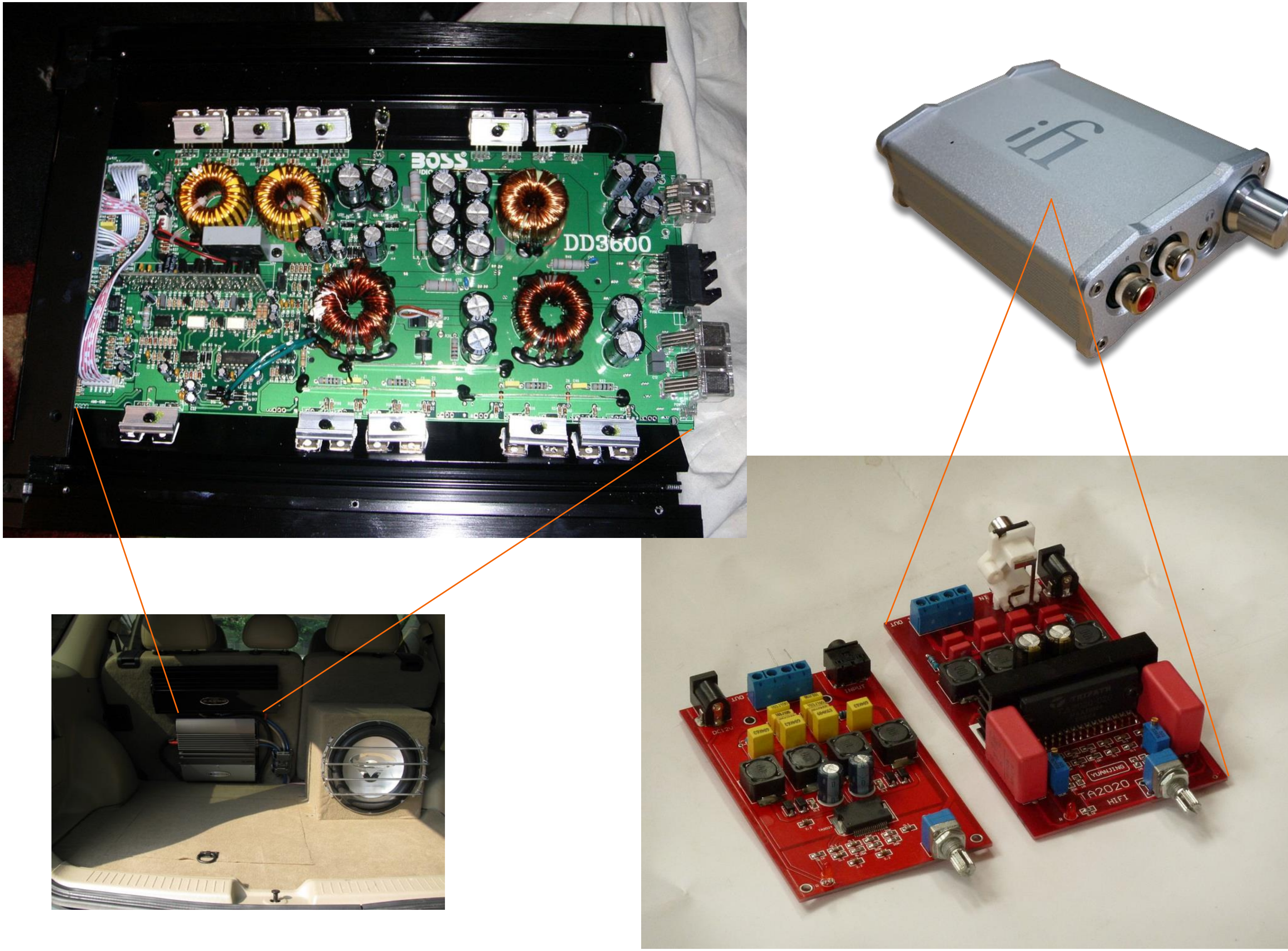
Digital advantages over analog

- Data processing and transmission – more efficient and reliable
- Data Storage – more compact storage and greater accuracy and clarity in reproduction
- Ease of design – In switching circuits, only the range in which the voltage or current fall is important not the exact values
- Accuracy and precision are easier to maintain – In analog systems, voltage and current signals are affected by temperature, humidity but in digital systems, information does not degrade
- Easy programmable operation
- Less affected by noise since exact value is not important in digital systems
- Ease of fabrication on IC chips – analog devices cannot be economically integrated.

Digital vs analog circuits



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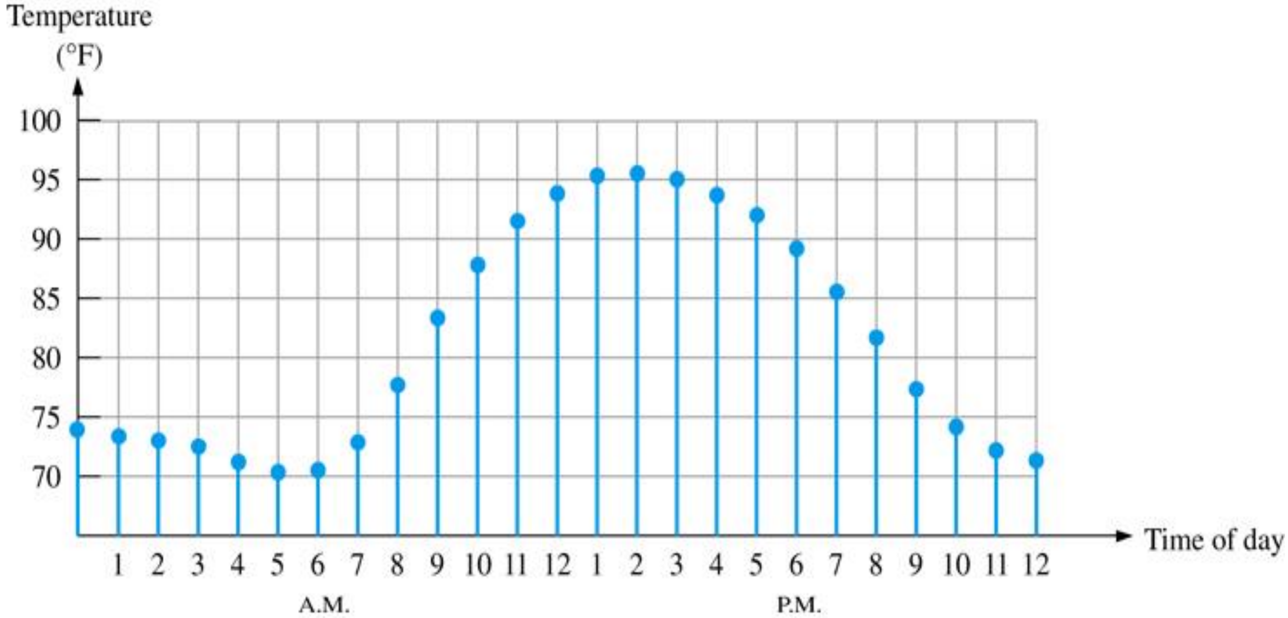
Limitations of digital techniques

