EE2016 Microprocessor Theory and Lab

EE Dept – *IIT Madras Fall, 2024*

Dr. R. Manivasakan

Presentation: Week 1 & 2

Introduction

Course Information

- Course Information
  - Credit Scheme
  - Syllabus (Curricula)
  - Text Books
    - William Stallings, “Computer Architecture and Organization: 8th Edition”,
    - Mazidi, “The AVR Microcontroller and Embedded System, using Assembly and C”
    - Welsh, “ARM Assembly Language Programming”
  - References
    - David A. Patterson and John L. Hennessy, “Computer Organization and Design: ...”, Elsevier, Third Edition, 2005
    - Carl Hamacher, Zvonko Vranesic and Safwat Zaky, “Computer Organization”, Tata McGraw Hill, Fifth Edition, 2002
  - Lab: 1 FPGA, 4 AVR Microcontrollers, 3 ARM based experiments

Course Information

- Syllabus

Mainly microcontroller, microprocessor concepts, design, architecture: CU, EU, buses, I/O, memory, Van Neumann / Harvard architecture, performance assessment, memory organization, cache management. Lab: Hands-on-assembly programming: AVR (8-bit) microcontroller and ARM 32-bit processor

- MuP bottom most stack in engineering – implementation of any engineering idea, theory --> practice to the core

- Positioning of EE2016
  - Physics--> Electronics-->Digital Circuits--> Digital Systems--> EE2016
  - Future Courses
    - VLSI Design --> Algorithms for VLSI Design
    - VLSI Technology
    - Hardware based courses in EE?

Credit Scheme (Tentative)

- Credit scheme
  - 50 % theory 50 % lab
- Theory (50 %)
  - 20 % - Quiz2
  - 30 % End semester theory
- Lab (50 %)
  - Regular Lab Session (30 %)
  - Endsem Lab Exam (20 %)
    - Online or written

Lecture 1: Overview

- Microprocessors, Microcontrollers & other closely related terms
- Applications of Microprocessor / Microcontrollers
  - Mother of ALL engineering disciplines
    - Wherever implementation of an engineering concept comes, muP / muC would be there
- Microprocessors
  - Definition
  - Architecture and Organization
  - Applications
- Categorization of Microprocessor / Computer Systems
- RISC or CISC
- Van-Neumann architecture and Harvard architecture

