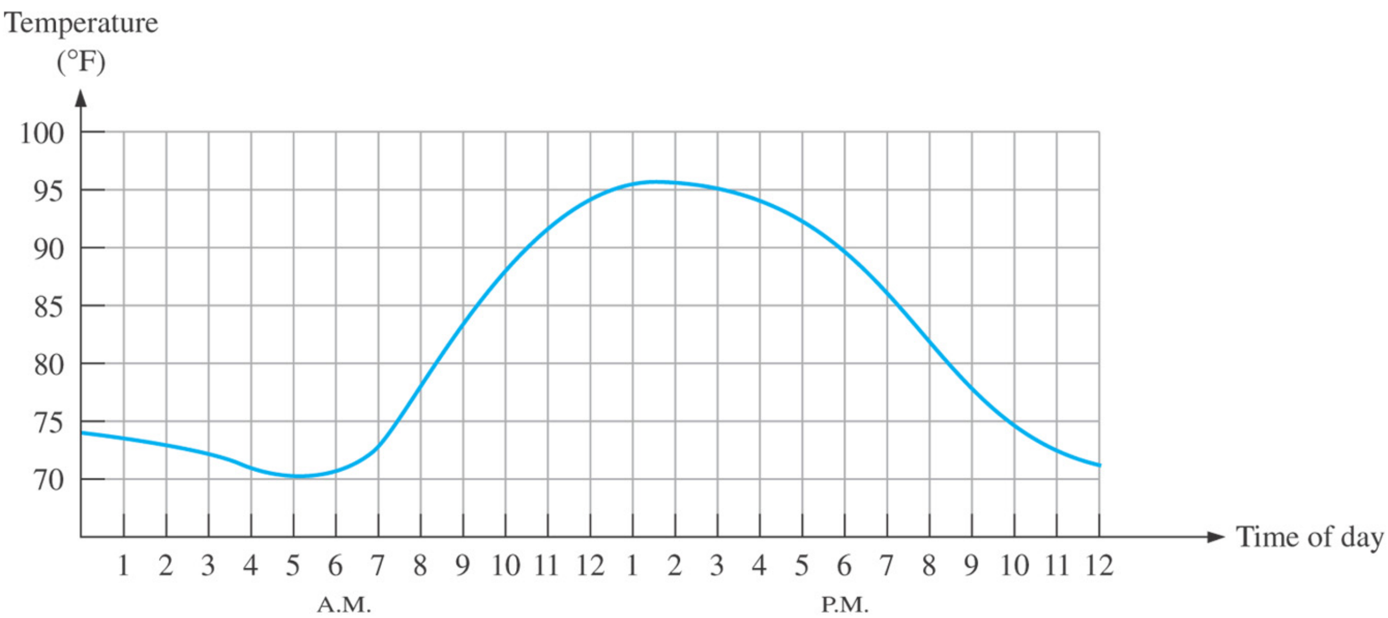
Chapter 1 Introduction to Digital System Design

Digital vs. Analog

- **Examples**
  - Thermometer
  - Photography
  - Audio System
  - Storage
  - Information Processing

Example I: Thermometer



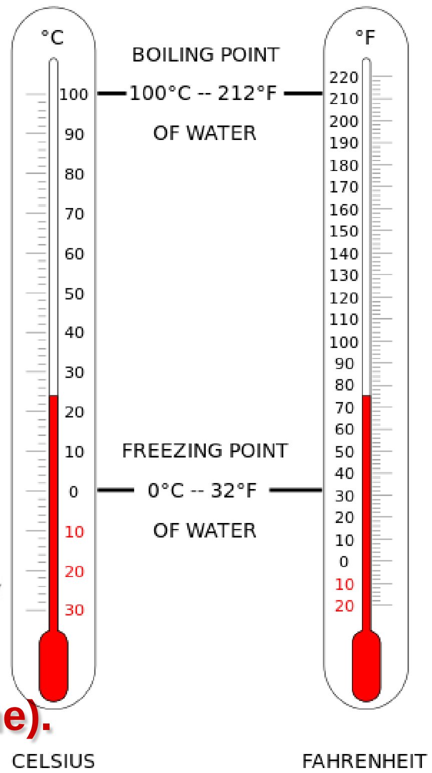


Figure 1–1 Graph of an analog quantity (temperature versus time).

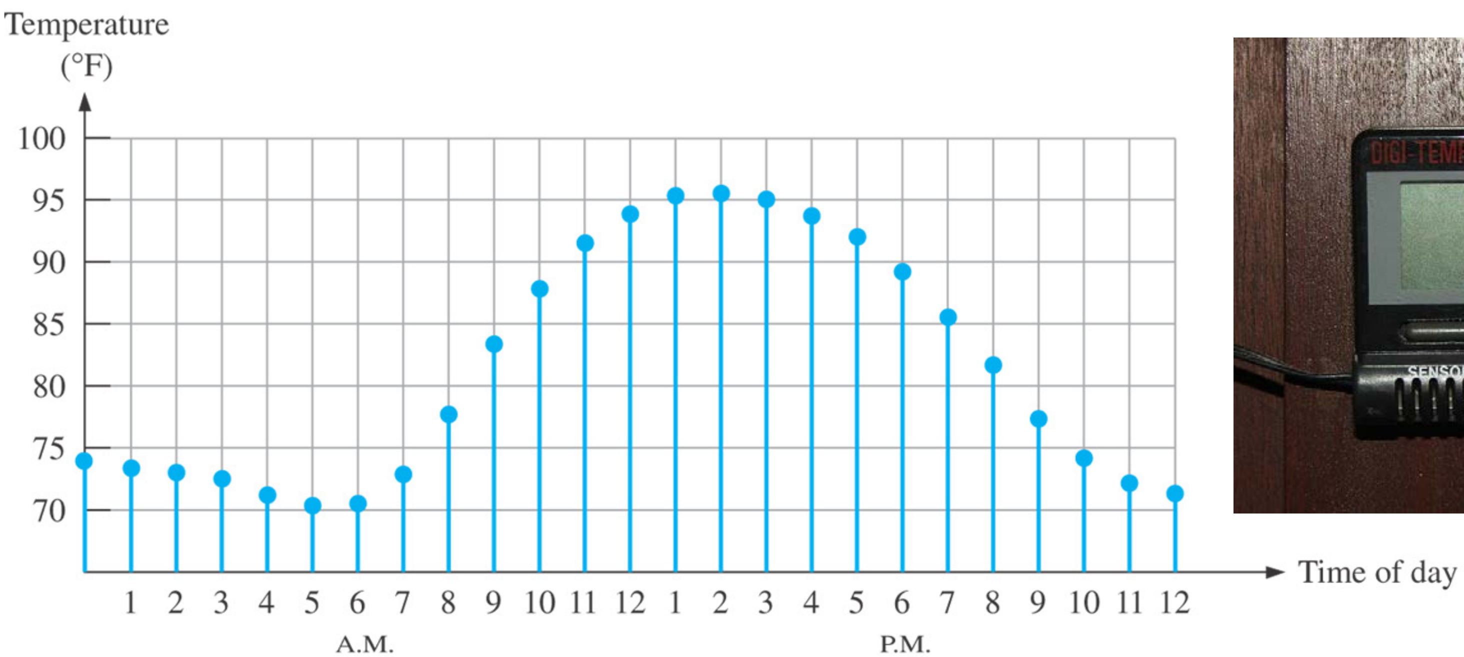
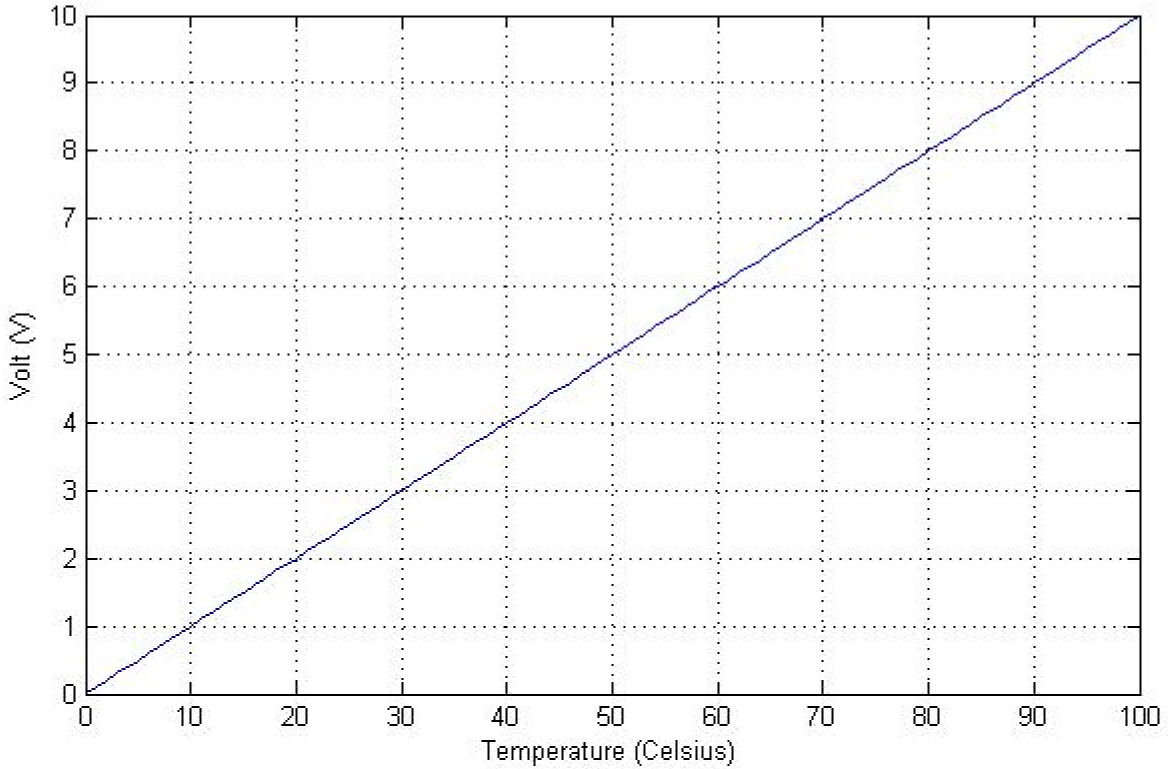


Figure 1–2 Sampled-value representation (quantization) of the analog quantity in Figure 1–1. Each value represented by a dot can be digitized by representing it as a digital code that consists of a series of 1s and 0s.

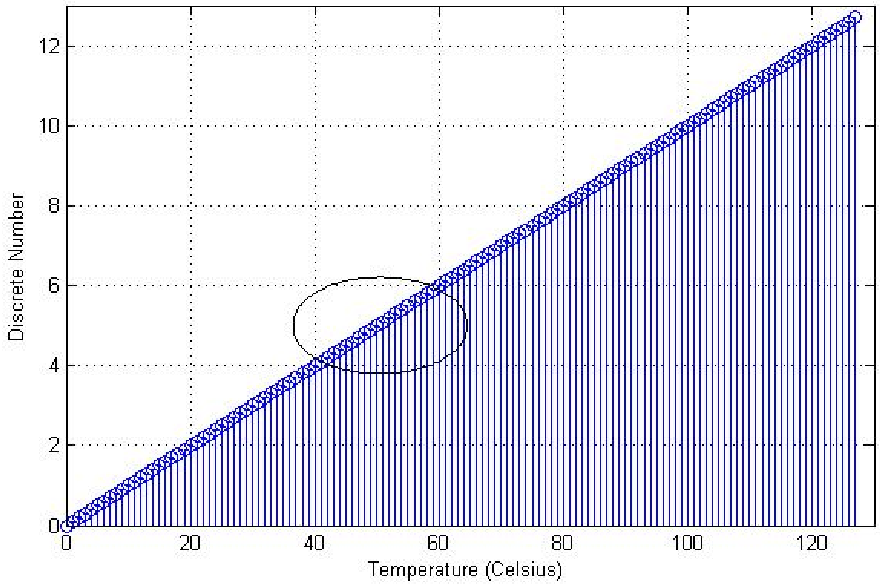
An Example

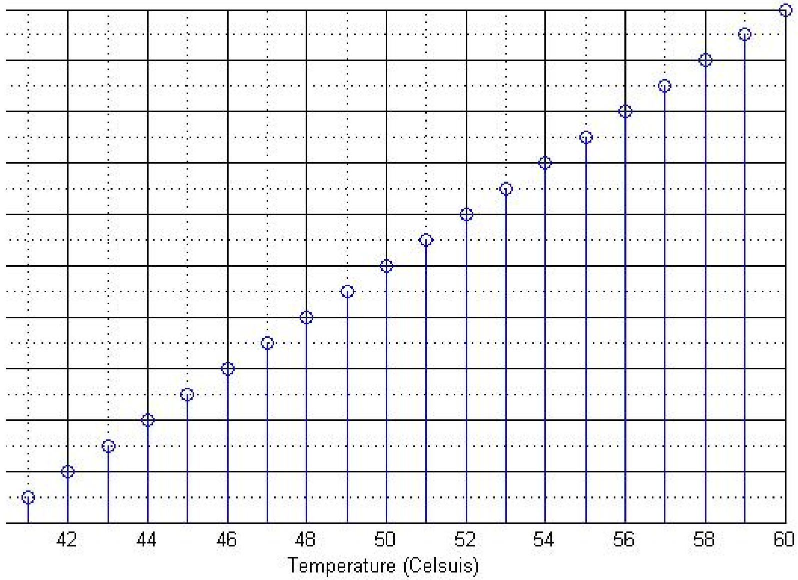
- Analog thermometer
  - 0V to 10V, could be used to represent 0°C to 100° C
  - Each 1/10 volt represents 1 degree



- Digital thermometer
  - 7-bit binary number could be used to represent 0°C to 127° C
  - 0000000 ----→ 0°C; 0000001 ----→ 1°C; ….