- The real world is analog in nature
- The analog nature of the world requires a time consuming conversion process:
    - Convert analog inputs to digital
    - Process (operate on) the digital information
    - Convert the digital output back to analog for consumption

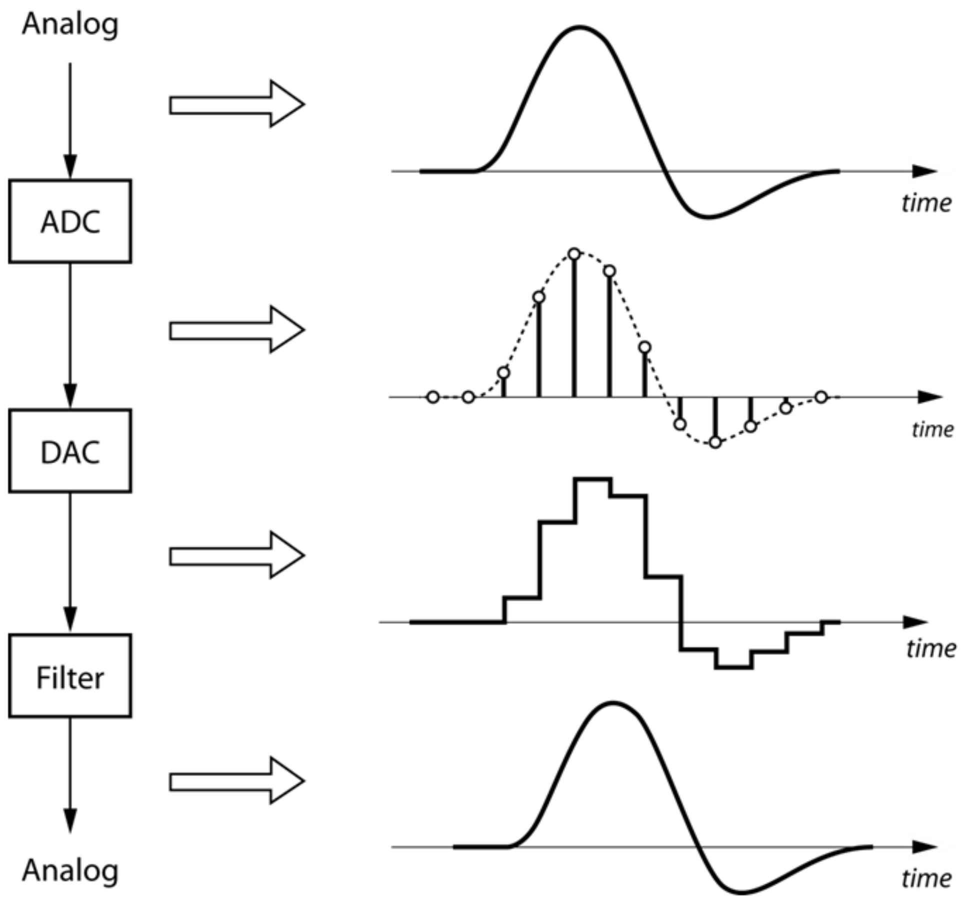
Analog-to-digital

- Analog-to-digital conversion (ADC) is an electronic process in which an analog signal is changed, without altering its essential content, into a digital signal through sampling
  - Input to ADC is a continuously variable voltage signal with (theoretically) infinite values
  - At fixed intervals (sampling period) the ADC measures the analog signal can records the value into a pre-defined level/state
  - Number of states is *almost* always a power of two value



Digital-to-analog

- The real world deals with analog values, so a digital value must be converted to analog using a DAC for human consumption
- Digital-to-analog conversion is the opposite of analog-to-digital conversion.
- A smoothing filter is often applied to regenerate an analog signal to reduce the stairstepping that occurs (either to undersampling or resolution)



Digital in an analog world

- Many systems use a mix of analog and digital electronics to take advantage of each technology
- Revisiting the analog amplifier example, a digital amplifier can perform the same tasks but in the digital domain thus requiring more steps to convert

