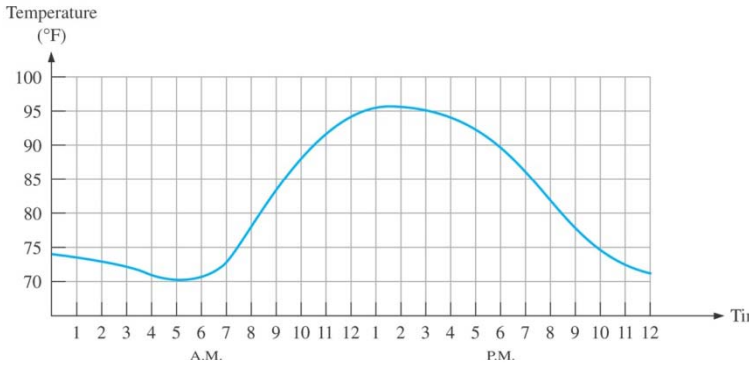
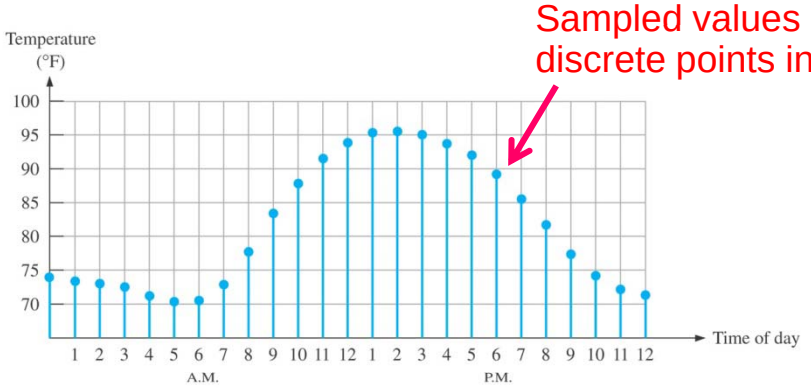
Digital Logic Circuits
Fundamentals I

Digital and Analog Quantities

- Electronic circuits can be divided into two categories.
  - Digital Electronics : deals with discrete values (= sampled values at discrete points in time: quantization)
  - Analog Electronics : deals with continuous values
- Most natural quantities that we see are analog and vary continuously.
  - (Ex: time, temperature, pressure, sound, light, distance, …)
- Digital Advantage
  - Digital data can be processed and transmitted more efficiently and reliably than analog data. Digital data has a great advantage when storage is necessary.



Analog quantity



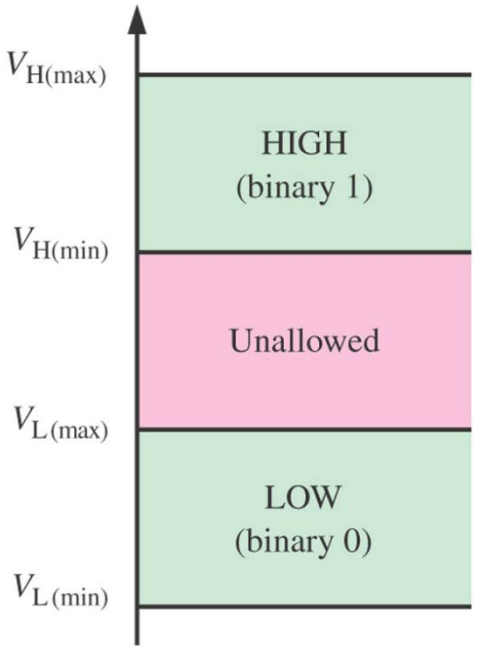
Digital quantity

Binary Digits and Logic Levels

• Digital electronics uses circuits that have two states, which are typically represented by two different voltage levels called HIGH and LOW. The voltages represent numbers in the binary system.

• In binary, a single number is called a *bit* (for *b*inary dig*it*). A bit can have the value of either a 0 or a 1, depending on if the voltage is LOW or HIGH.

• In positive logic, HIGH = 1 & LOW = 0.