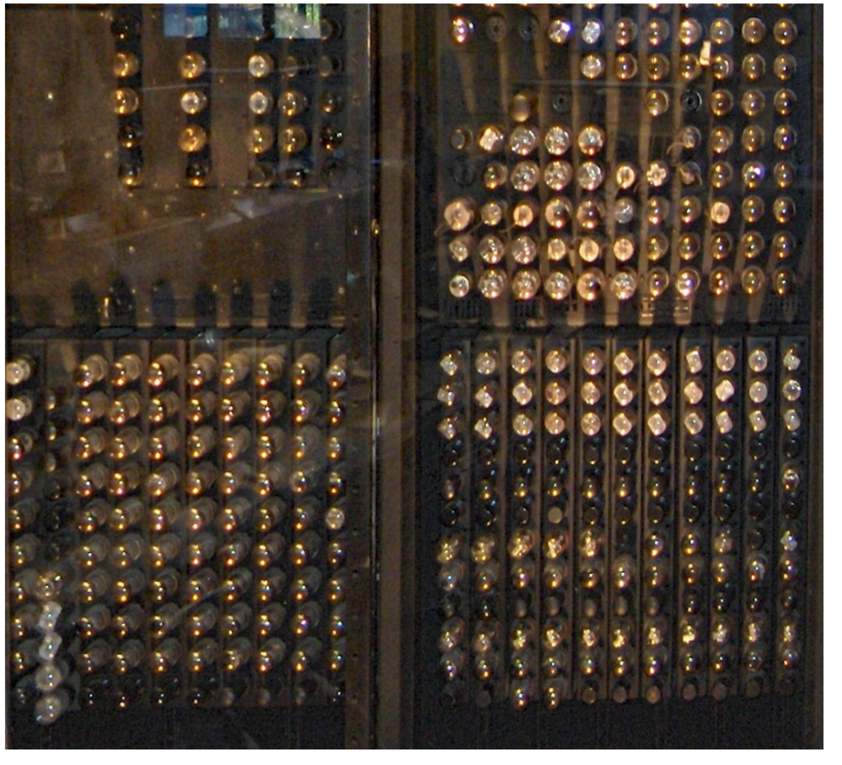
Lecture 1

- Microcontroller technology is the mother of ALL disciplines of engineering as it implements theory
  - All theory developed, have to be implemented, in the real world.
  - Implementation through microcontrollers
- Microprocessors & Microcontrollers
  - Commercial muPs/ muControllers, companies
  - Difference between muPs and muControllers
  - Closely related terms: Embedded systems, microcomputers, ASIC, SoC, SoM, Embedded processor, FPGA etc
  - CoM, microcomputer, server, work station, main frame computer & super computer.
- Overview of Microprocessors
  - Architecture and Organization
  - Applications
    - Main frame, server, work station & microcomputer

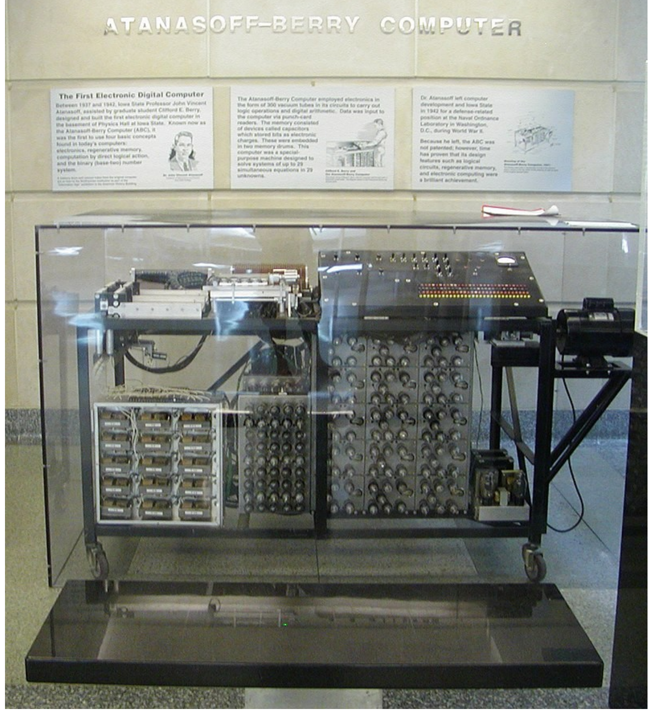
Microprocessor

- A Microprocessor
  - Is a multi-purpose clock driven, register based digital IC of logical and arithmetic computation capability, that accepts binary input, processes it according to instructions stored in memory (externally connected to it) and provides results as output (via I/O module externally connected to it).
    - Combines combinational and sequential logic
    - Operate on numerals and symbols represented in binary numeral systems

Before microprocessors, small computers were built using racks of circuit boards (1970’s). Even before that computers were built using vaccum tubes (1940’s).