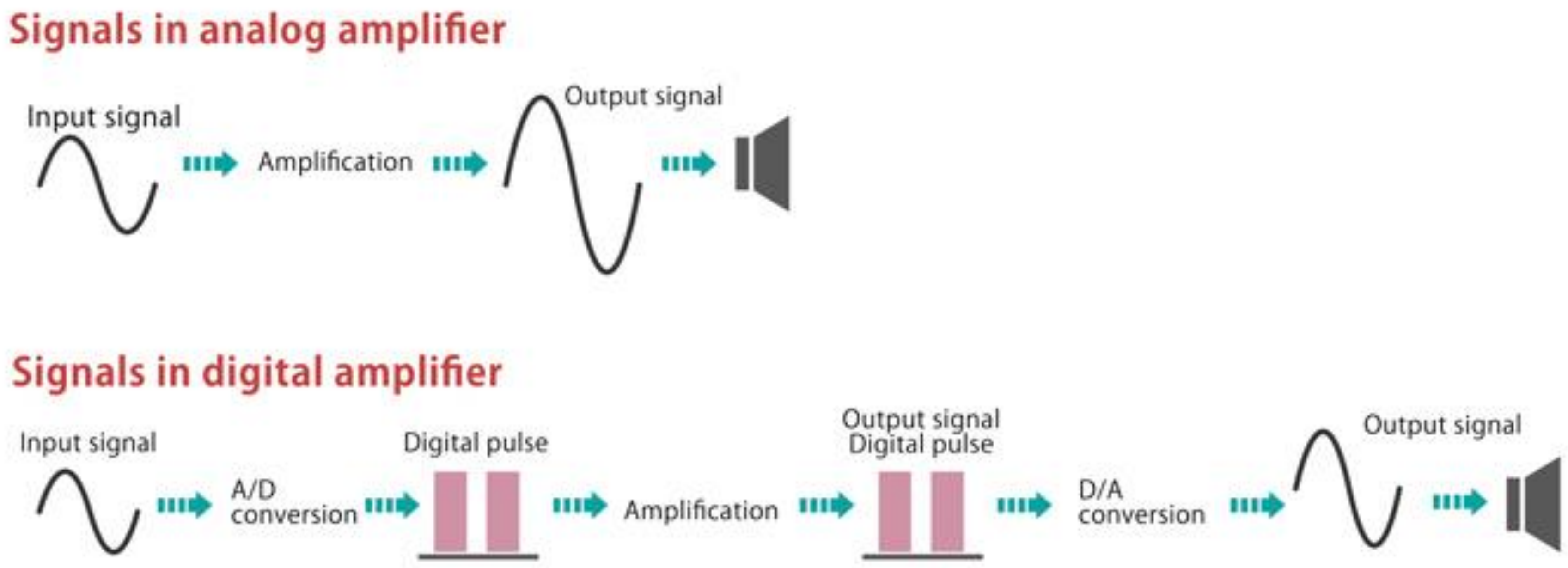
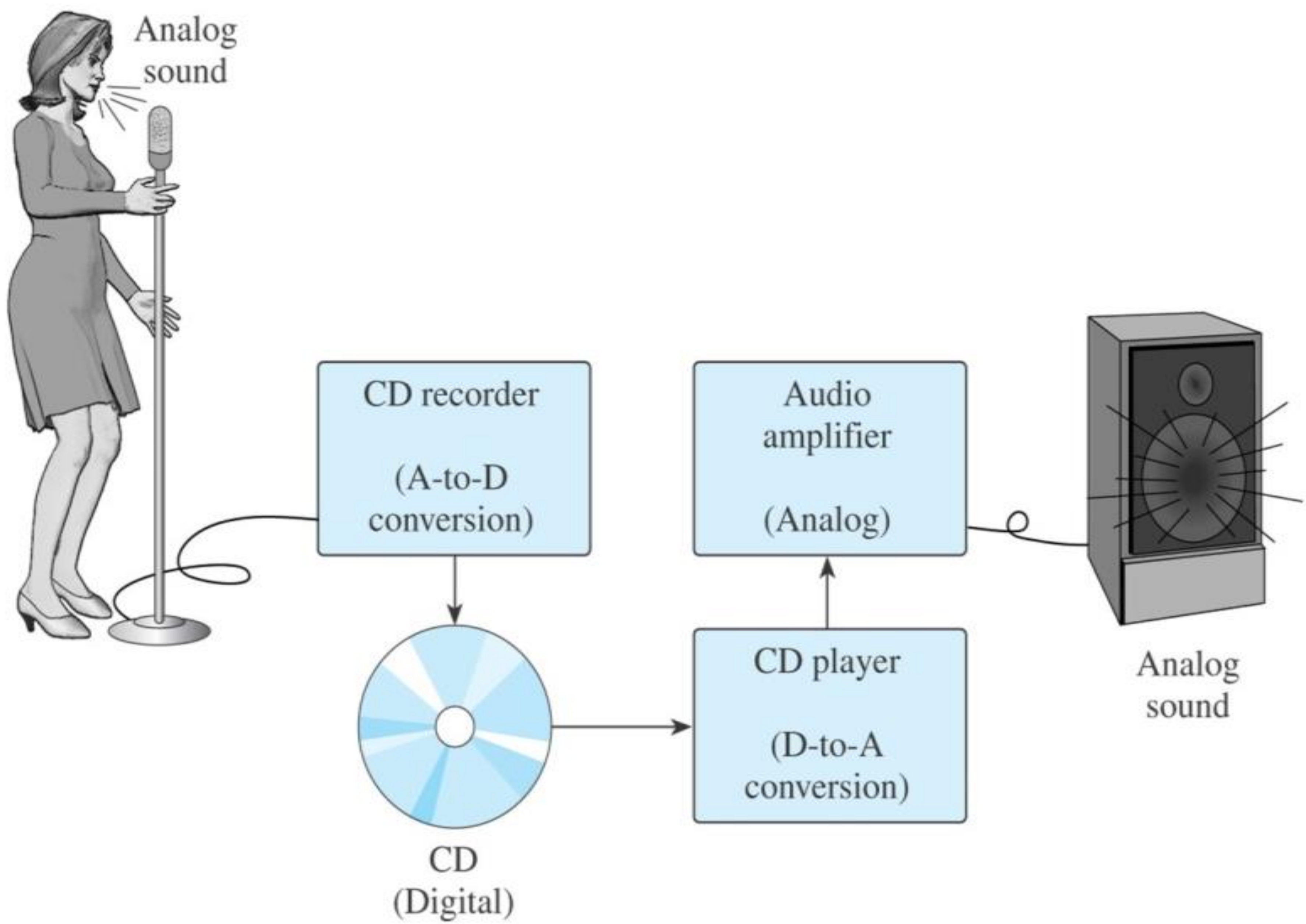


Image source: http://www.toa.jp/soundoh_wiki/index.php?Soundindex%2FDigital%20Amplifier