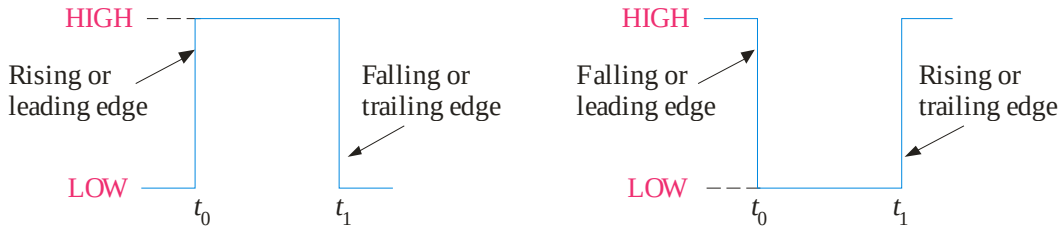


• Groups of bits (combinations of 1s and 0s) are called "codes". (Ex: binary code, ASCII code)

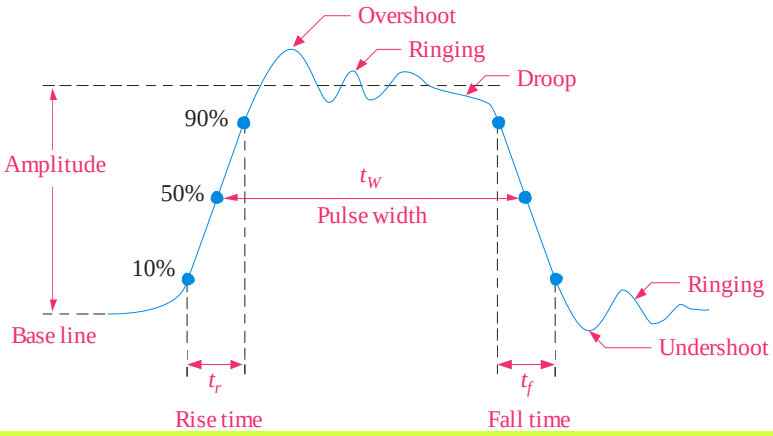
• Codes are used to represent numbers, letters, symbols, instructions, …, etc.

Digital Waveforms and Pulses

• Digital waveforms change between the LOW and HIGH levels. A positive going pulse is one that goes from a normally LOW logic level to a HIGH level and then back again. Digital waveforms are made up of a series of pulses.

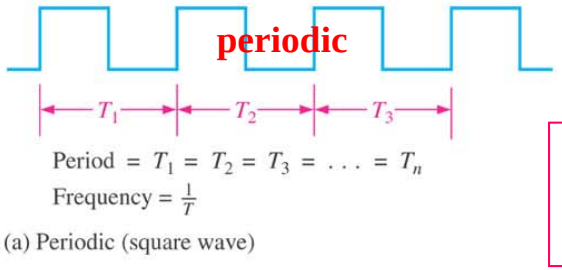


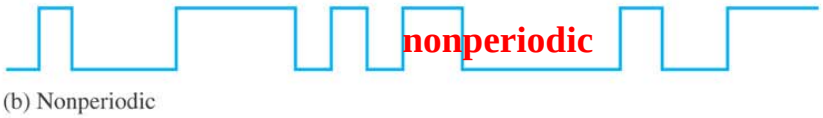
• Actual pulses are not ideal but are described by the rise time, fall time, amplitude, and other characteristics.



Periodic Pulse Waveforms

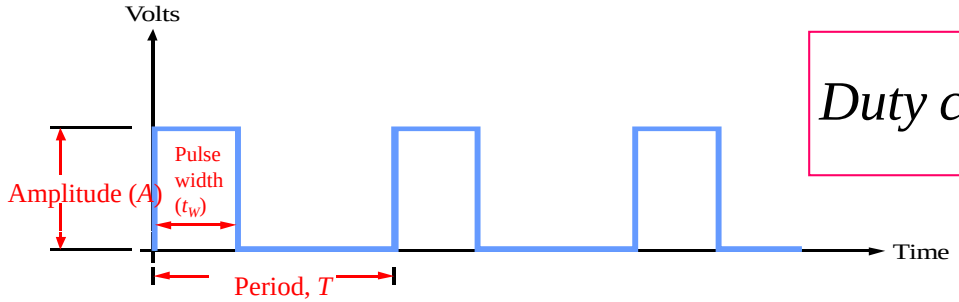
• Periodic pulse waveforms are composed of pulses that repeats in a fixed interval called the **period (T)**. The **frequency** (*f*) is the rate it repeats and is measured in hertz (Hz).