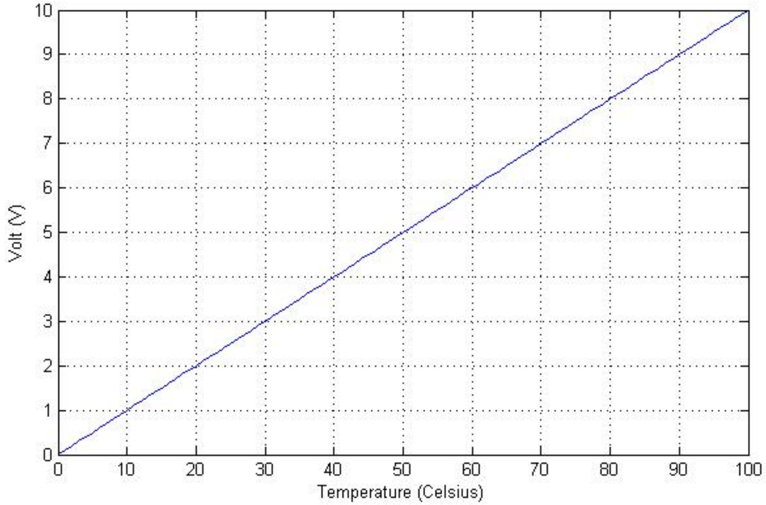
    1111111 ----→ 127 °C

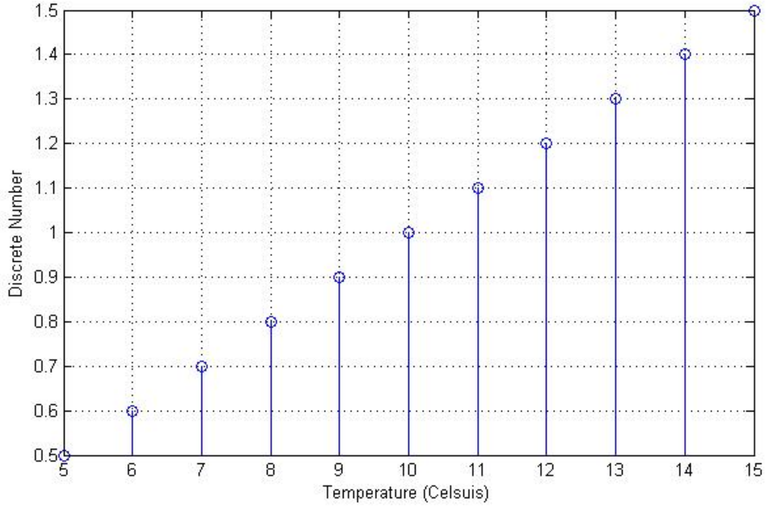




Digital Precision

- How would you represent 10.5° C?
- Analog example: 1.05V
- Digital example:
  - $0001010_2 = 10_{10}$ ----→ 10°C
  - $0001011_2 = 11_{10}$ ----→ 11°C
  - We must either add bits or decrease the range



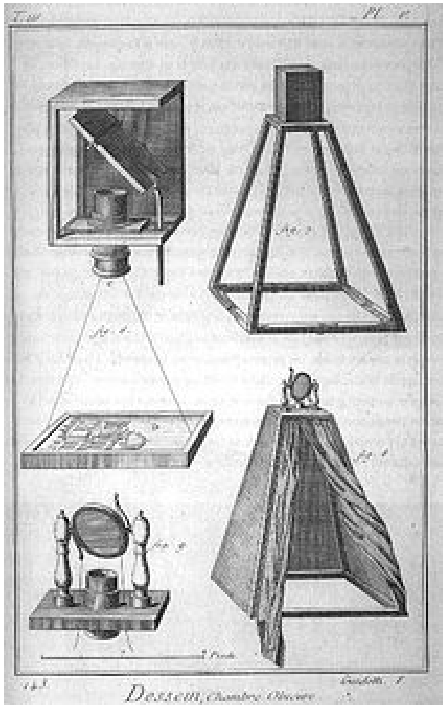


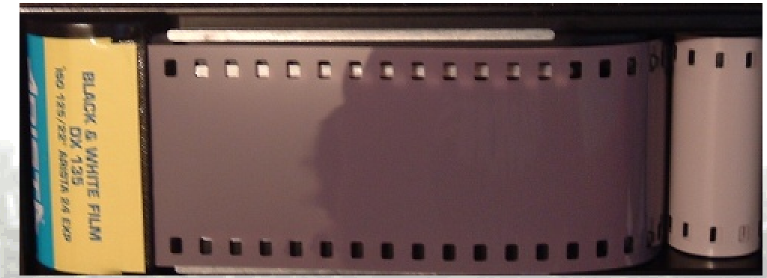
Digital Precision

- 9-bit thermometer, 0° to 127.75° C
  - Each discrete number increase represents 0.25° C
  - 10.5° C → 10.5/0.25 = 42 = 000101010_2
- 7-bit thermometer, 0° to 12.7° C
  - Each discrete number represents 12.7°/127 = 0.1° C
  - 10.5° C → 10.5/0.1 = 105 = 1101001_2
- It is impossible to represent *all* values exactly using digital representation
  - Example: 1/3 can't be represented in binary, just like it can't be represented in decimal

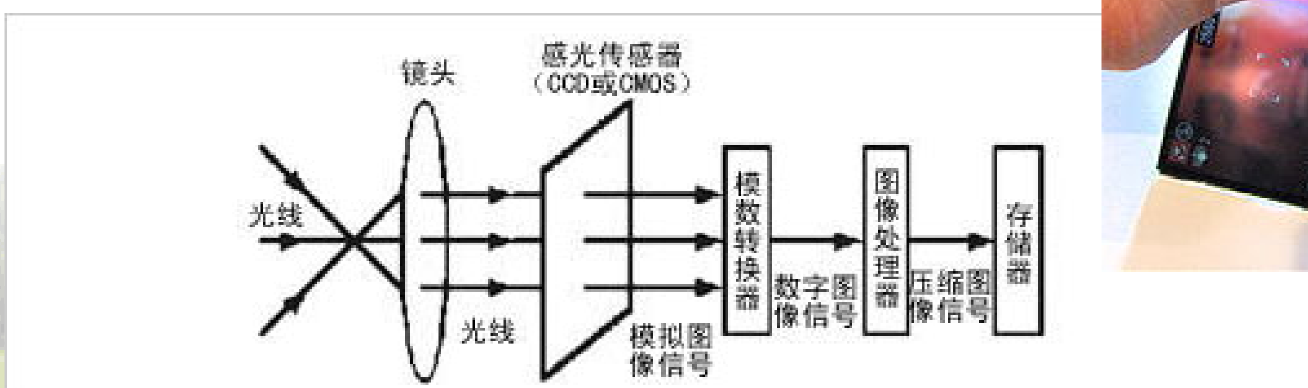
Example II: Photography

- Analog photography
    - An analog camera uses a chemical reaction in the film when exposed to light
    - The amount of exposure is directly related to the amount of light that hits the film





- **Digital Photography**
  - A digital camera uses an array of light-sensitive receptors that measures the light as a binary number
  - Image quality is determined mostly by two factors:
    - The number of bits per pixel
    - The number of pixels per image



Example: Digital Photography

1284x897 pixels, 24-bit color

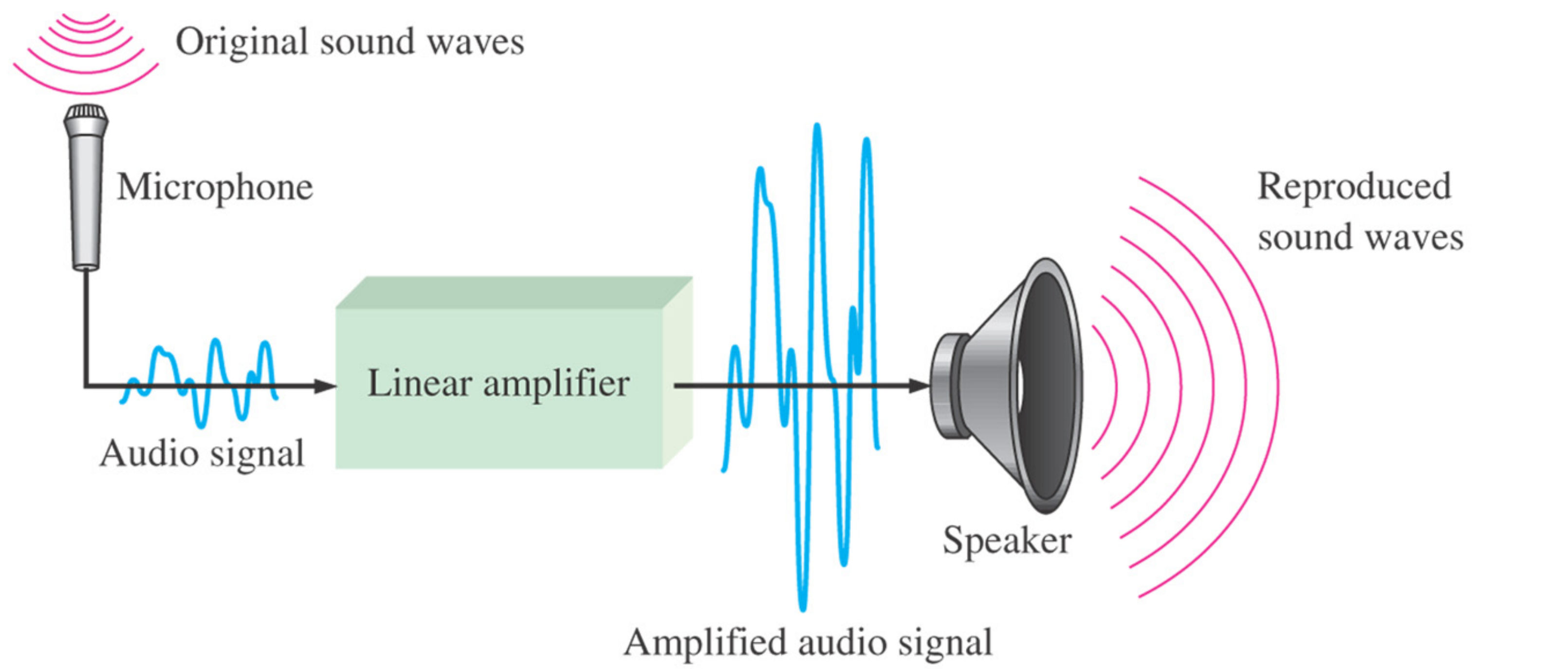
100x70 pixels, 24-bit color

1284x897 pixels, 6-bit color

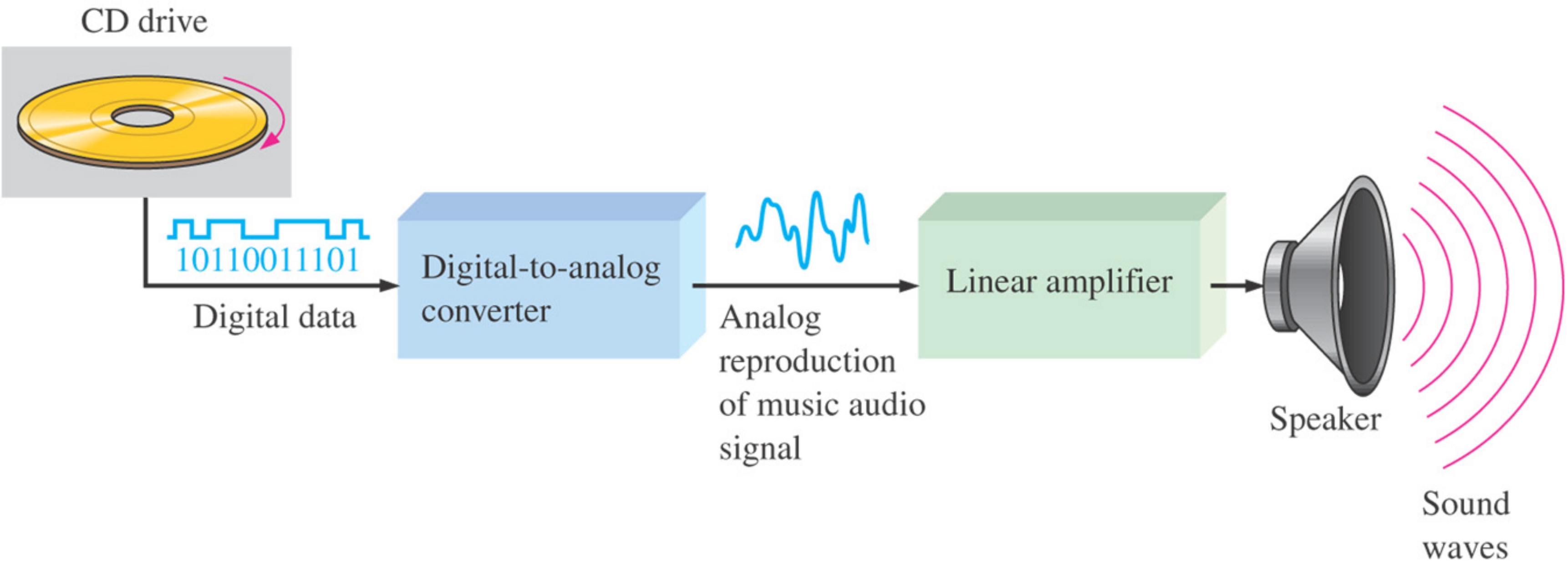
100x70 pixels, 6-bit color

Example III: Audio System

A basic audio public address system.

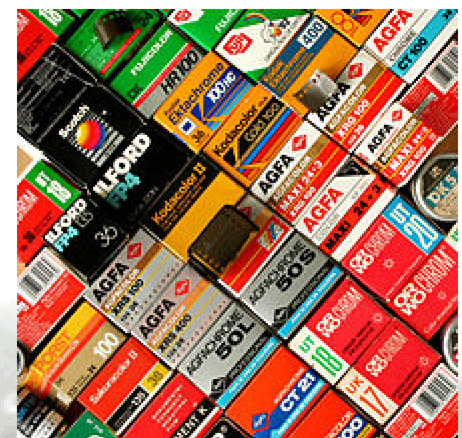


Basic block diagram of a CD player.