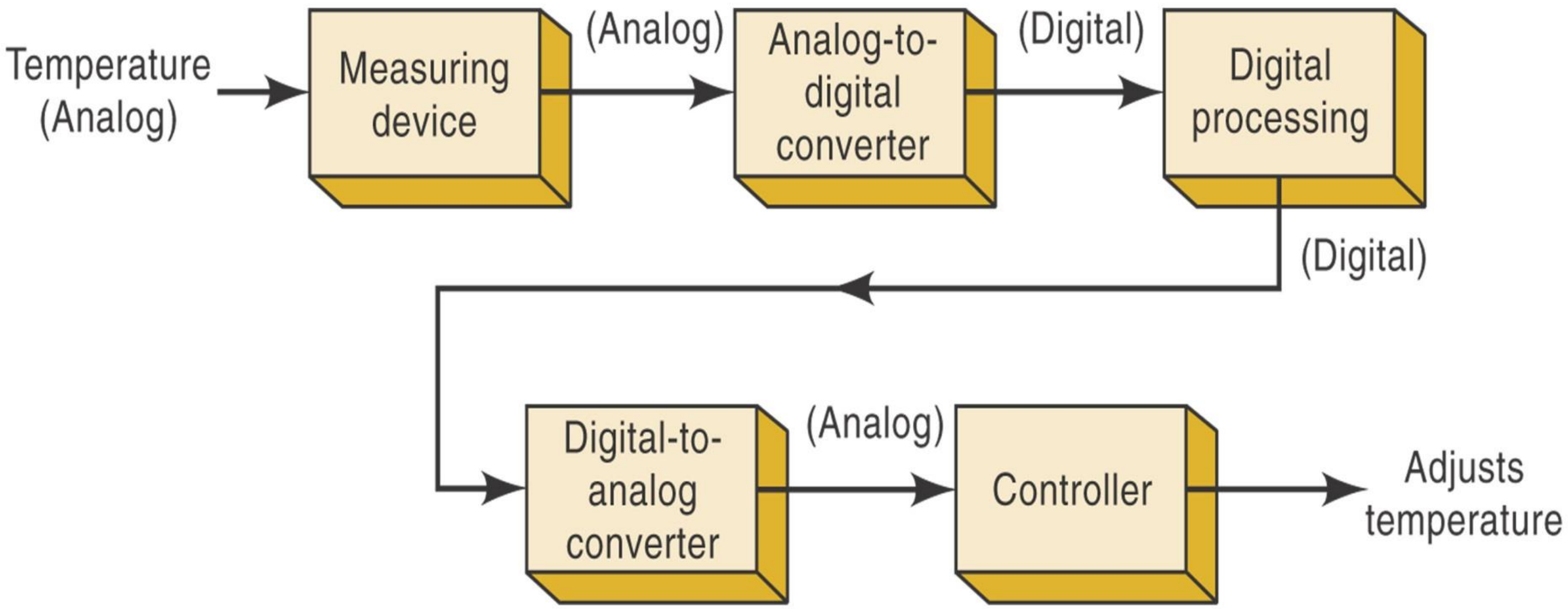
Digital and analog together

- Example 1:
  - The audio CD is a typical hybrid (combination) system.
  - Analog sound is converted into analog voltage.
  - Analog voltage is changed into digital through an ADC in the recorder.
  - Digital information is stored on the CD .
  - At playback the digital information is changed into analog by a DAC in the CD player.
  - The analog voltage is amplified and used to drive a speaker that produces the original analog sound.


Analog
sound
CD recorder
(A-to-D
conversion)
CD
(Digital)
CD player
(D-to-A
conversion)
Audio
amplifier
(Analog)
Analog
sound

Digital and analog together

- Example 2:
  - Digital thermostat (temperature control system)
  - The analog to digital conversion (ADC) and digital to analog process complicates circuitry.



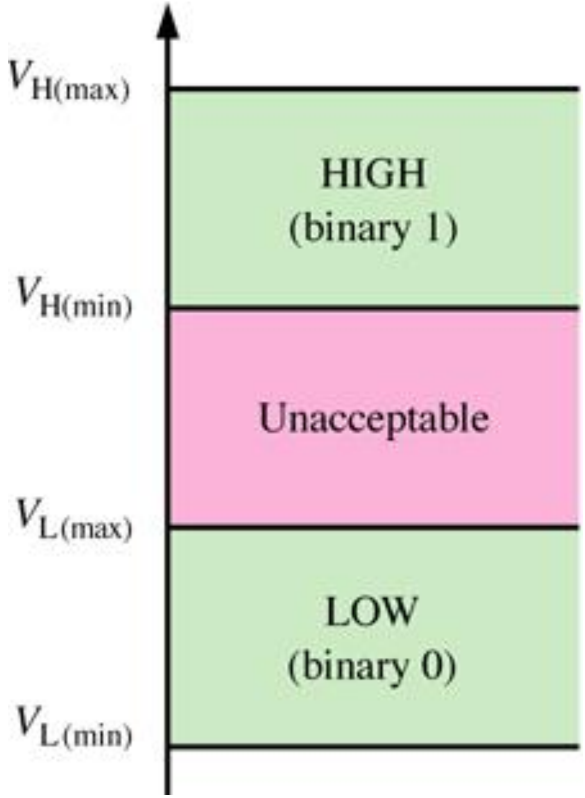
Comparison

	ANALOG	DIGITAL
Signal	Continuous signal representing physical measurement	Discrete time signals generated by digital modulation/sampling
Waveform	Typically sinusoidal	Typically square waved
Noise response	More likely affected by noise	Less affected (especially with noise reduction)
Storage	In the form of analog values from wave signal	Typically stored in binary bit form
Power consumption	Requires larger power	Lower power draw
Transmission	Subject to signal deterioration	Less susceptible to signal degradation during transmission
Hardware	Usually larger and less portable	Digital circuitry allows miniaturization
Manipulation	Can be done real-time but in limited ways	Possibly done in real-time but in unlimited manner

Binary Digits and Logic Levels

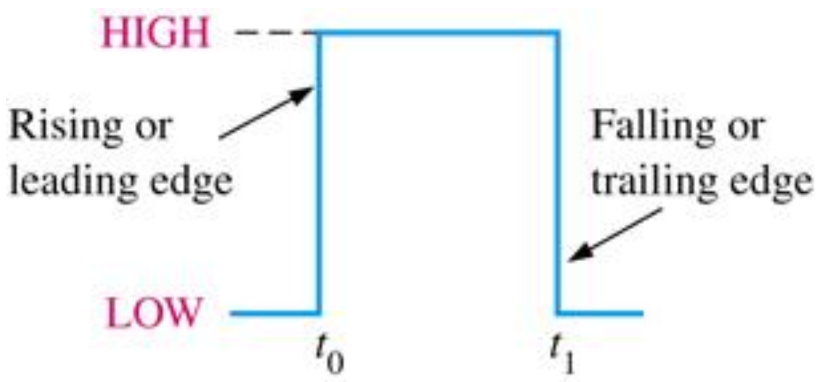
- Digital electronics uses circuits that have two states, which are represented by two different voltage levels called HIGH and LOW. The voltages represent numbers in the binary system.
- Positive logic → HIGH = 1, LOW = 0
- Negative logic → HIGH = 0 , LOW =1

- Logic Levels = the voltages used to represent a 1 and a 0
- E.g.:
  - For TTL ,HIGH=2V to 5 V and LOW=0 V to 0.8 V

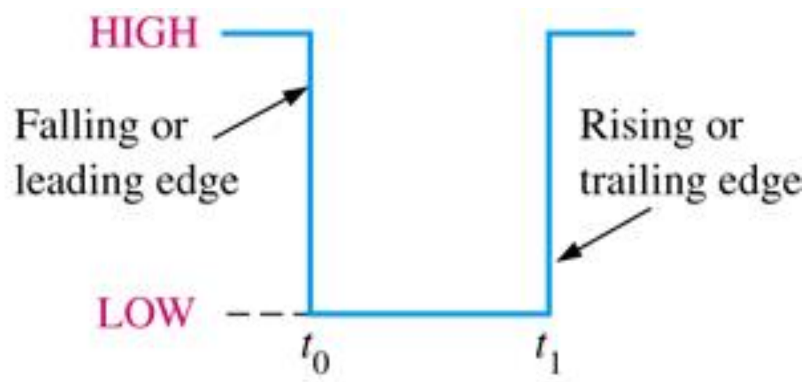


Digital waveforms

- Digital waveforms are made up of a series of pulses
- They consist of voltage levels that are changing back and forth between HIGH and LOW states.
- Ideally, the waveforms should form a square wave with clean rising/leading edges …. why?