The 1946 ENIAC computer used more than 17,000 vacuum tubes



Replica of the Atanasoff–Berry computer at Iowa State University

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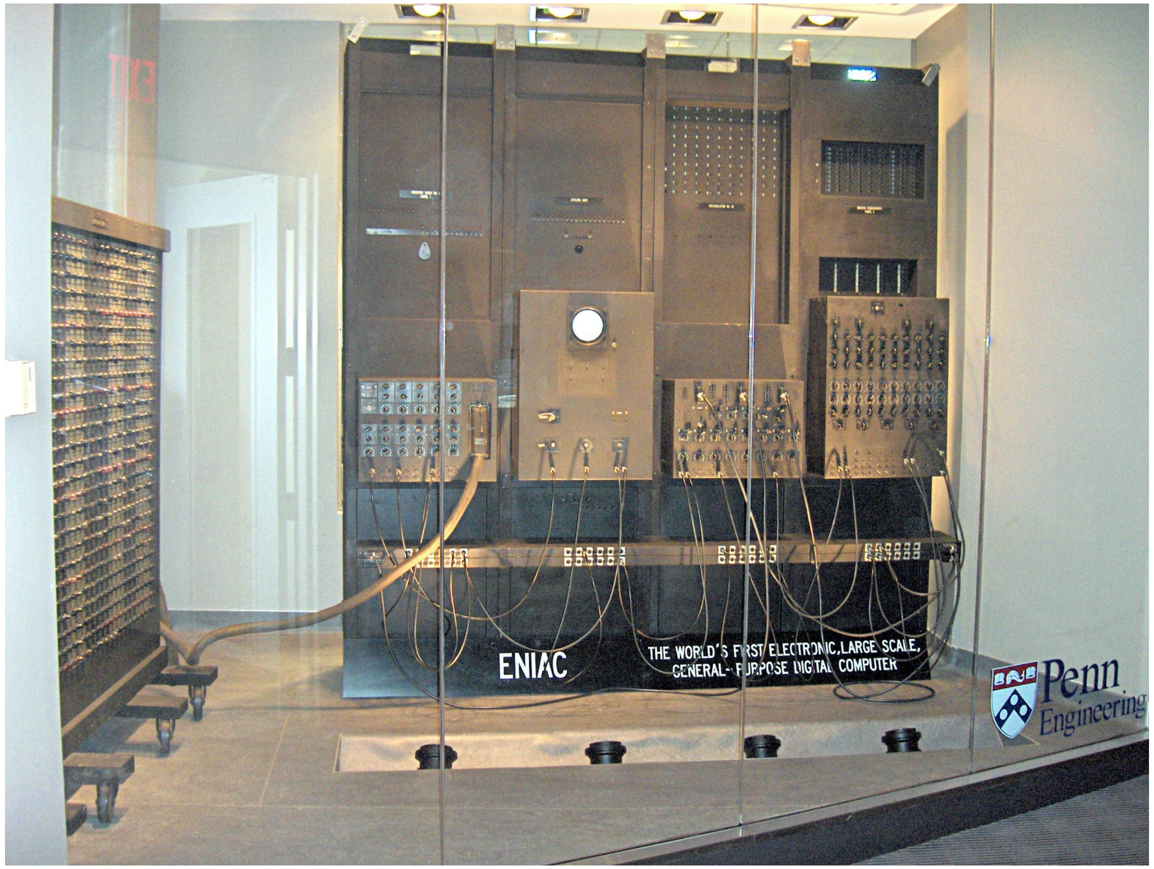
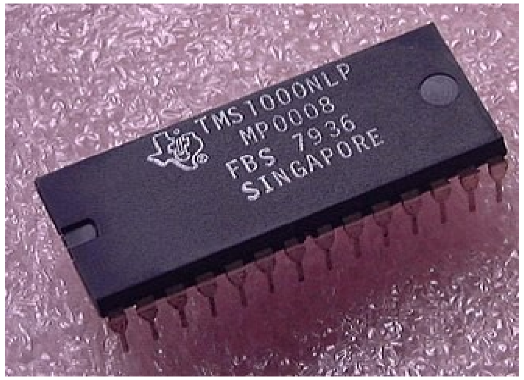
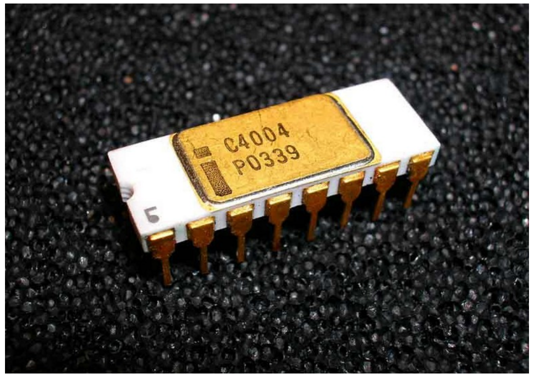
Microprocessor