Example IV: Storage

- *Analog* storage mediums fade over time due to gradual physical degradation
  - Photos turn yellow with time
  - Cassette audio tapes lose their clarity



Example IV: Storage

- ***Digital*** storage mediums don’t “fade” like analog
  - If a 0 or 1 fades it will still be a 0 or 1
  - A .jpg image taken 10 years ago is *exactly* the same today


Analog vs. Digital Storage

- Making an analog copy implies measuring the storage medium
  - Always introduces some errors
  - Copies of copies are even worse
- Making digital copies implies distinguishing 0’s from 1’s so copies are exact
  - Copies can be made without any error
  - Copies of copies are identical

Example V: Analog vs. Digital Processing

- Modern computers and digital circuits make it easy to do extremely complex processing
- Digital processing allows precision and error to be exactly predicted

1-1 Digital and Analog Quantities

- **Analog quantity: having continuous values**
  - Analog systems represent information using physical quantities
  - Voltage on a wire, magnetic field strength
- **Digital quantity: having a discrete set of values**
  - Digital systems represent information using binary digits, or *bits*
  - 1 or 0, high or low, on or off

How to represent digital quantity?

-- Positional Number Systems

- Two discrete values are insufficient for most applications
- We combine bits to represent more values
- We use a positional number system for binary just like we do in decimal

Positional Number Systems

- ***Decimal,*** base 10, means we have 10 digits (0-9)
  - Example:

$$1032_{10} = 1\times10^3 + 0\times10^2 + 3\times10^1 + 2\times10^0$$

- ***Hexadecimal,*** base 16, means we have 16 digits (0-9, A-F)
  - Example:

$$2A5_{16} = 2\times16^2 + 10\times16^1 + 5\times16^0 = 512 + 160 + 5 = 677$$

- ***Binary,*** base 2, follows the same pattern
  - Example:

$$1011_2 = 1\times2^3 + 0\times2^2 + 1\times2^1 + 1\times2^0 = 8 + 0 + 2 + 1 = 11$$

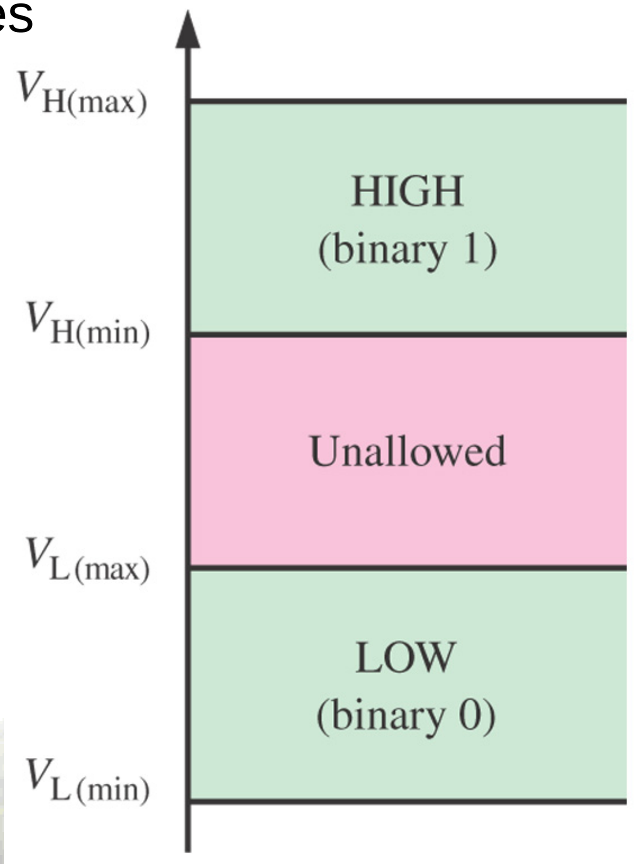
- Counting in any base is analogous to counting in decimal

1-2 Binary Digits, Logic Levels, and Digital Waveforms

- **Binary Digits**
  - ***Positive logic***
    - ***'1' is represented by HIGH***
    - ***'0' is represented by LOW***
  - Negative logic
  - Groups of bits: ***codes***

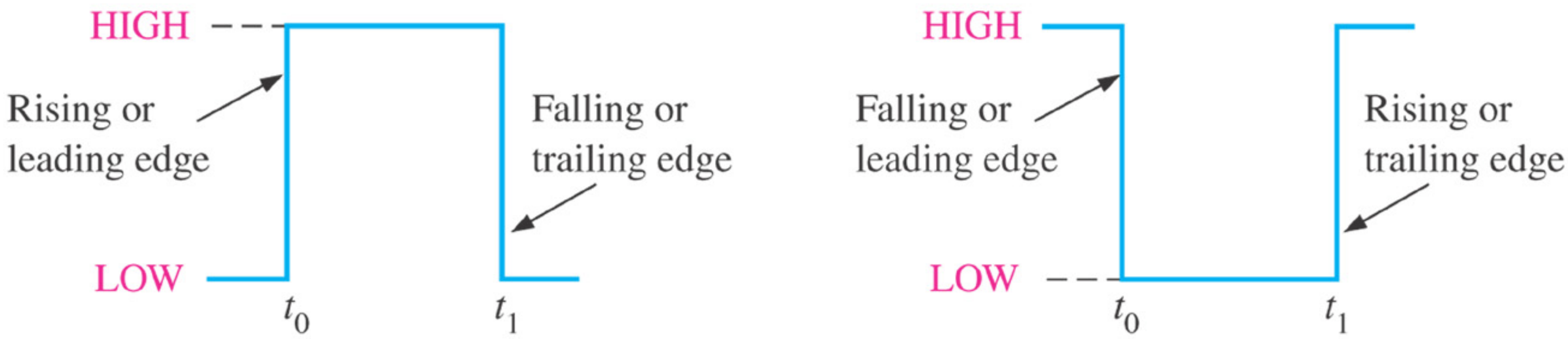
Logic Level

- Logic levels: the voltages used to represent a ‘1’ and a ‘0’
- This figure answers the question how to represent the binary logic with voltages



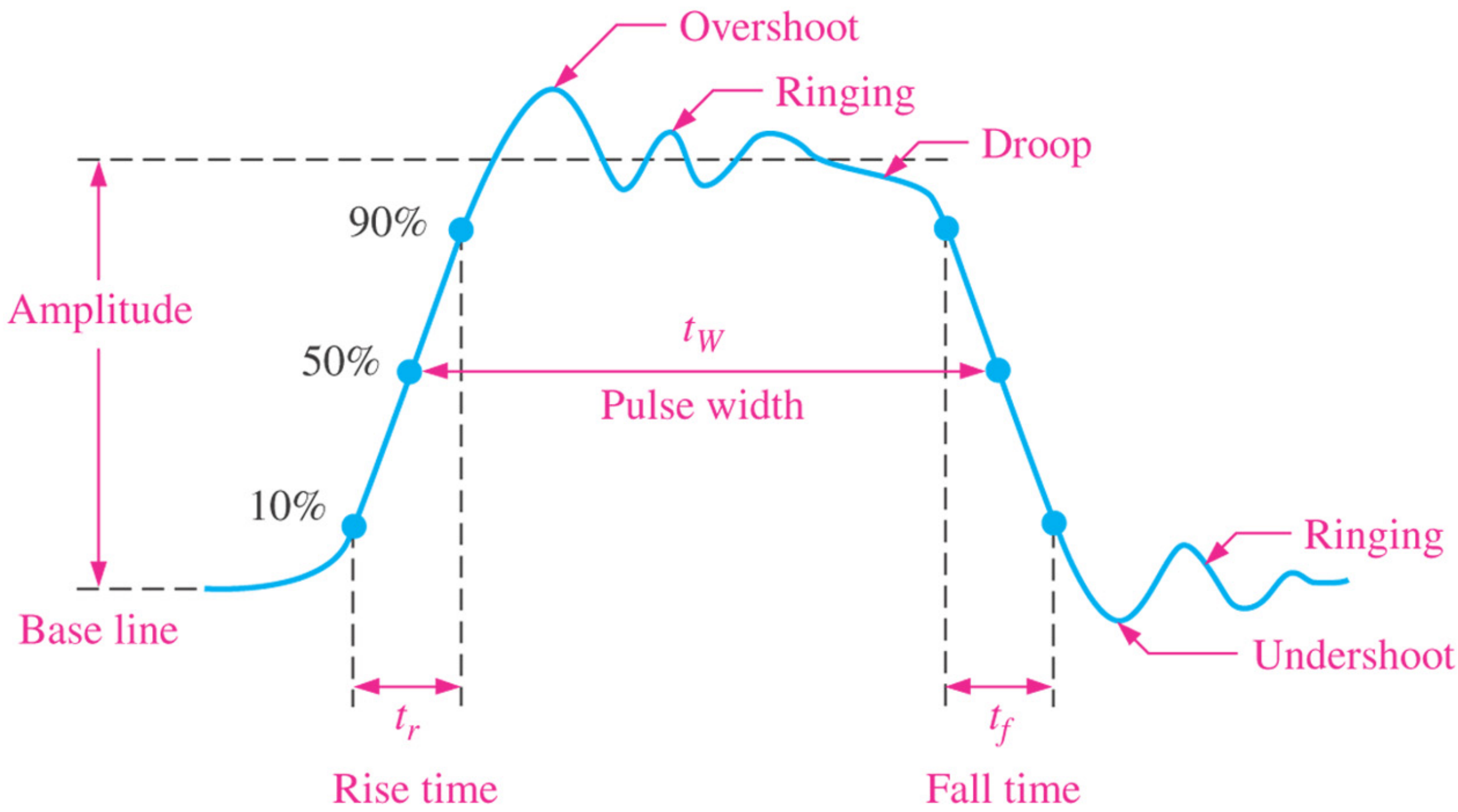
Logic level ranges of voltage for a digital circuit.

- **Digital Waveforms**



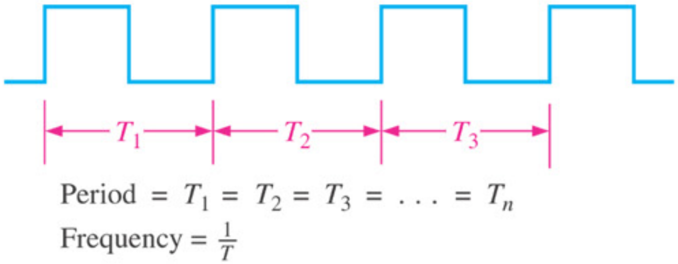
(a) Positive–going pulse (b) Negative–going pulse

Ideal pulses



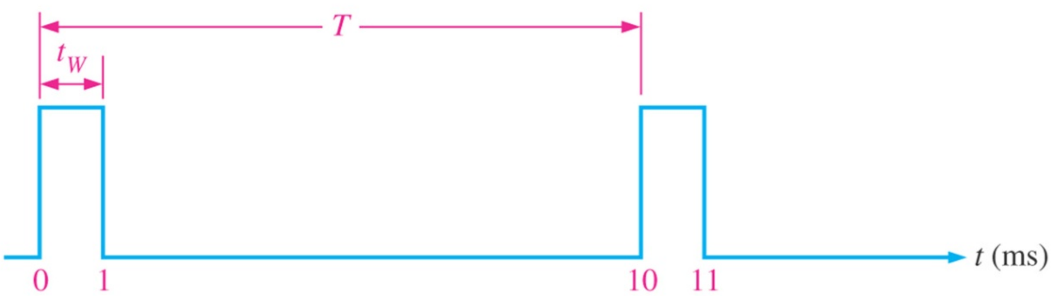
Nonideal pulse characteristics.

- **Waveform characteristics**
  - Period （周期）
  - Frequency （频率）
  - Duty cycle（占空比）



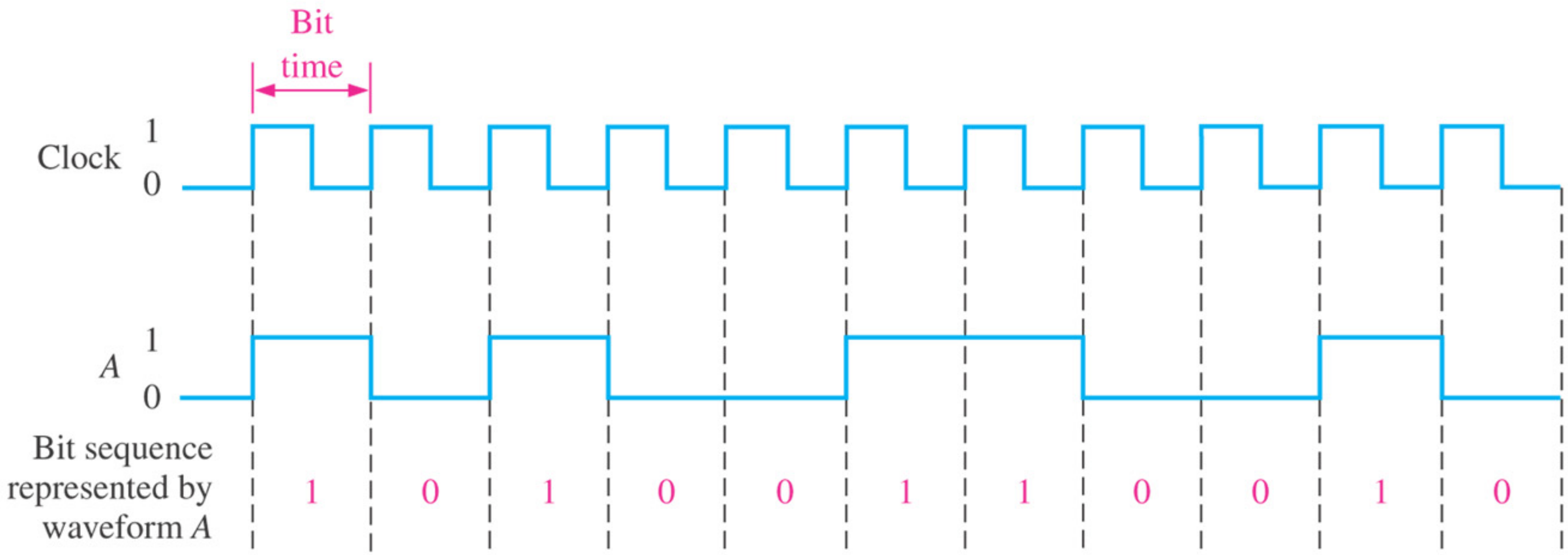
(a) Periodic (square wave)