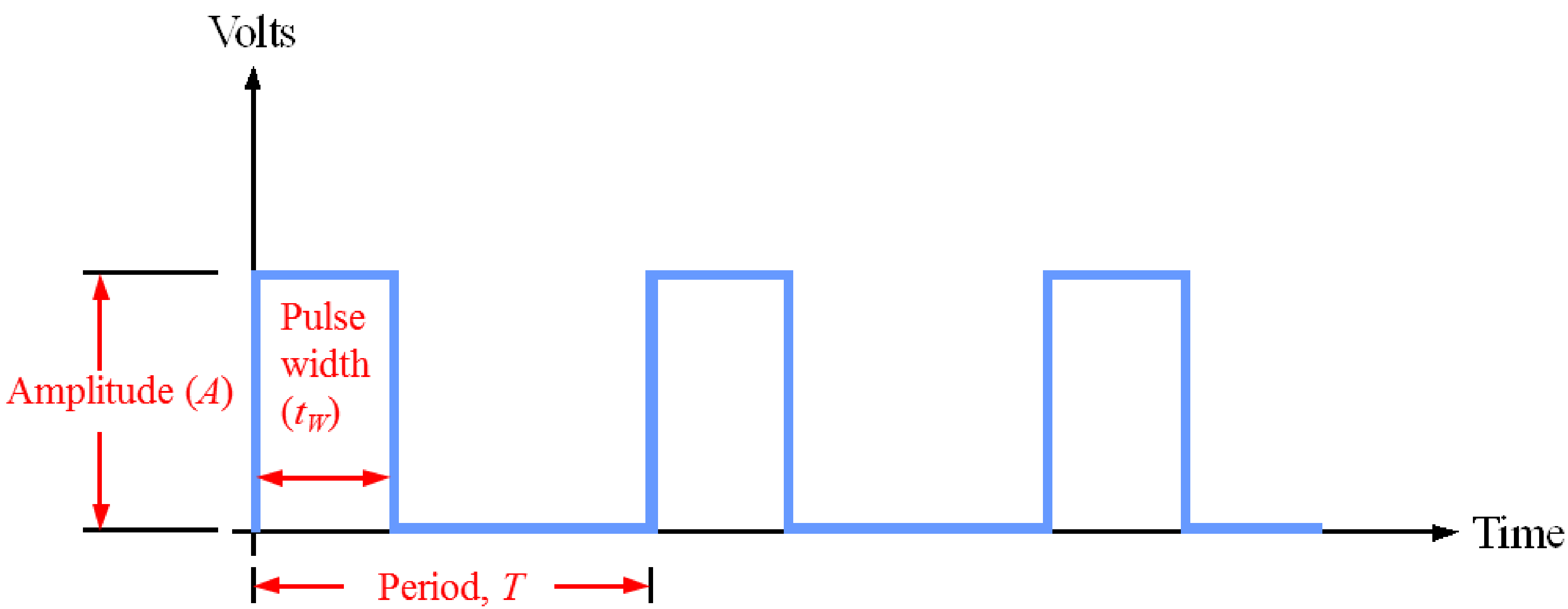
(a) Positive–going pulse



(b) Negative–going pulse

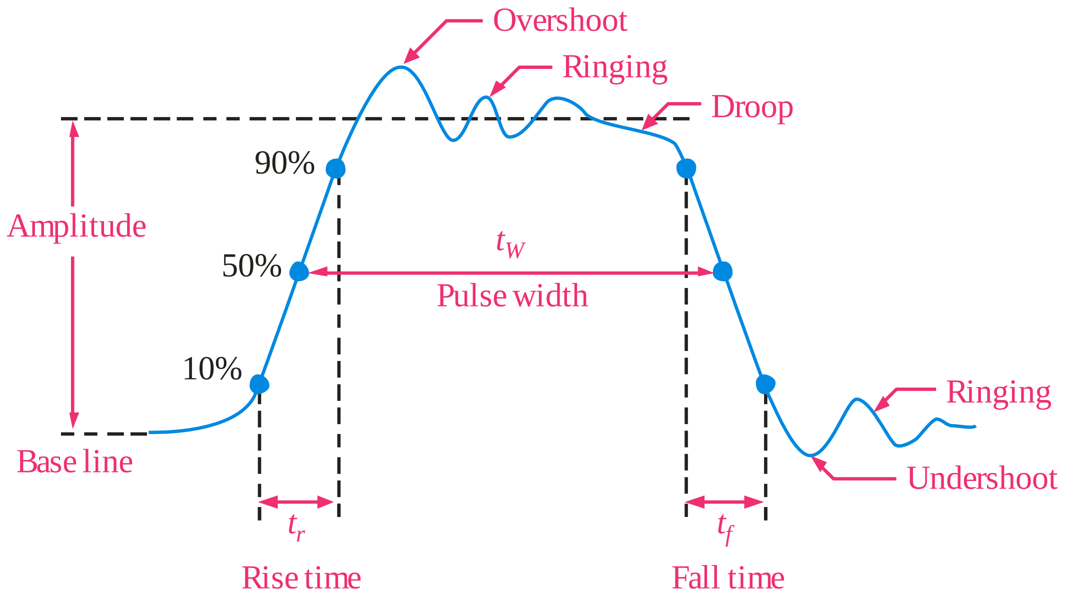
Digital pulse definitions

- In addition to frequency and period, repetitive pulse waveforms are described by the amplitude (A), pulse width (t_W) and duty cycle.
- Duty cycle is the ratio of t_W to T.



Digital waveforms (cont.)