- ENIAC computer

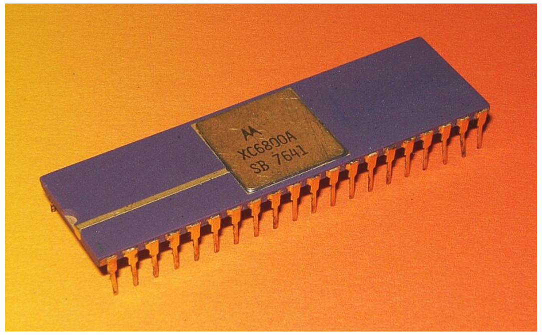


- Intels first processor



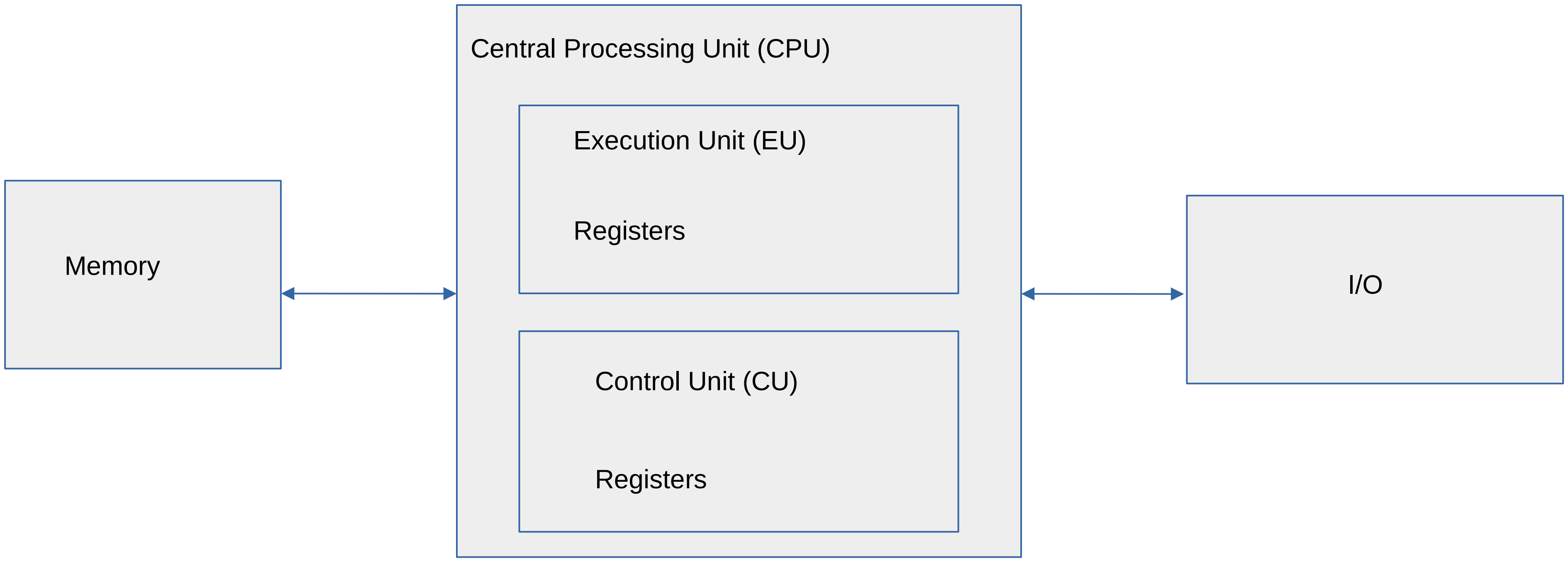


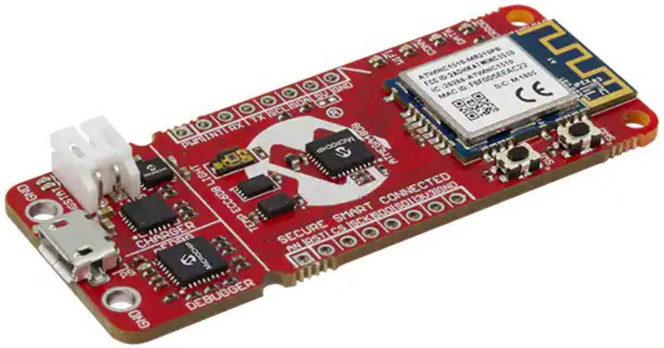
Intel’s first processor 4004!