$$f = \frac{1}{T} \qquad T = \frac{1}{f}$$

• Repetitive waveforms are described by the frequency, period, amplitude (*A*), pulse width (t_W) and duty cycle. Duty cycle is the ratio of t_W to *T*.



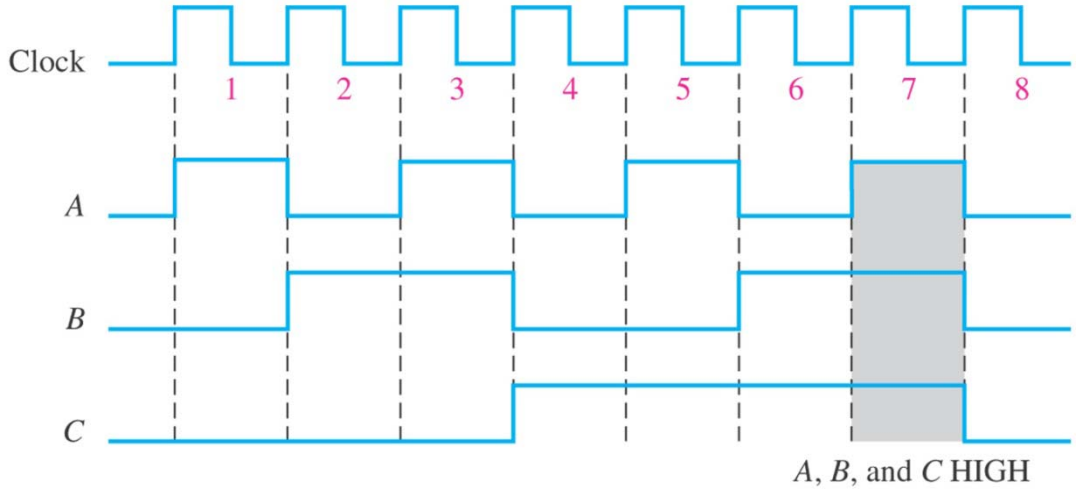
$$Duty\ cycle = (\frac{t_w}{T}) * 100\ \%$$

• The **clock** is a basic timing signal that is an example of a periodic wave.

• What is the period of a repetitive wave if *f* = 1 GHz? $T = \frac{1}{f} = \frac{1}{1\,\text{G Hz}} = 1\,ns$

Timing Diagrams

• A timing diagram is a graph of digital waveforms showing the actual time relationship of two or more digital waveforms.



A diagram like the above can be observed directly on a logic analyzer or an digital oscilloscope.

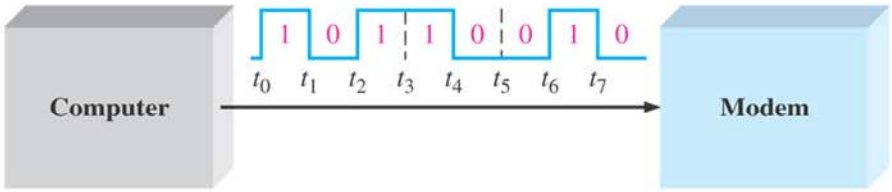
Data Transfer

• Data refers to groups of bits (or group of codes) that convey some type of information.