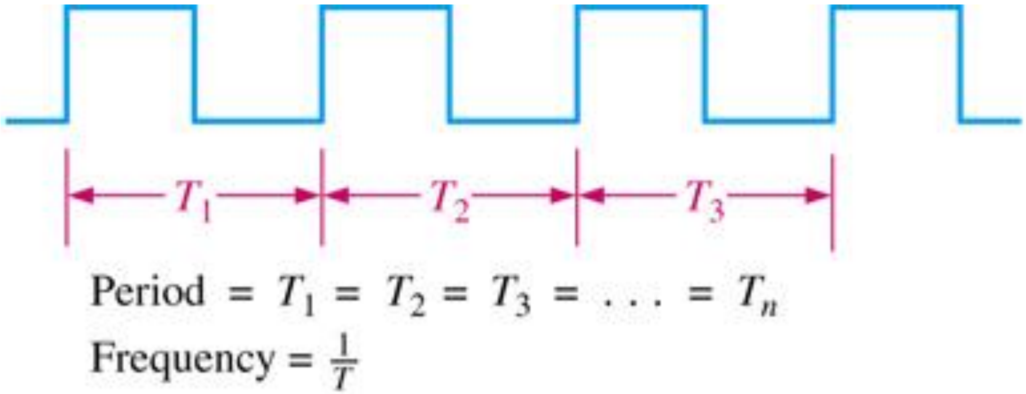
- In reality, actual pulses are not ideal but are described by the rise time, fall time, amplitude, and other characteristics
- Waveforms can form other patterns like saw, sinusoidal, triangle etc making non-ideal waveforms - This makes it difficult to detect when the signal change occurs



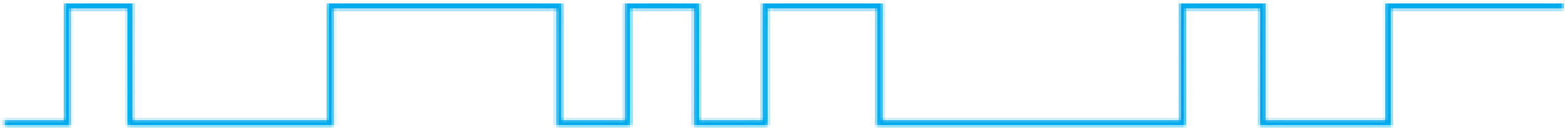
  - Rise Time – measured from 10% of the pulse amplitude to 90% of the pulse amplitude
  - Fall Time – measured from 90% of the pulse amplitude to 10% of the pulse amplitude
  - Pulse Width – time interval between the 50% points on the rising and falling edges

Digital waveform characteristics

- Periodic and non-periodic waveforms
  - Periodic pulse waveform – One that repeats itself at fixed intervals, called a period
  - Non-periodic pulse waveform – Composed of pulses of randomly differing time interval between pulses (pulse width)



(a) Periodic (square wave)



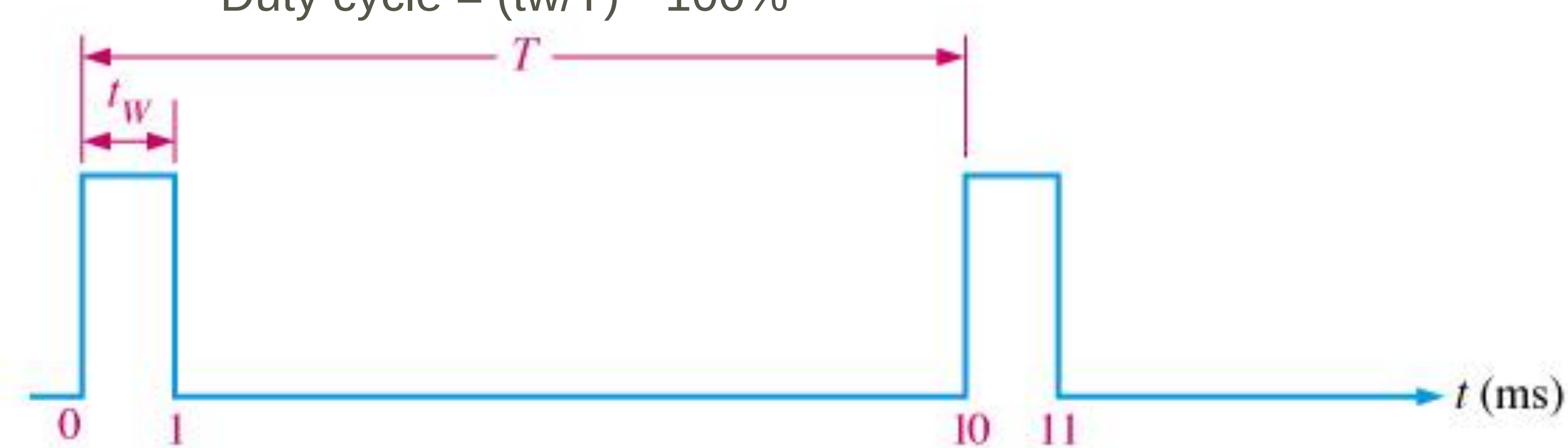
(b) Nonperiodic

Characteristics (cont.)

- Period vs. frequency
  - Frequency (f) is the rate at which an occurance repeats itself
    - Measured in cycles per second or Hertz (Hz)
    - 1Hz = 1 cycle per second
  - Period (T) is the time required for a periodic waveform to fully repeat itself
    - Measured in seconds
  - Relationship between frequency and period
    - $f = 1/T$
    - $T = 1/f$

Characteristics (cont.)

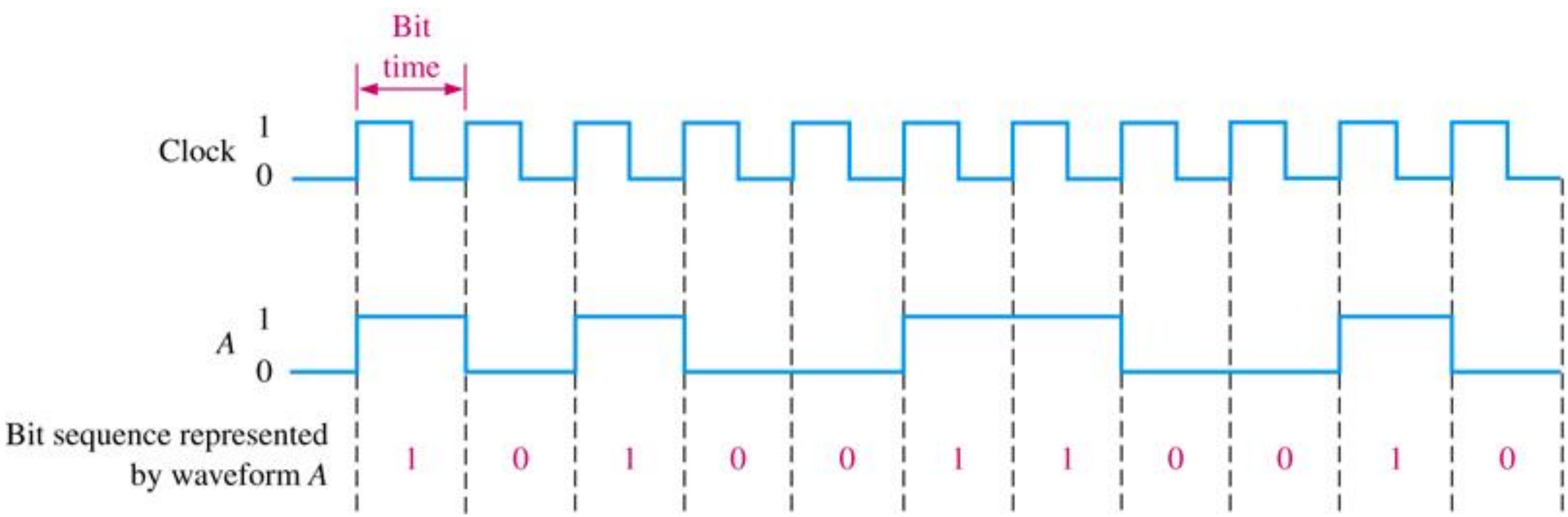
- Duty cycle
  - Duty cycle is the ratio of the pulse width to the period and expressed as a percentage
    - Duty cycle = (tw/T) * 100%