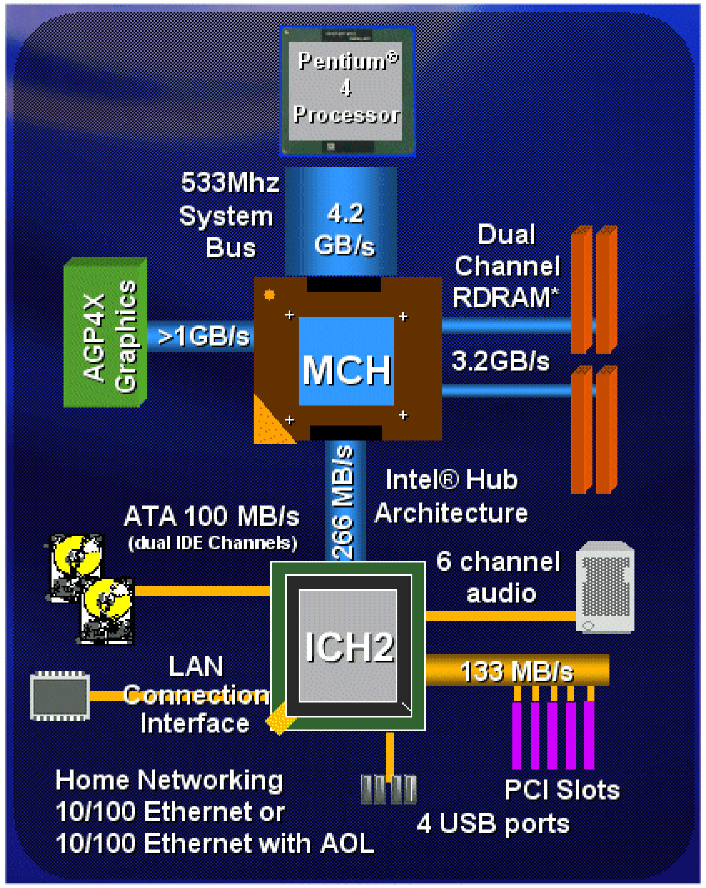
Microcomputer

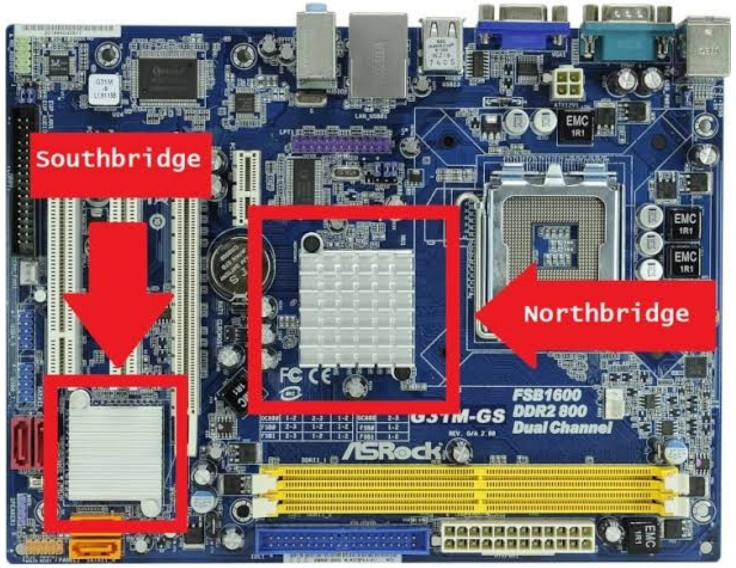
- A microcomputer is built over a microprocessor
- I/O and memory are interfaced to muP to get a working form - microcomputer





Ready to use sensor module
(AVR-IoT module)





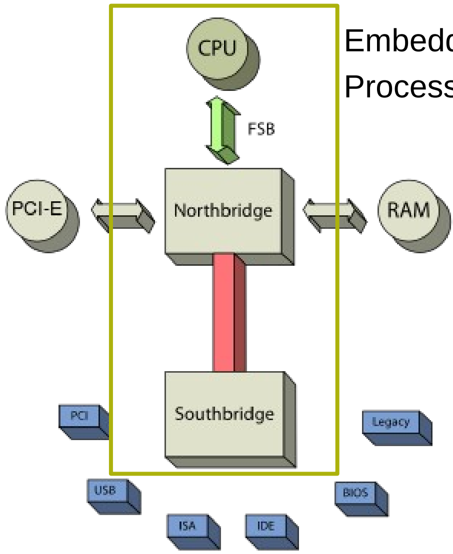
A Desktop Motherboard: Block Diagram.