• Data can be transferred in two ways:

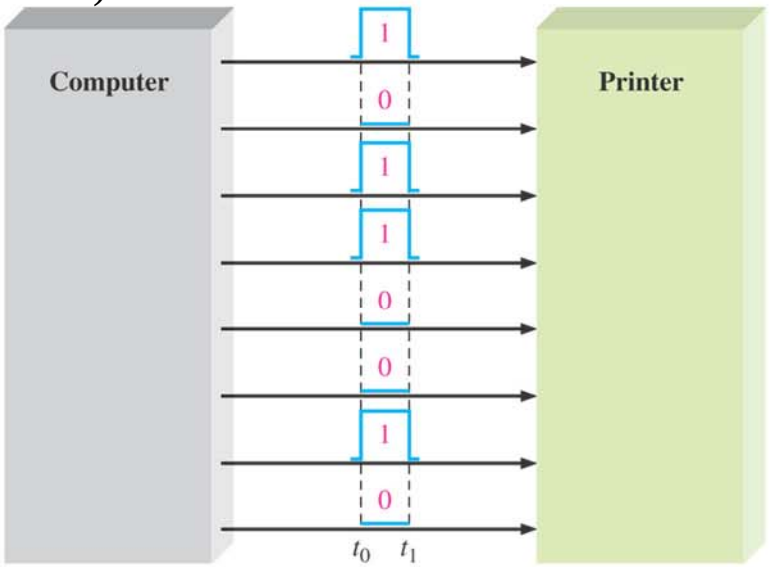
- **Serial transfer** (disadvantage : It takes longer time to transfer a given number of bits than with parallel transfer.)

- **Parallel transfer** (disadvantage: It takes more lines.)



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

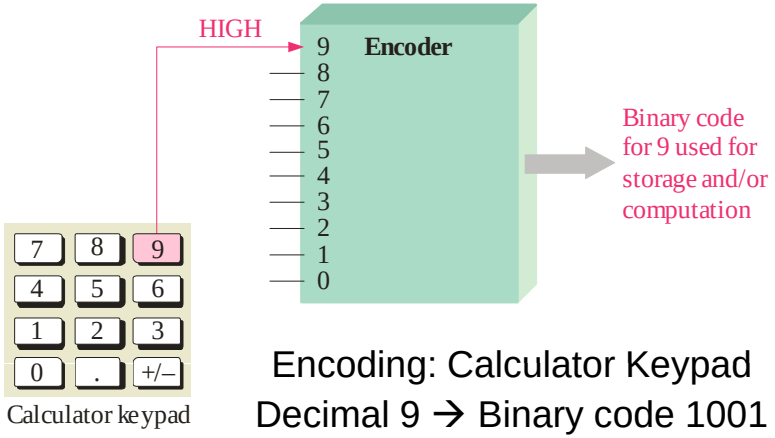
Serial Transfer



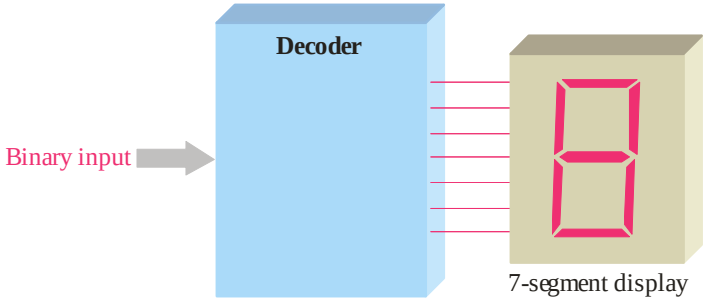
(b) Parallel transfer of 8 bits of binary data from computer to printer. The beginning time is t_0.

Parallel Transfer

- Code Conversion Function
  - **A code is a *set of bits arranged in a unique pattern and used to represent specified information*.**
  - **A code converter changes one form of coded information into another coded form. (Ex. Binary code → Binary Coded Decimal (BCD) code or Gray code.)**
- Encoding Function
  - The **encoder** converts information (such as a decimal number or an alphabetic character) into some coded form.
- Decoding Function
  - The **decoder** converts coded information (such as a binary number) into some non-coded form (such as a decimal form).



Encoding: Calculator Keypad
Decimal 9 → Binary code 1001



Decoding: 7-segment display
Binary code 1000 → Decimal 8

Integrated Circuits

• A monolithic Integrated Circuits (IC) is an electronic circuit that is constructed entirely on a single small chip of silicon.