- Example:
  For the above periodic waveform, determine the following
  a. Period b. Frequency c. Duty cycle
- Solution:
  Period = 10 ms, Frequency = 100 Hz , Duty cycle = 10%

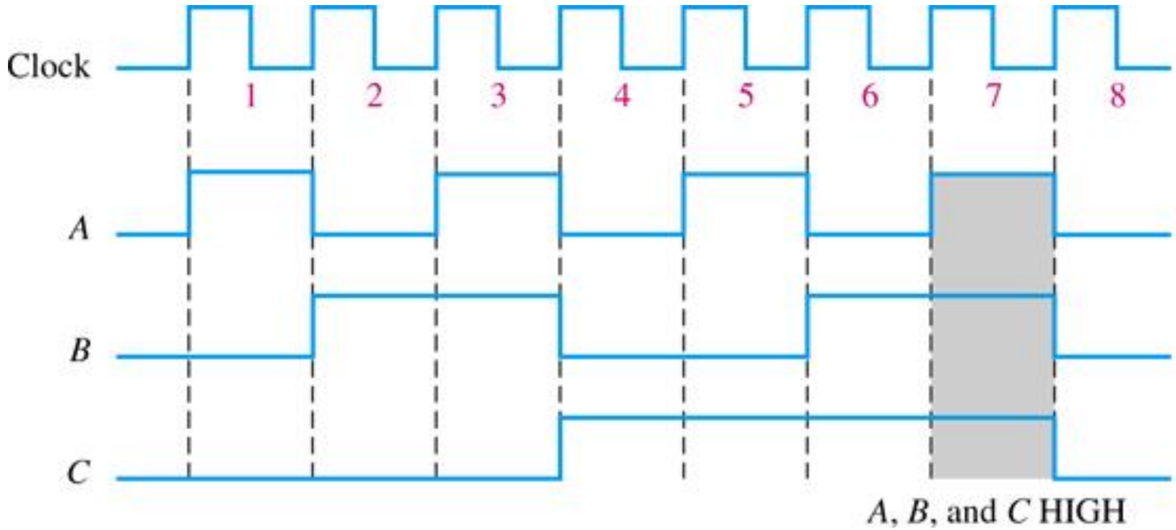
Representation of bit sequences

- The clock is a periodic waveform in which each interval between pulses (period) equals the time for one bit (bit time)
- Here waveform A level change occurs at the leading edge of the clock waveform



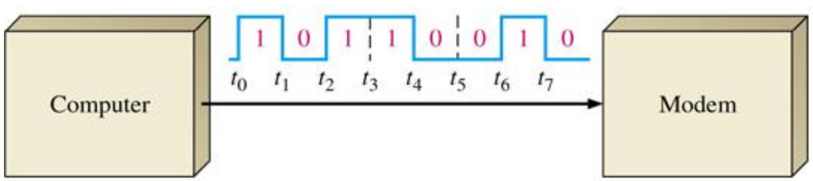
Timing diagrams

- Graph of digital waveforms showing the actual relationship of two or more waveforms and how each waveform changes in relation to the others. E.g. to show voltage versus time.
- Horizontal scale represents regular intervals of time beginning at time zero - used to show how digital signals change with time.
- Used to compare two or more digital signals.
- The oscilloscope and logic analyzer are used to produce timing diagrams.
- Here waveforms A, B, and C are HIGH only during bit time 7

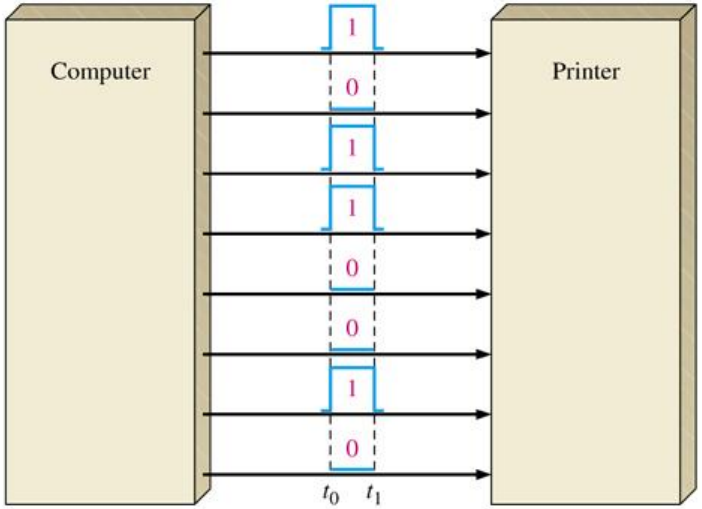


Binary data transfer

- Serial transfer - sent one bit at a time along a single conductor
  - Advantage: only one line is required
  - Disadvantage: takes longer to transfer a given number of bits
- Parallel Transfer - all the bits in a group are sent out on separate lines at the same time
  - Advantage: Higher speed of transfer
  - Disadvantage: More lines are required