(b) Nonperiodic

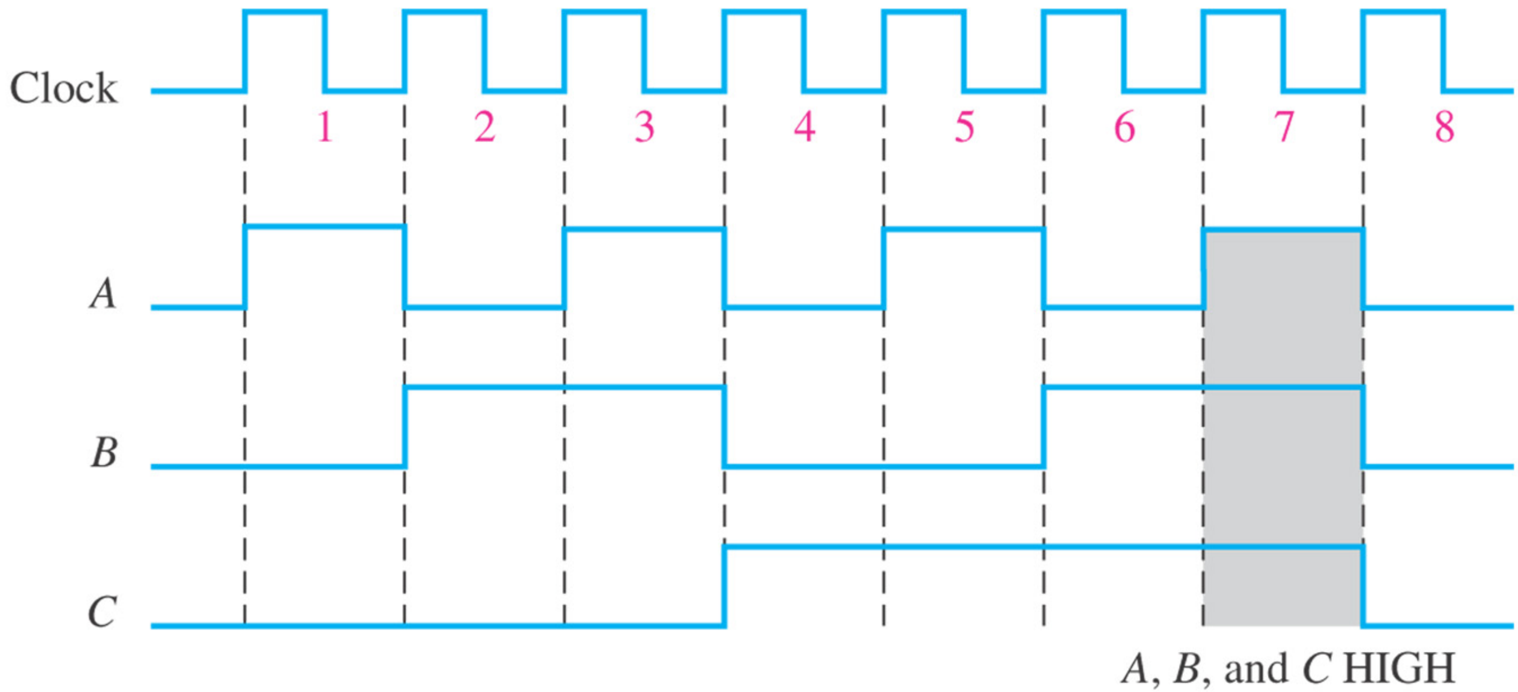


$$\text{Duty cycle} = \left(\frac{t_w}{T}\right)100\%$$

A Digital Waveform Carries Binary Information

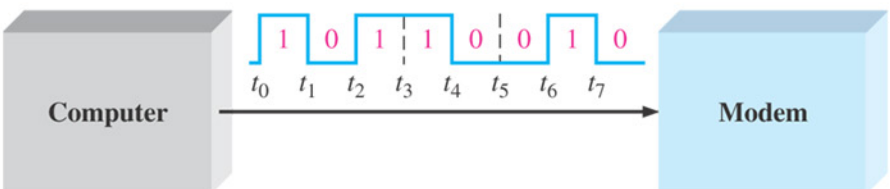


Example of a clock waveform synchronized with a waveform representation of a sequence of bits.

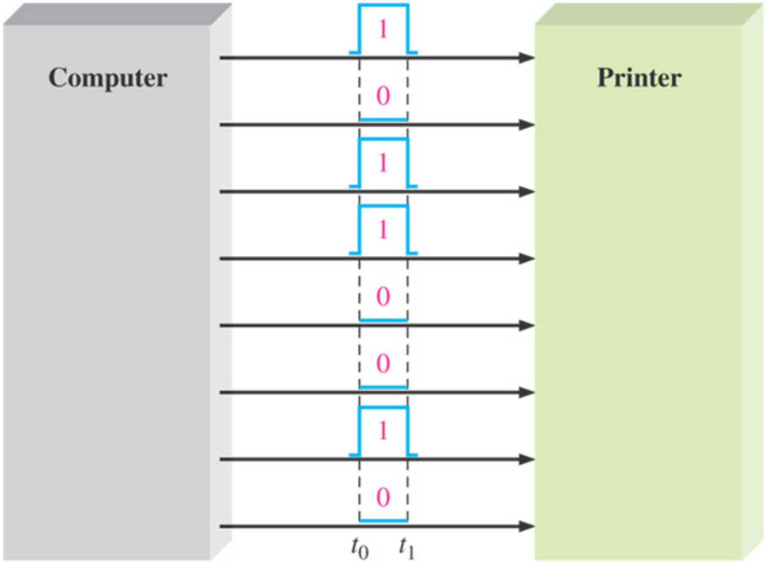


Example of a timing diagram.

- **Data Transfer**
  - Serial transfer （串行传输）
  - Parallel transfer（并行传输）



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

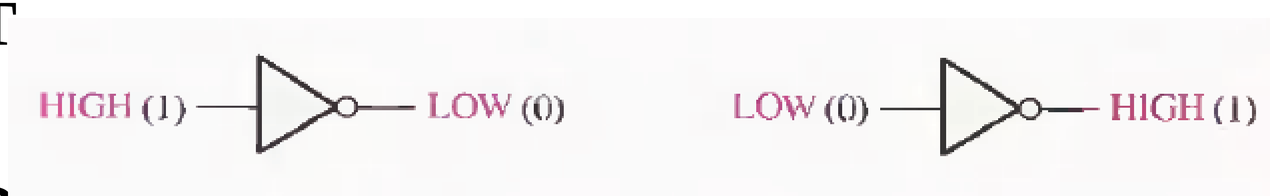


(b) Parallel transfer of 8 bits of binary data from computer to printer. The beginning time is t_0.

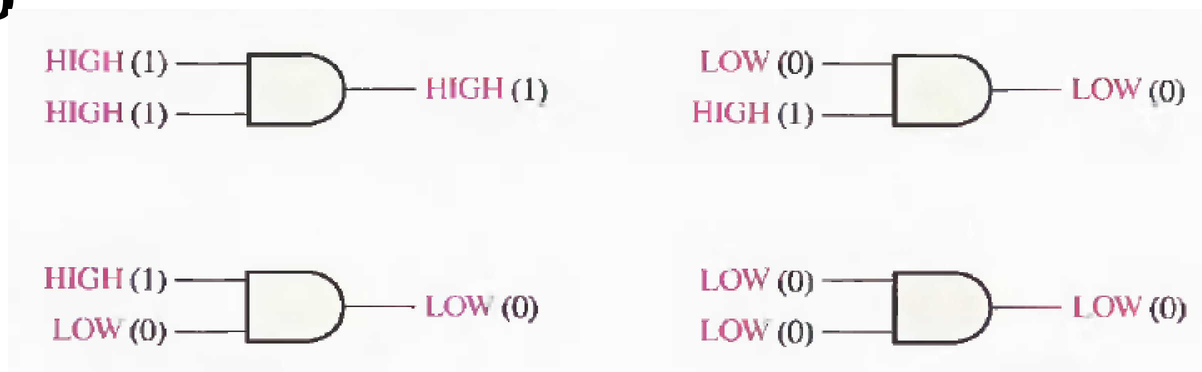
Illustration of serial and parallel transfer of binary data. Only the data lines are shown.

1-3 Basic Logic Operations

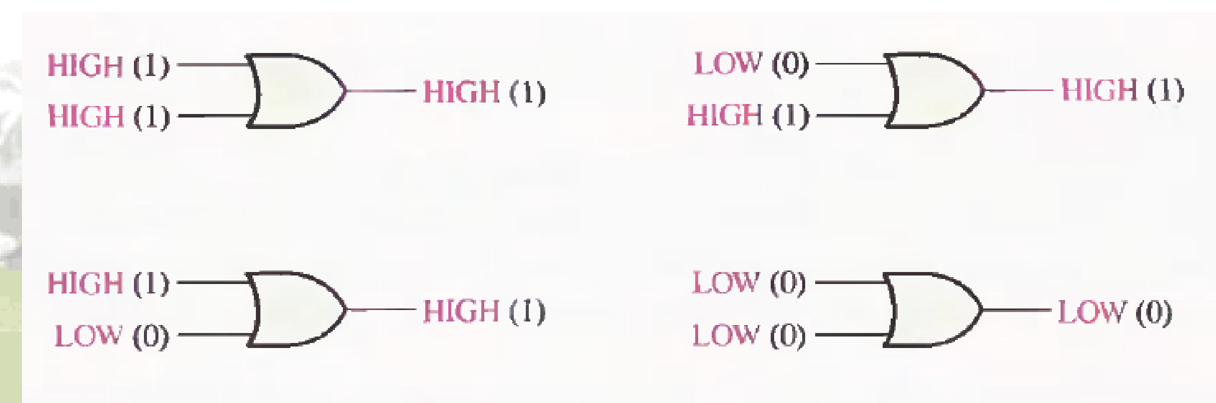
- **NOT**



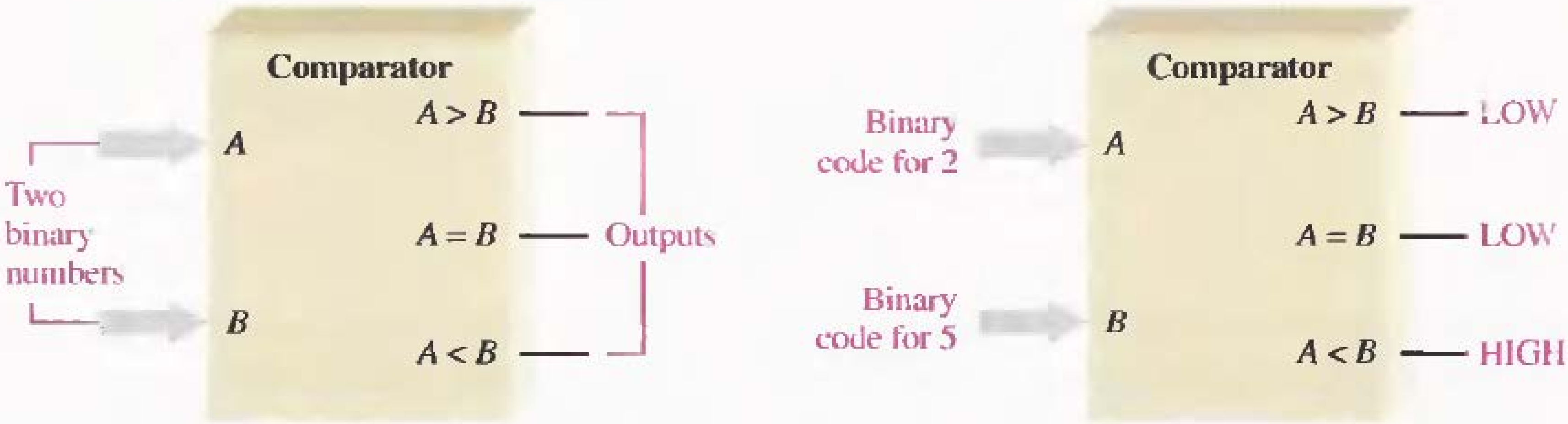
- **AND**



- **OR**



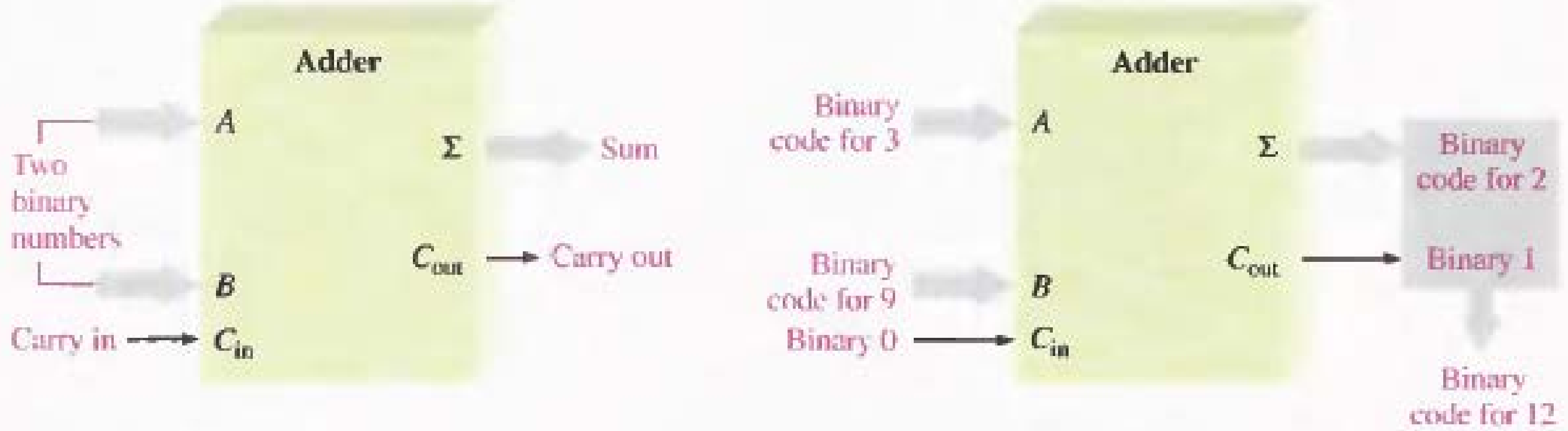
Example. Comparator



(a) Basic magnitude comparator

(b) Example: A is less than B ($2 < 5$) as indicated by the HIGH output ($A < B$)