• Two broad categories of digital IC

  • Fixed-Function Logic Devices

    → the logic functions are set by the manufacturer

    and can not be changed. (Ex: Intel CPUs, Samsung DRAMs)

  • Programmable Logic Devices

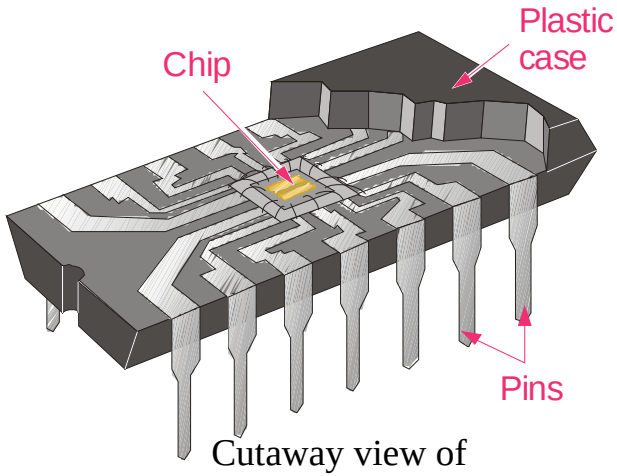
    → can be programmed to perform specific logic functions

    by the manufacturer or by the user. (Ex: Xilinx FPGAs)

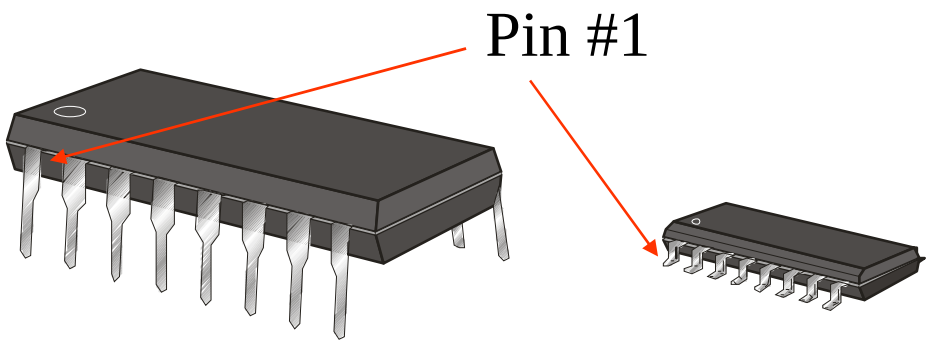
• IC Package types

  - Through hole type packages
    : Dual in-line package (DIP)
  - Surface-mount technology (SMT) type packages
    : Small-outline IC (SOIC)
    : Plastic-leaded chip carrier (PLCC)
    : Leadless-ceramic chip carrier (LCCC)
  - Contackless packages.

CPGA



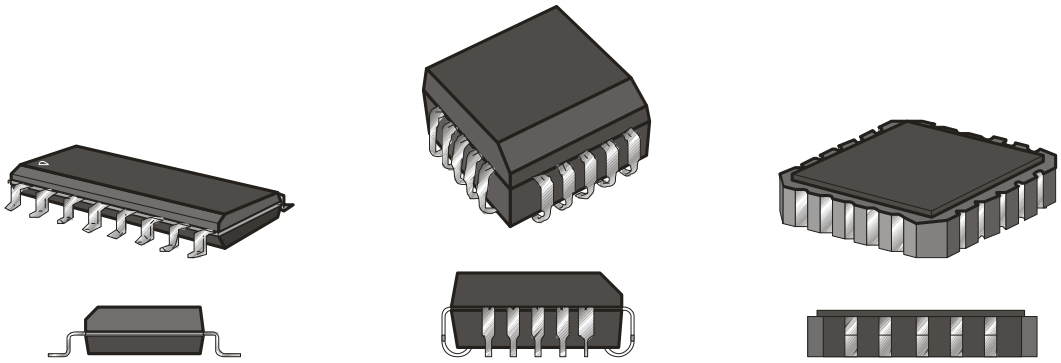
Cutaway view of DIP (Dual-In-line Pins) package



Dual in-line package

Small outline IC (SOIC)

- Other surface mount packages:



SOIC PLCC LCCC

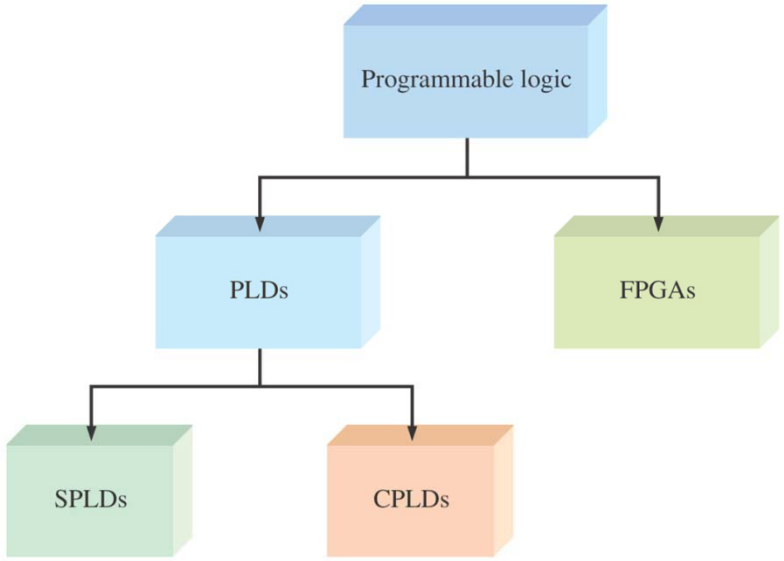
Introduction to Programmable Logic

• Programmable logic devices can be programmed to perform specific logic functions by the manufacturer or by the user.

• Two major categories of user-programmable logic are PLD and FPGA.

  • Programmable logic requires both hardware and software.

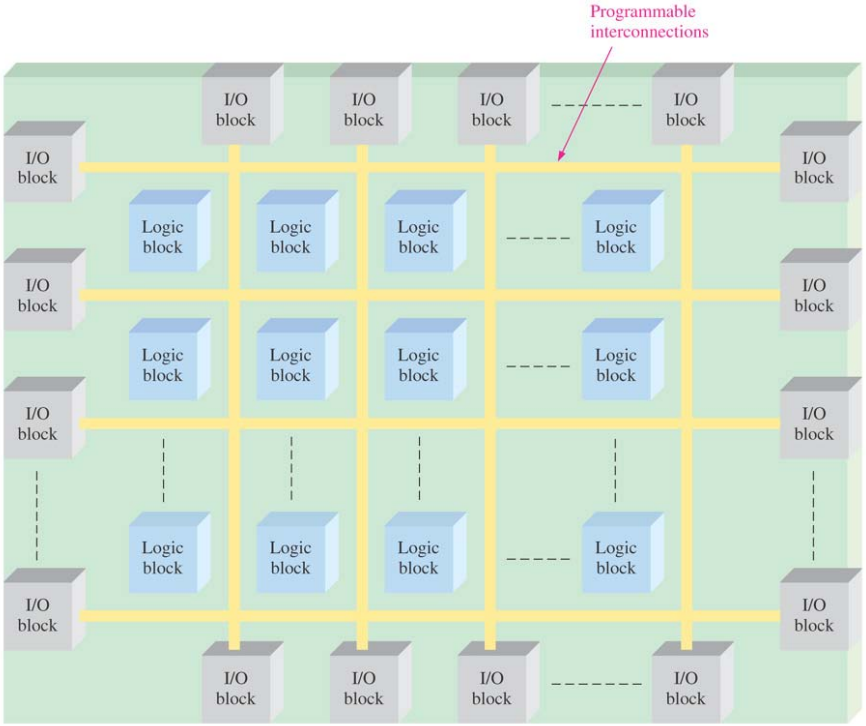
  • One advantage of programmable logic is that designs can be readily changed without rewiring or replacing components. Also, a logic design can be implemented faster.