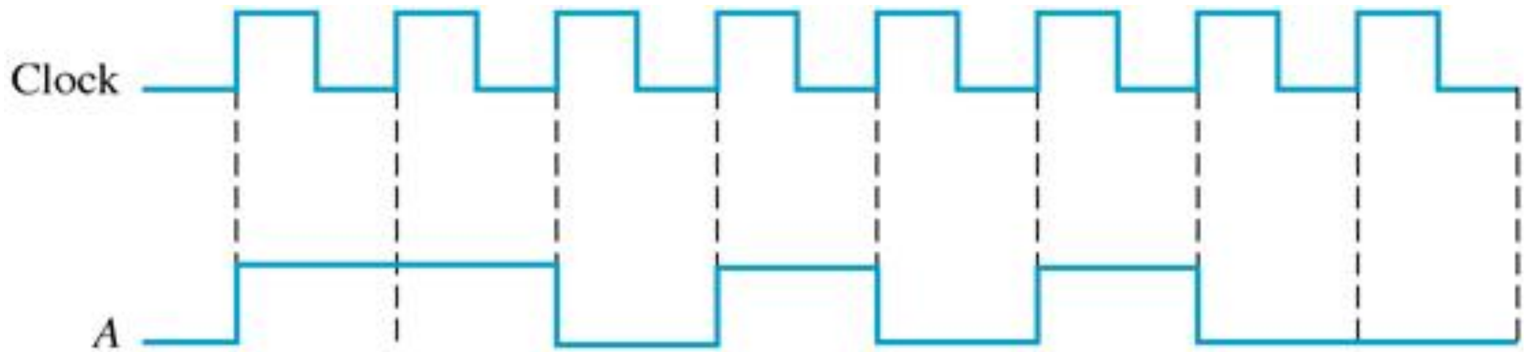
(a) Serial transfer of 8 bits of binary data from computer to modem. Interval t_0 to t_1 is first.



(b) Parallel transfer of 8 bits of binary data from computer to printer. The beginning time is t_0.

Binary data transfer example

- Problem:
  Determine the total time required to serially transfer the eight bits contained in waveform A and indicate the sequence of bits. The 100kHz is used as reference.
- What is total time to transfer the same eight bits in parallel?



- Solution:

  Period T=1/f = 10 microseconds

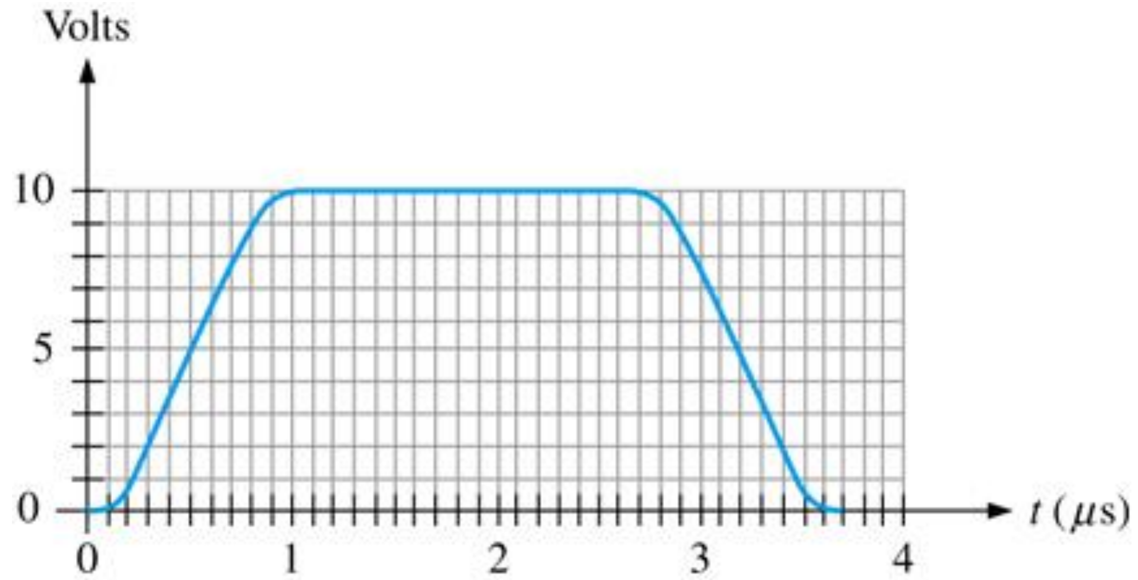
  Total time required for serial transfer = 8 T = 80 microseconds

  Bit Sequence = 11010100

  Total time required for parallel transfer = 1T =10 microseconds

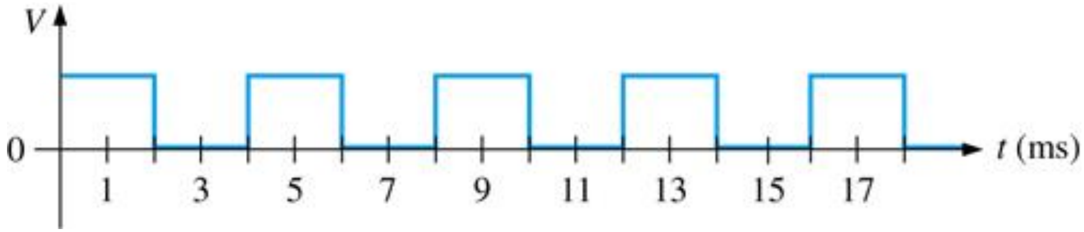
Solve this

- Determine the following:
  - Rise time
  - Fall time
  - Pulse width
  - Amplitude



- Solution:

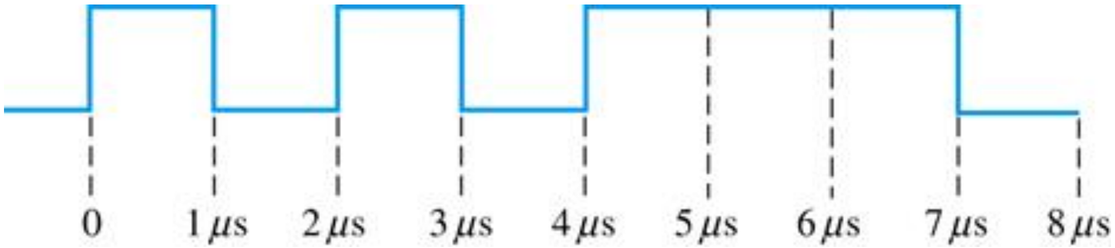
Solve this



- Determine the following for the signal graph shown above
    - Period
    - Frequency
    - Duty cycle
- Determine the waveform is periodic or non-periodic

- Solution:

Solve this



- Determine the bit sequence
- Determine the total serial transfer time for the eight bits
- Determine the total parallel transfer time

- Solution:

Summary

- Selected key terms you should know

Analog	Being continuous or having continuous values
Digital	Being discrete; having a set of discrete and distinct values
Binary	Having two values/states; describes number system that has base of two and utilizes 1 and 0 as its only digits
Pulse	A change from one level to another and after a period of time a change back to original level
Clock	Basic timing signal in a digital system; a periodic waveform used to synchronize actions

- Digital systems allow for easier manipulation of data but requires convertors to convert to/from analog domain
- Serial transfers are slower than parallel (although in reality, this fact is no longer valid)