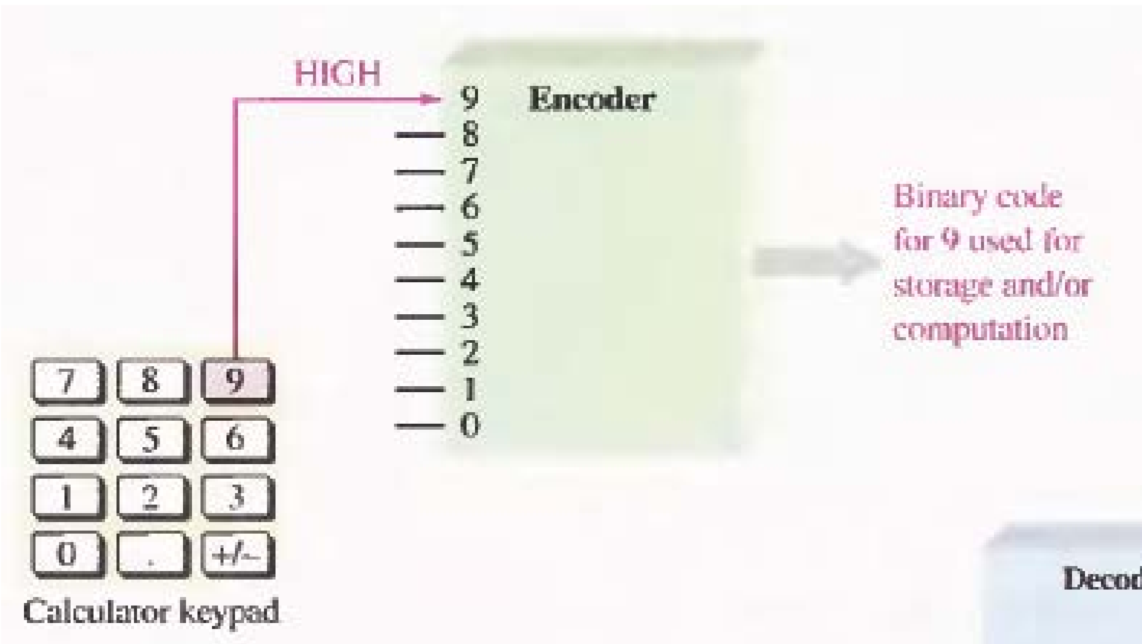
Example. Adder



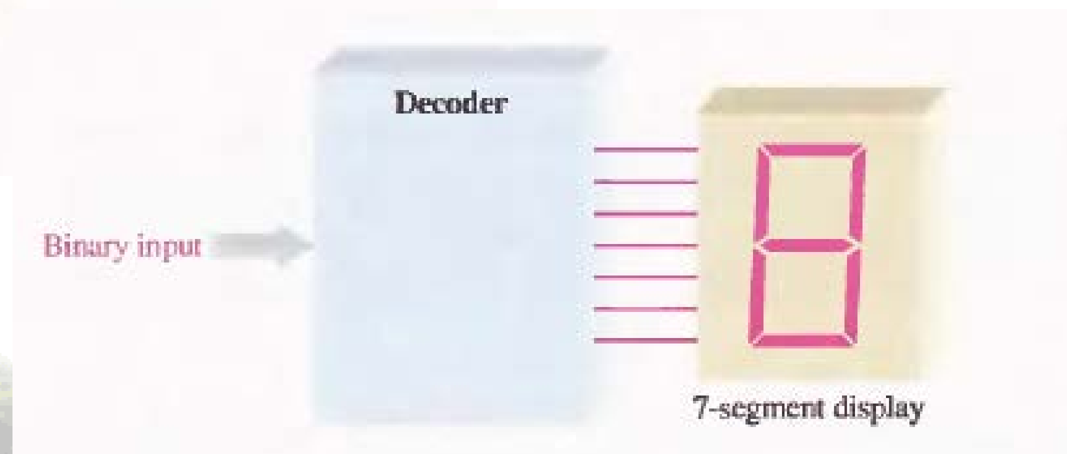
(a) Basic adder

(b) Example: A plus B $(3 + 9 = 12)$

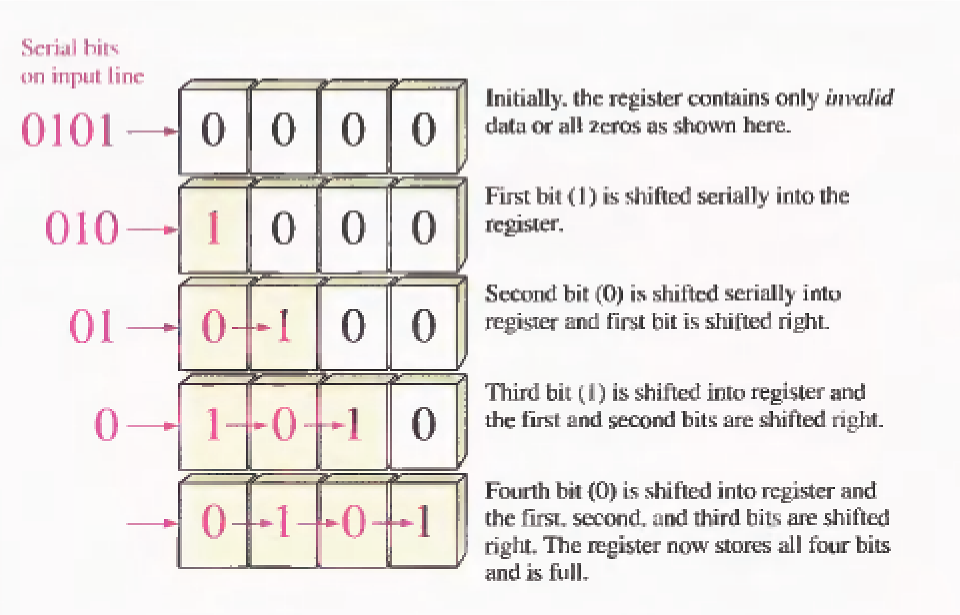
Example. Encoder and decoder

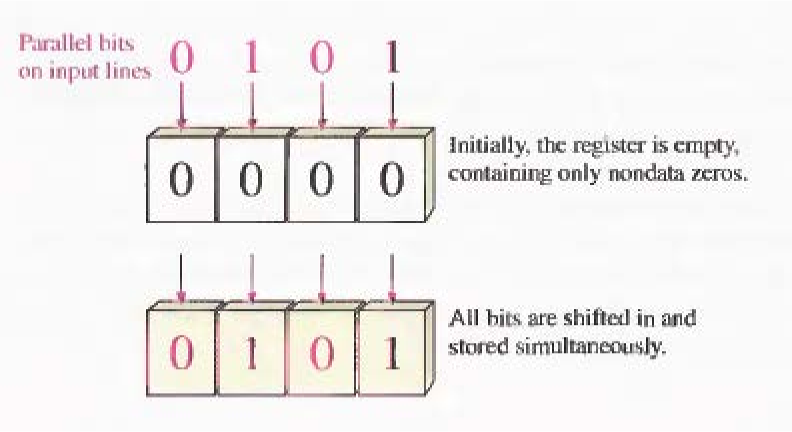


9:1001
8:1000
7:0111
6:0110
…
1:0001
0:0000

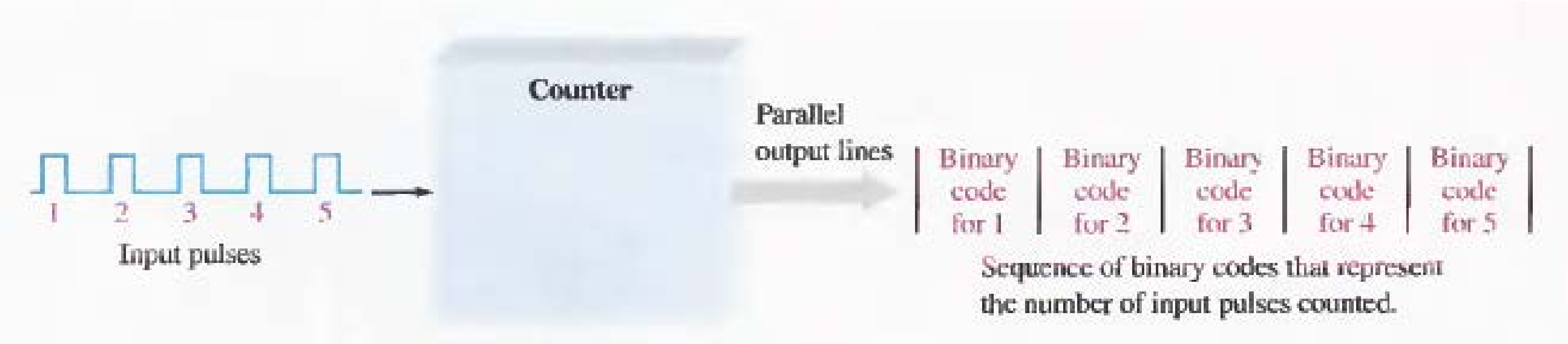


Example. Storage





Example. Counter



1-4 Overview of Integrated Circuits

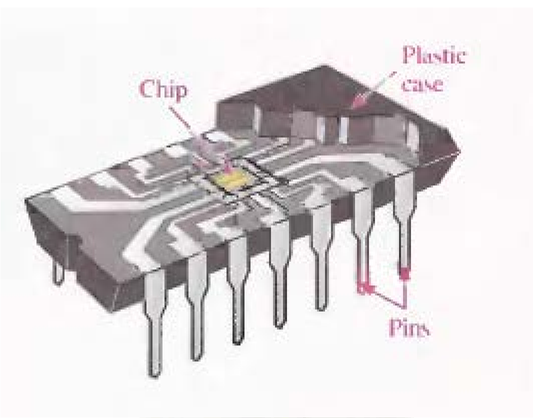
- Fixed-function Integrated Circuits
- Programmable Logic Circuits

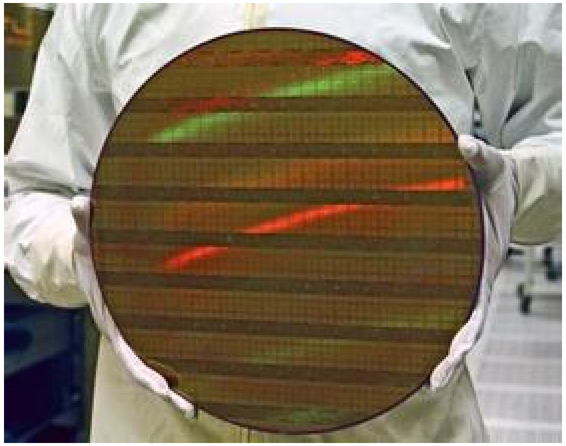
Fixed-function Integrated Circuits

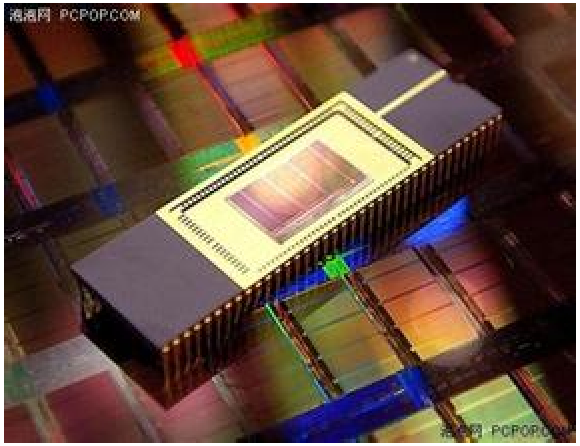
Fixed-function integrated circuits

- Constructed on a single small chip of silicon
- The logic functions are set by the manufacturer
- The logic cannot be altered

(a) Dual in-line package (DIP)　(b) Small-outline IC (SOIC)