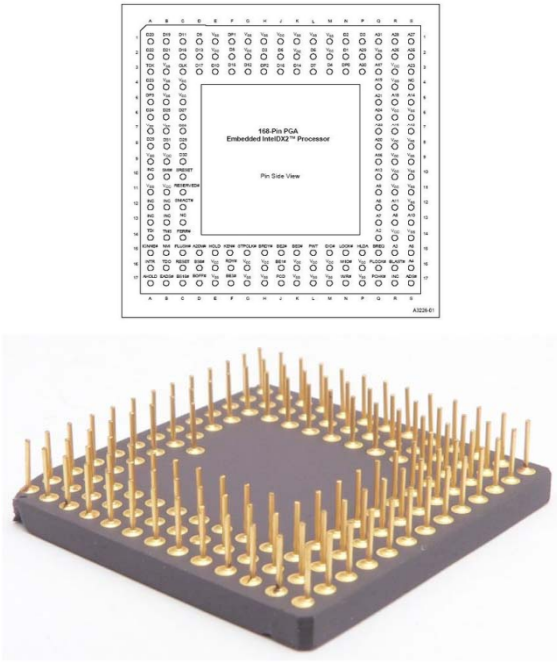
- PLD : Programmable logic device
- SPLD : Simple programmable logic device
- CPLD : Complex programmable logic device (44-160 pin packages)
- FPGA : Field-programmable gate array (>1000 pins)

FPGA

- **Field Programmable Gate Array (FPGA)**
  - **An FPGA is generally more complex and has a much higher density.**
  - **The 3 basic elements in an FPGA are the logic blocks, the programmable interconnections, and the input/output (I/O) blocks.**
  - **Large FPGAs can have tens of thousands of logic blocks in addition to memory and CPUs.**
  - **A typical FPGA ball-grid array (BGA) package has over 1000 pins.**