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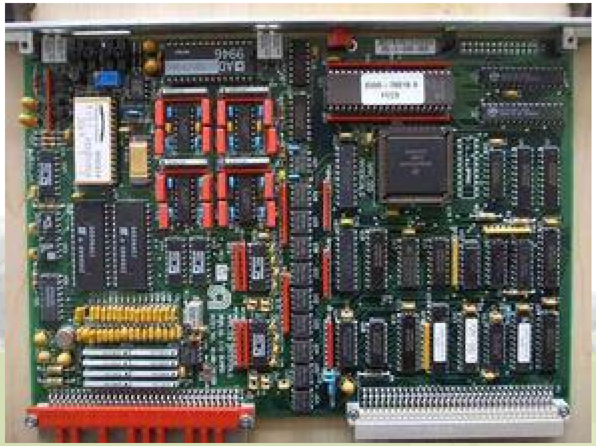
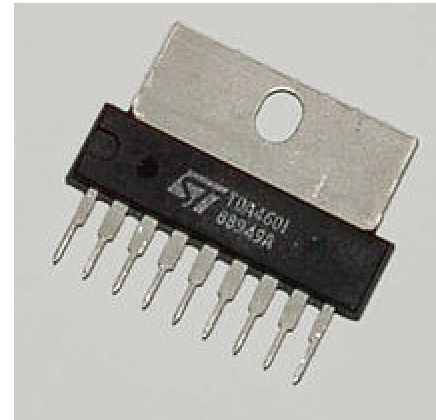
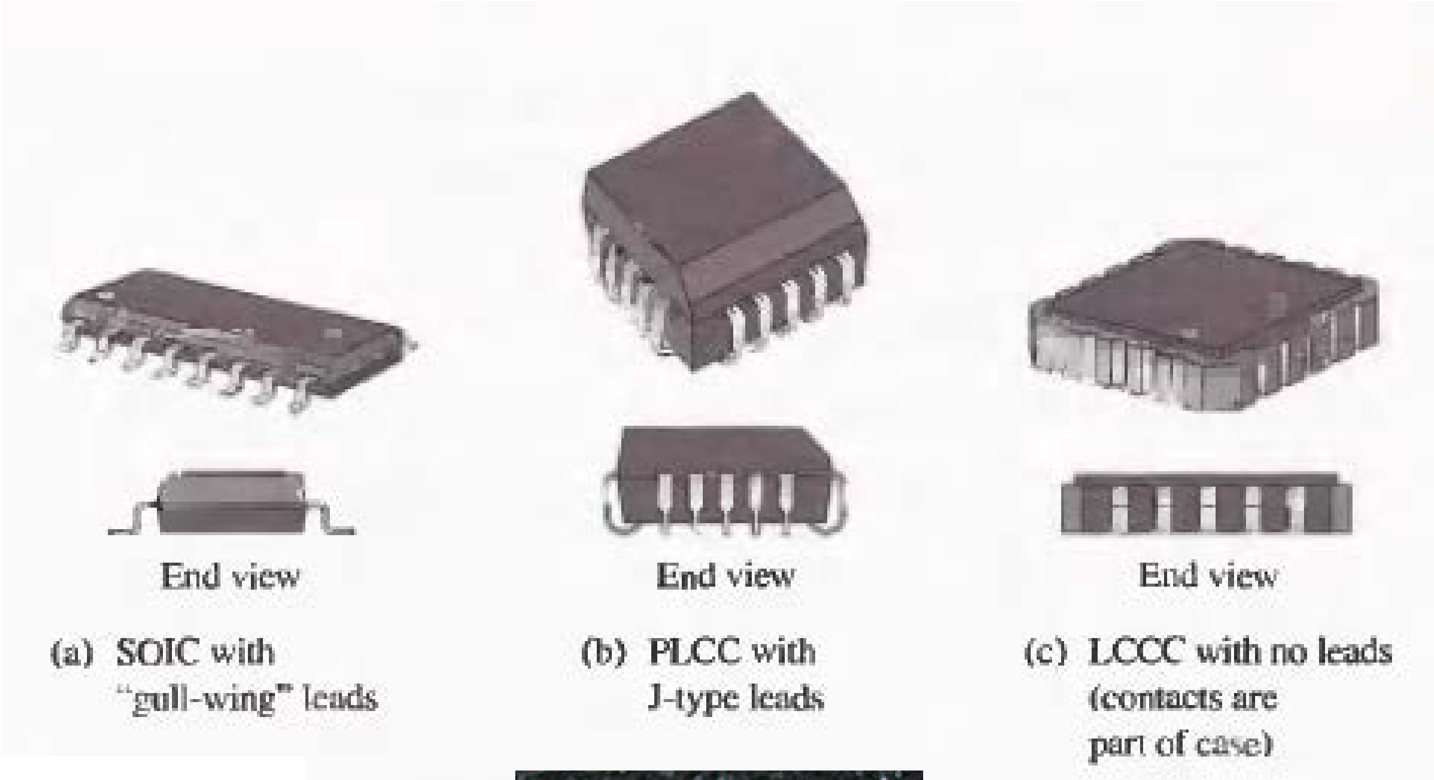


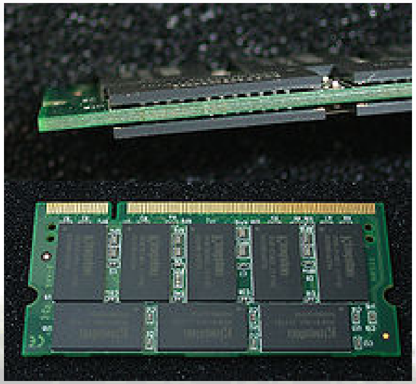
IC Packages



- **SIP: Single in-line package**
- **DIP: Dual in-line package**
- **SMT: Surface-mount technology**
  - SOIC: small-outline IC
  - PLCC: Plastic leaded chip carrier
  - LCCC: Leadless ceramic chip carrier
  - SSOP: Shrink small-outline package
  - TSSOP: Thin shrink small-outline package
  - TVSOP: Thin very small-outline package
  - BGA: ball grid array



Bottom view of an Intel Embedded Pentium MMX, showing the blobs of solder

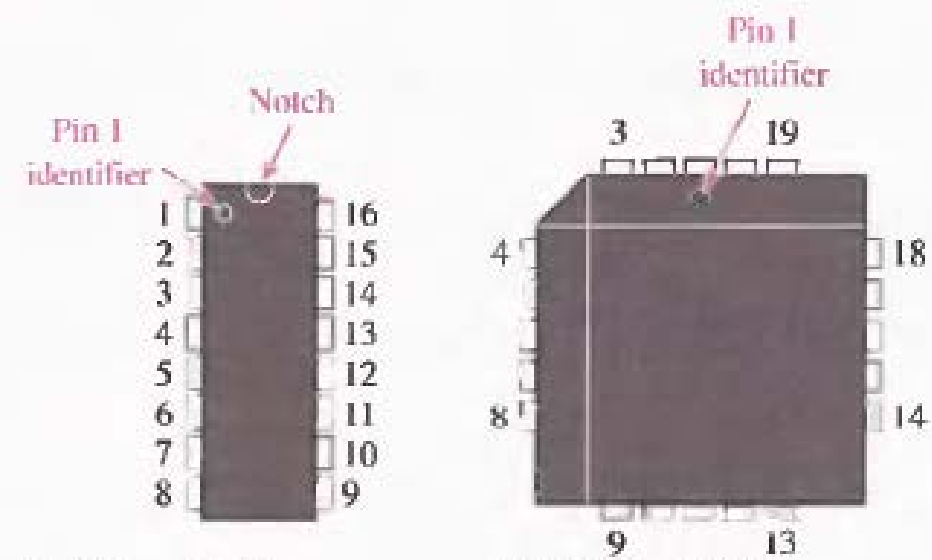


BGA ICs assembled on a PCB

Intel Mobile Celeron in a BGA2 package (FCBGA-479

Pin Numbering

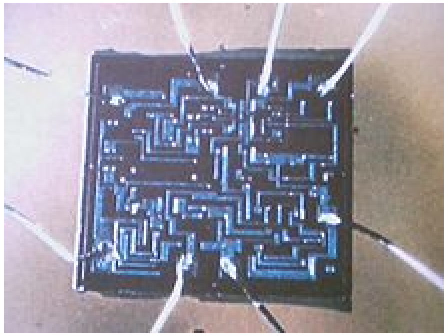
- Pin 1 is indicated by an identifier
- A small dot, a notch, or a beveled edge
- The dot is always next to pin 1.



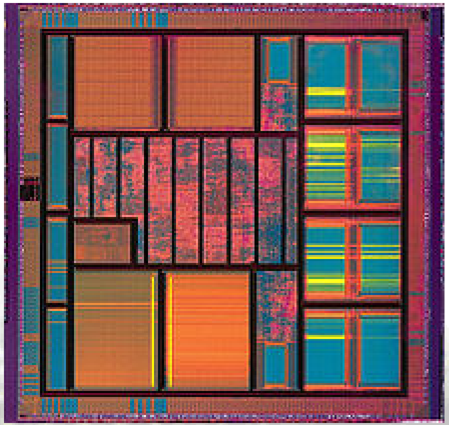
(a) DIP or SOIC (b) PLCC or LCCC

Complexity Classifications for Fixed-Function ICs

- **Small-scale integration (SSI)**
  - <10 equivalent gate circuits on a single chip
- **Medium-scale integration (MSI)**
  - 10~100
- **Large-scale integration (LSI)**
  - 100~10000
- **Very large-scale integration (VLSI)**
  - 10,000~100,000
- **Ultra large-scale integration (ULSI)**
  - >1000,000



A small-scale integrated circuit die, with bond wires attached

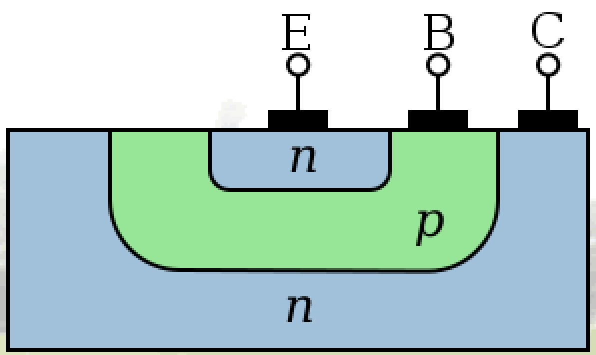


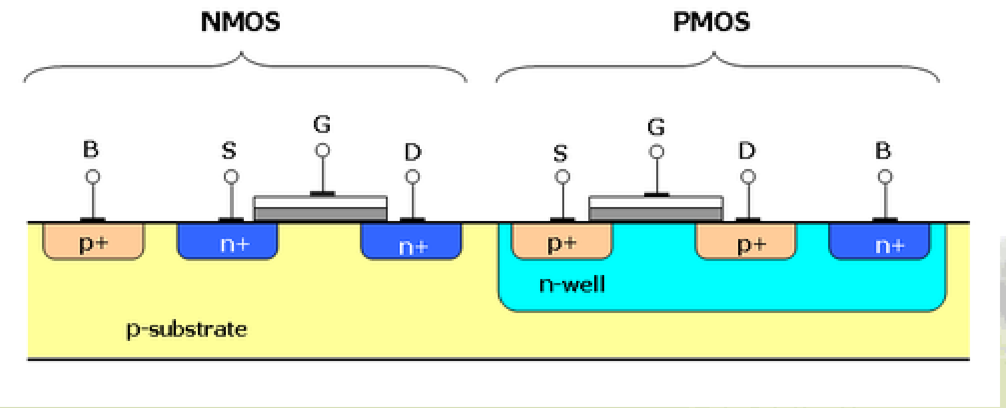
A VLSI integrated-circuit die

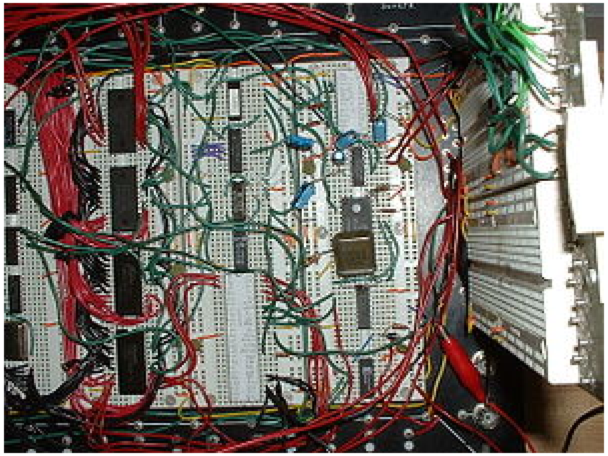
Semiconductor manufacturing processes
•10 µm — 1971
•3 µm — 1975
•1.5 µm — 1982
•1 µm — 1985
•800 nm (.80 µm) — 1989
•600 nm (.60 µm) — 1994
•350 nm (.35 µm) — 1995
•250 nm (.25 µm) — 1998
•180 nm (.18 µm) — 1999
•130 nm (.13 µm) — 2000
•90 nm — 2002
•65 nm — 2006
•45 nm — 2008
•32 nm — 2010
•22 nm — 2012
•14 nm — approx. 2014
•10 nm — approx. 2015
•7 nm — approx. 2020
•5 nm — approx. 2022

Integrated Circuit Technologies

- **CMOS (Complementary Metal-Oxide Semiconductor)**
  - Implemented with MOSFETs (Metal-Oxide Semiconductor Field-Effect Transistors)
- **TTL (Transistor-Transistor Logic)**
  - With bipolar junction transistors
- **BiCMOS**
  - Combination of both CMOS and TTL







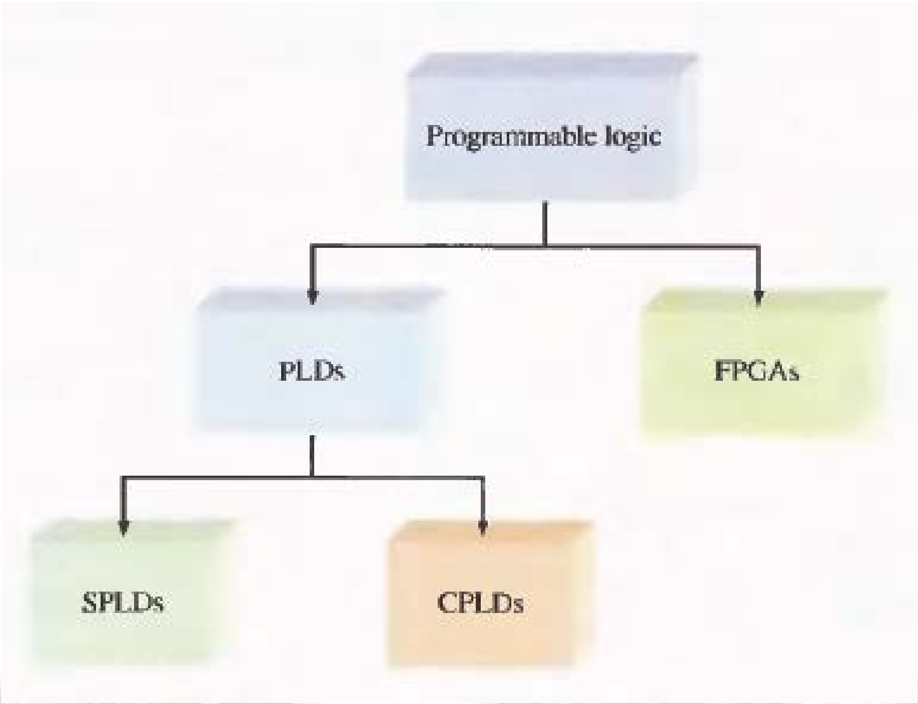
A Motorola 68000-based computer with various TTL chips mounted on protoboards

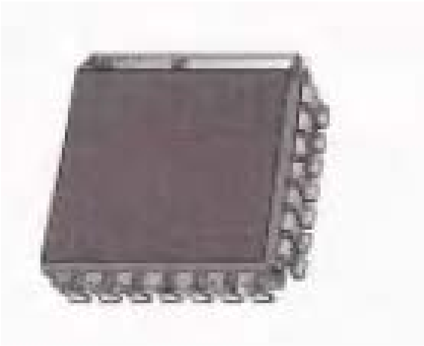
A micro ATX motherboard with some faulty capacitors

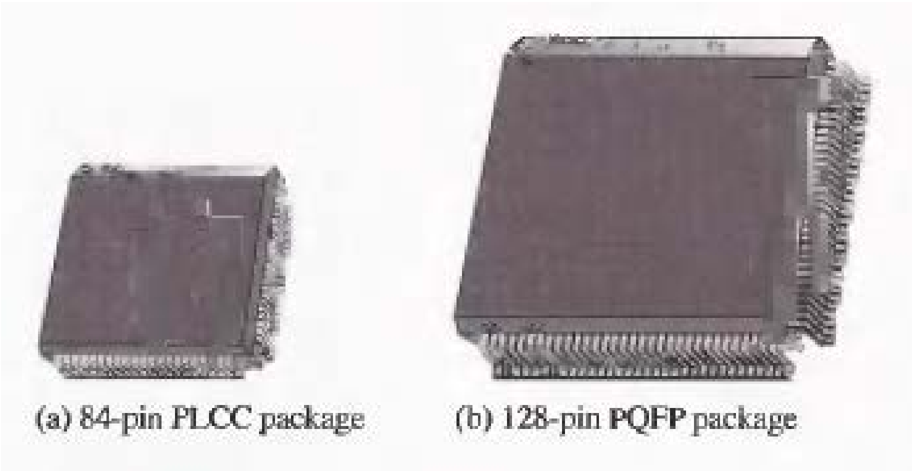
Programmable Logic Circuits

Types of Programmable Logic Devices

- PLD: Programmable Logic Device
- FPGA: Field Programmable Gate Array
- SPLD: Simple PLD
- CPLD: Complex PLDs