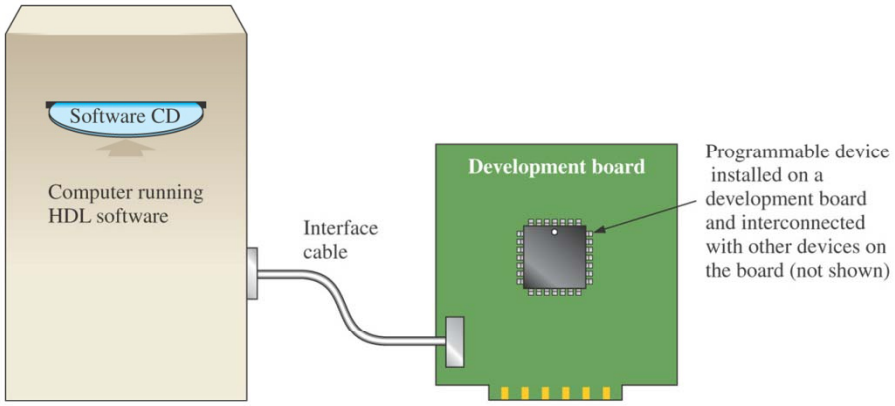


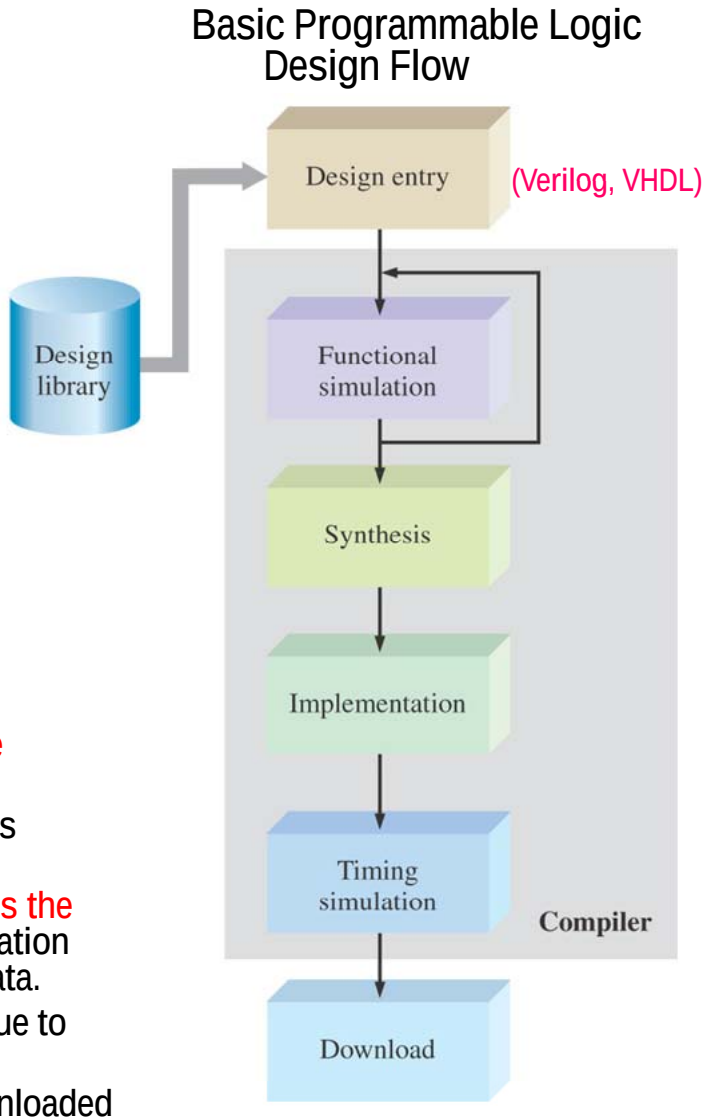
Basic structure of an FPGA



BGA package for FPGAs

Programming Process of PLDs and FPGAs





- The programming process requires a software development package (installed on a computer) to implement a circuit design in the programmable device (chip, installed on a development board).

Design Flow

- Design entry : Describes the logic circuit function with hardware description languages such as Verilog or VHDL.
- Functional simulation : Confirm that the logic circuit functions as expected in functional level.
- *Synthesis* and Implementation : The synthesis process translates the Verilog or VHDL design into a netlist (gate level). The implementation process is called 'place and route' and generates a bit-stream data.
- Timing Simulation : Confirm design errors or timing problems due to propagation delays.
- Download : After generating the bitstream data, it has to be downloaded to the device chip to implement the software design in hardware.

Test and Measurement Instruments

- Analog Oscilloscope
- Digital Oscilloscope
- Logic Analyzer
  - Large # of signals (over 100) can be measured simultaneously.
- DC Power Supply
- Function Generator
- Digital Multimeter (measures voltage, current, & resistance)

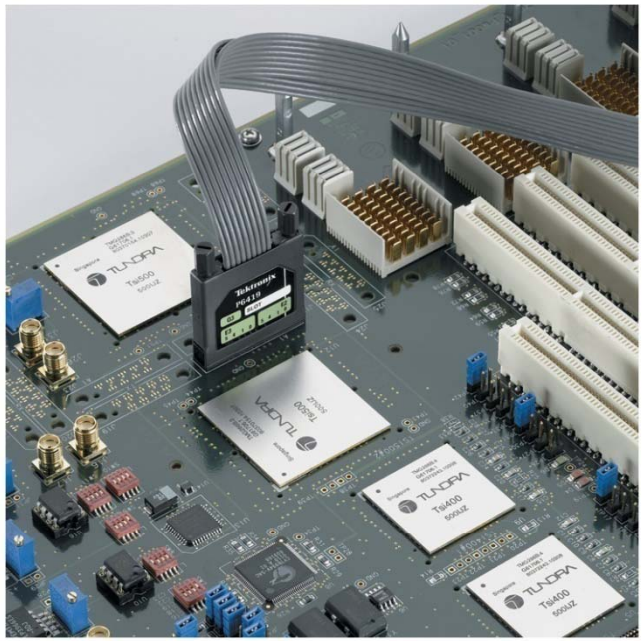
Digital Oscilloscope

Probe

• Logic Analyzer

: The logic analyzer can display multiple channels of digital information or show data in tabular form.

Logic Analyzer



Multichannel logic analyzer probe

Universal Anynchronous Receiver Transmitter (UART)

- A UART (Universal Asynchronous Receiver Transmitter) includes a serial-to-parallel data converter and a parallel to serial converter.

- UARTs are commonly used in small systems where one device must communicate with another. Parallel data is converted to asynchronous serial form and transmitted.