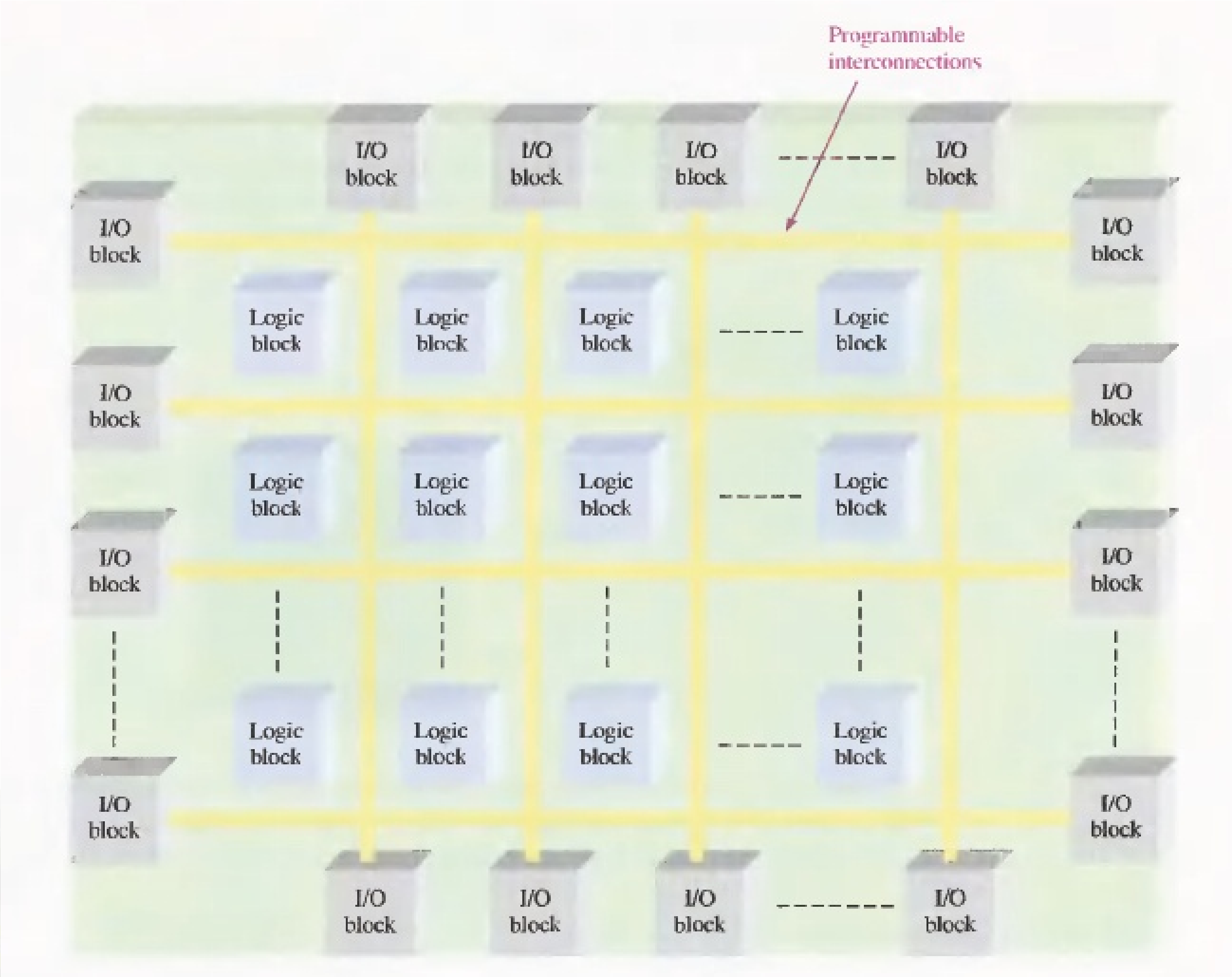




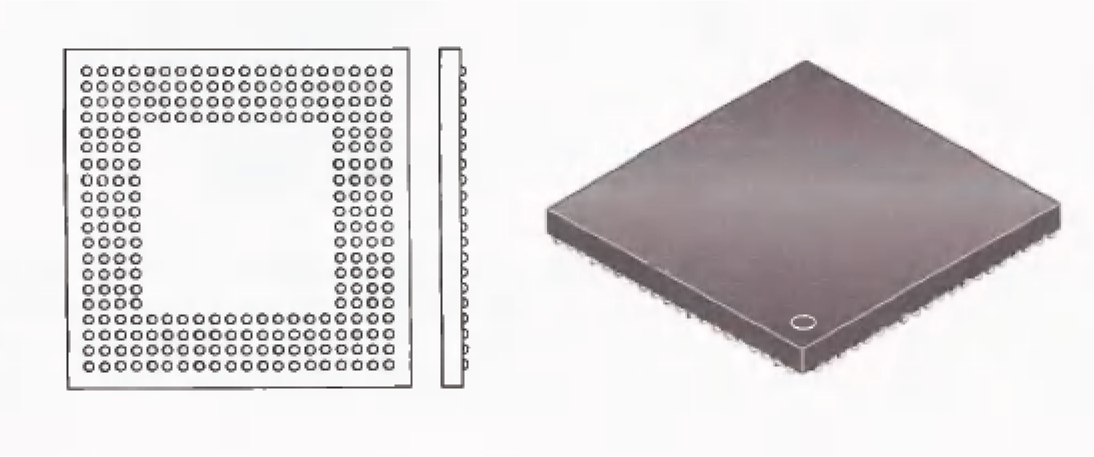
Typical package of SPLD

Typical CPLD packages

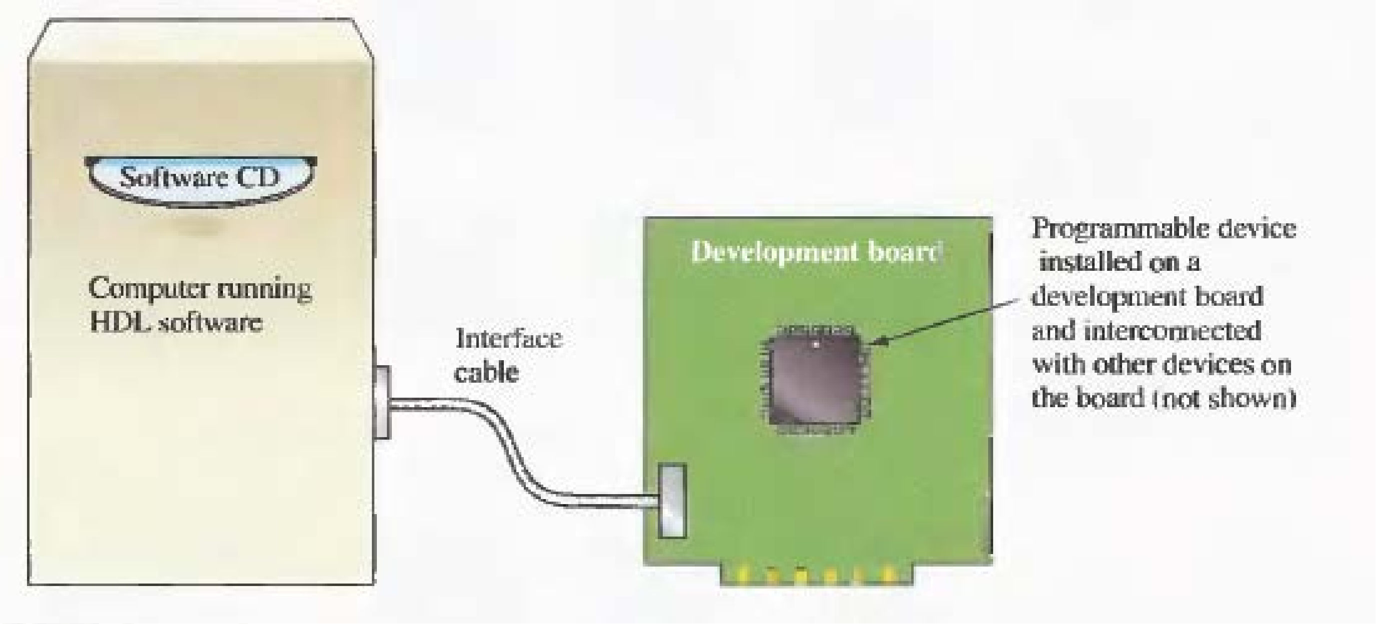
Basic structure of an FPGA

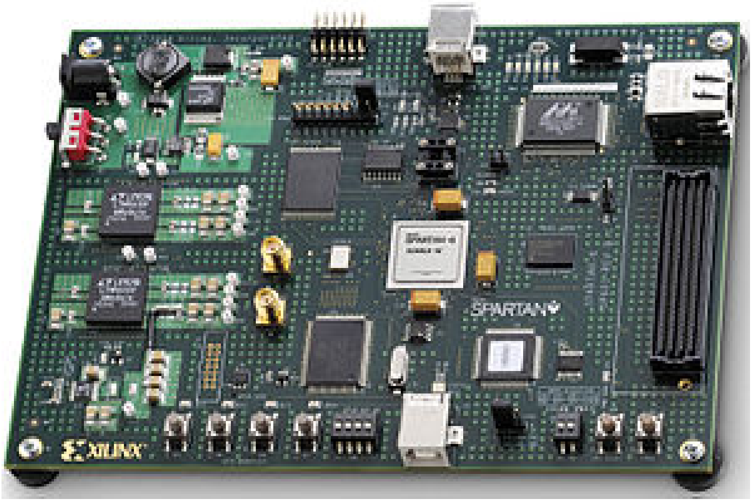


A typical ball-grid array package configuration



The Programming Process

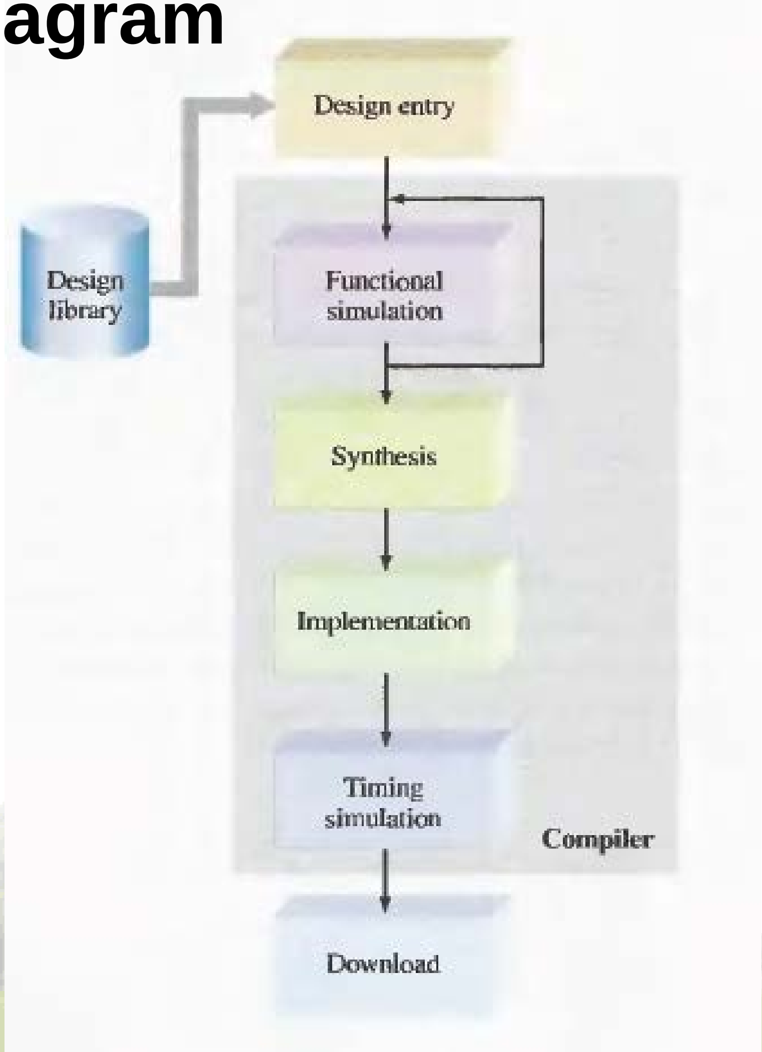




An example of a Xilinx Spartan 6 FPGA programming/evaluation board

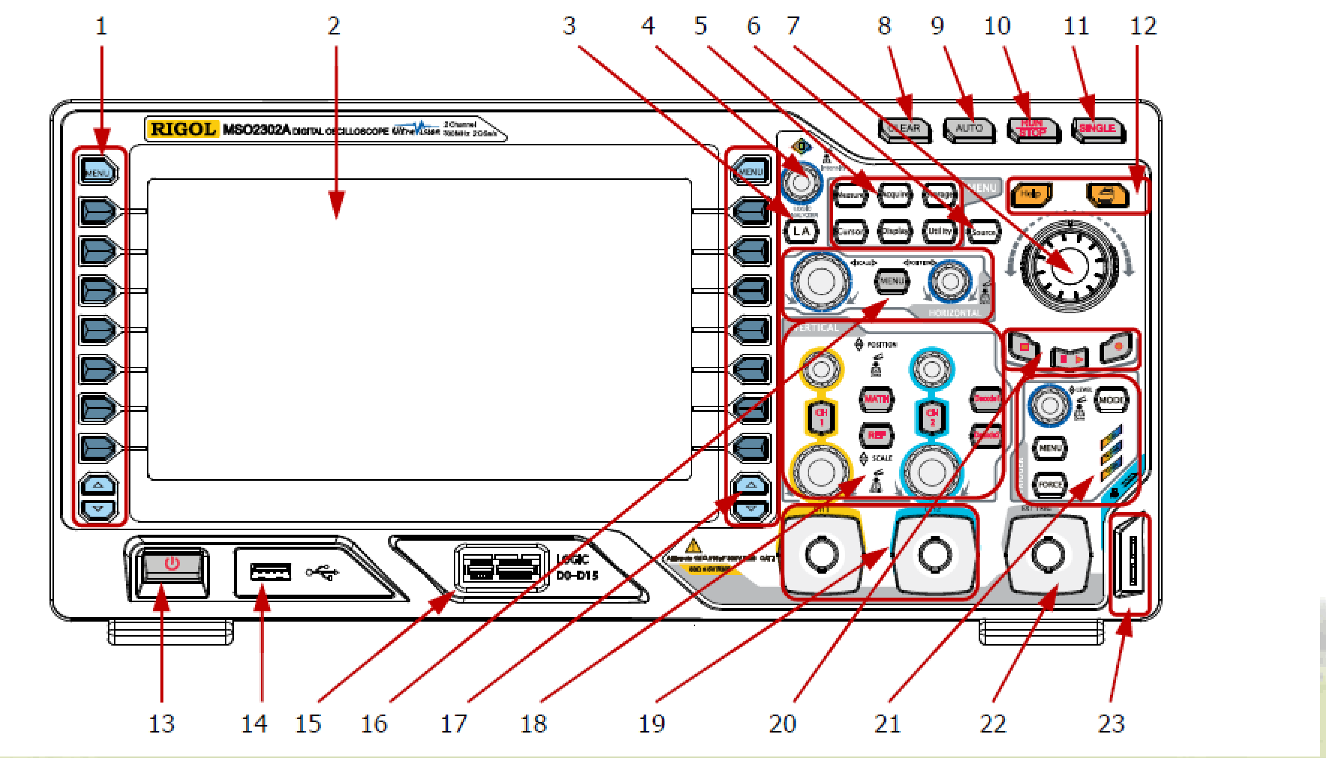
An Altera Stratix IV GX FPGA

Basic programmable logic design flow block diagram

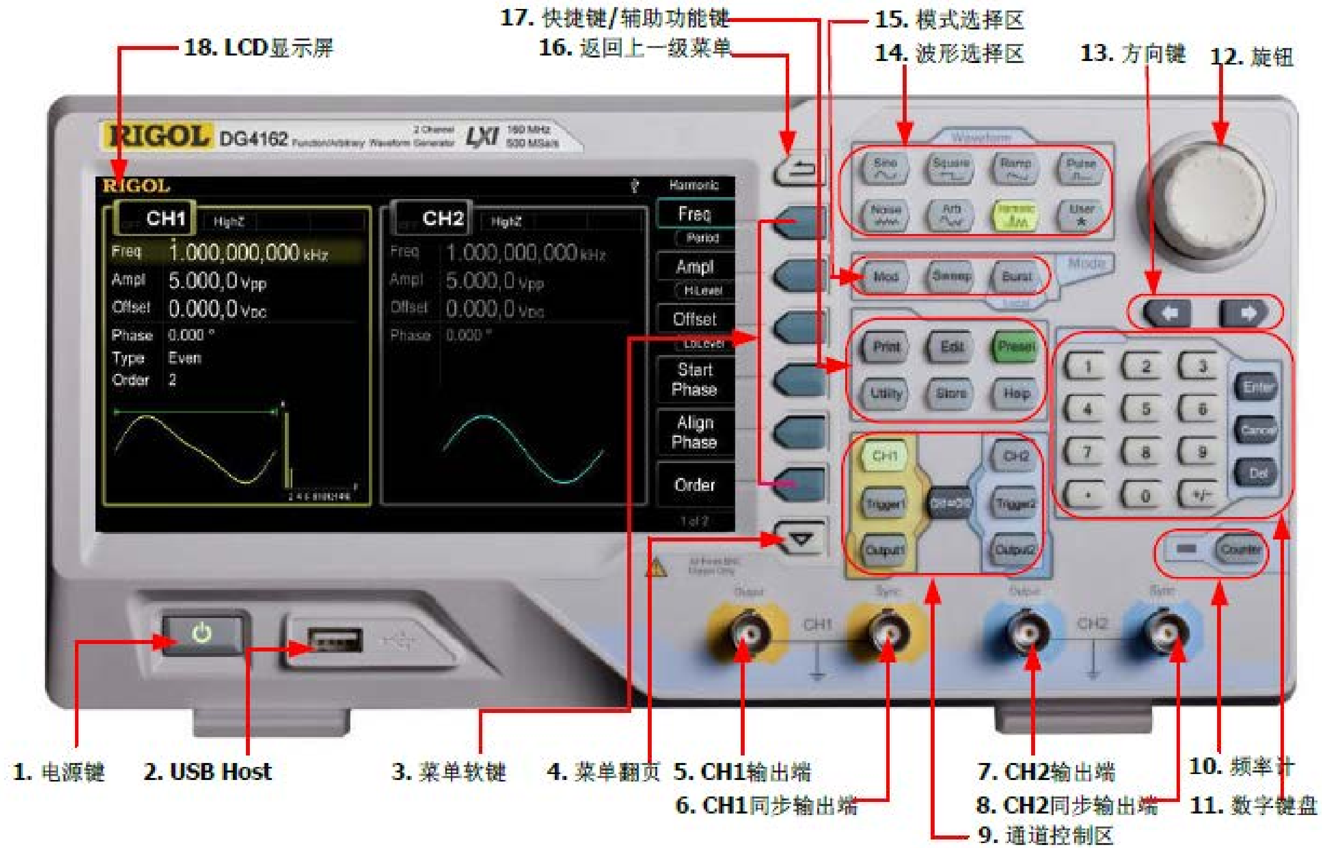


1-5 Test and Measurement Instruments

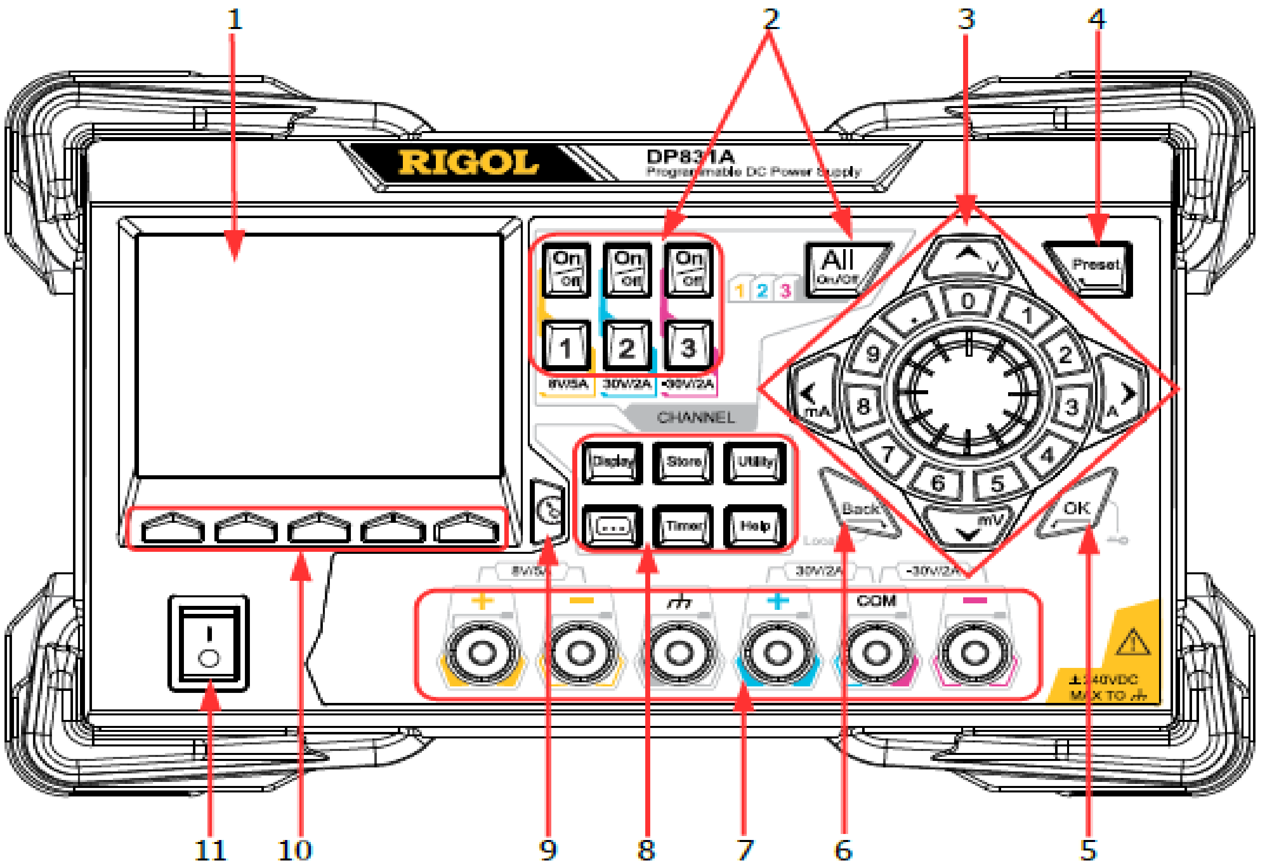
- **Oscilloscope**



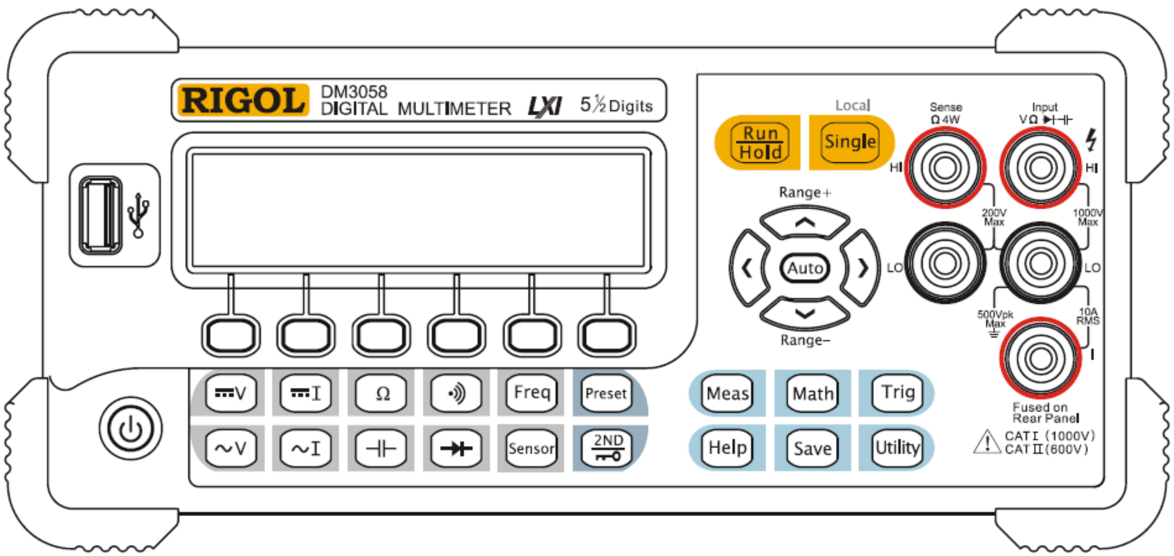
Signal generators



DC Power Supply



Digital Multimeter (DMM)



Summary

- Analog and digital
- Positional number systems
- Some basic concepts in digital design
- Basic logic operation
- Brief introduction of IC
- Test and measure instruments

HW

- **Page 12 (Edition 10)**
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