MCH – Memory Controller Hub
ICH2 – I/O Controller Hub

A Pluggable Computer on
Module (CoM)

A desktop computer

Desktop motherboard



Embedded
Processor

An embedded
Motherboard (only
CPU slot with I/O

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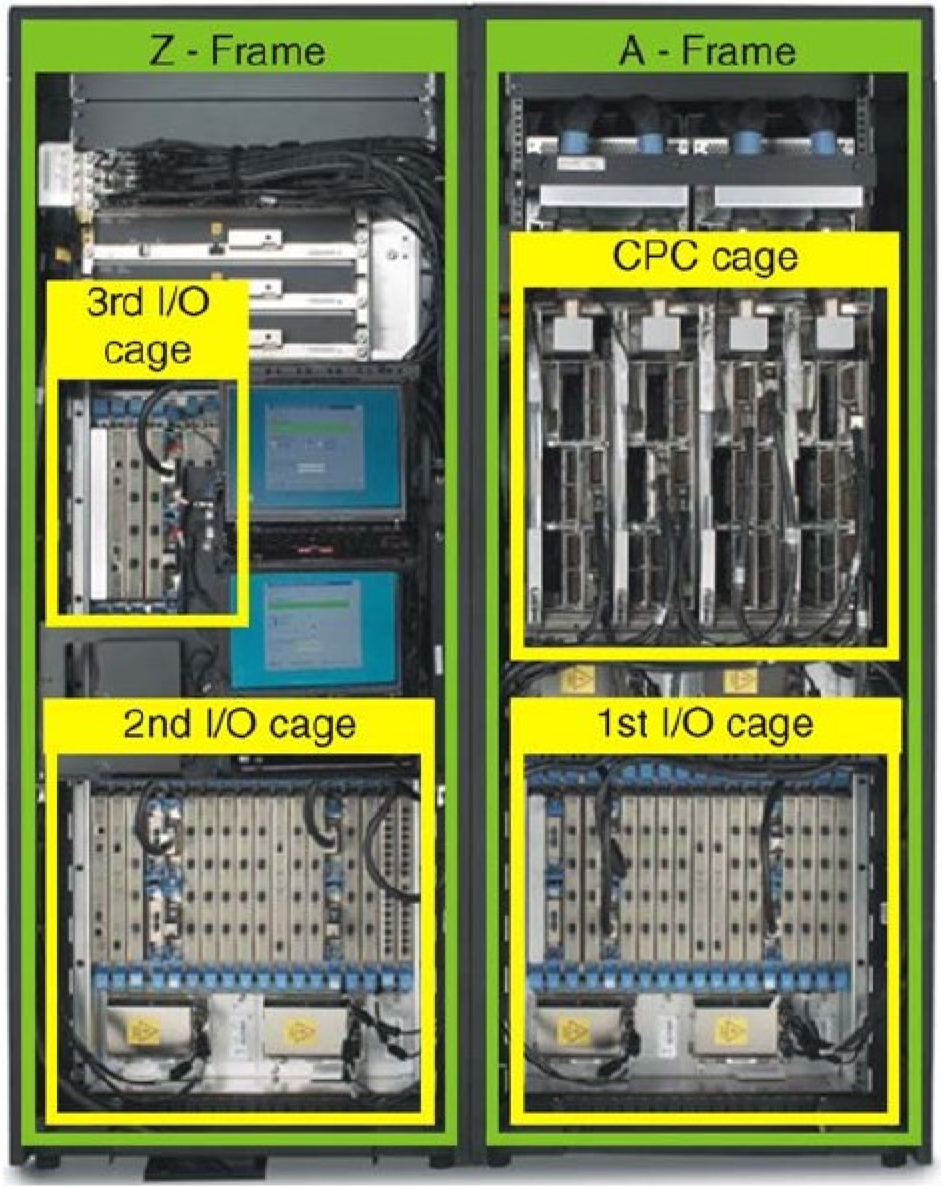
Week 1: 2^{nd} Class (30.7.24)

Super computer

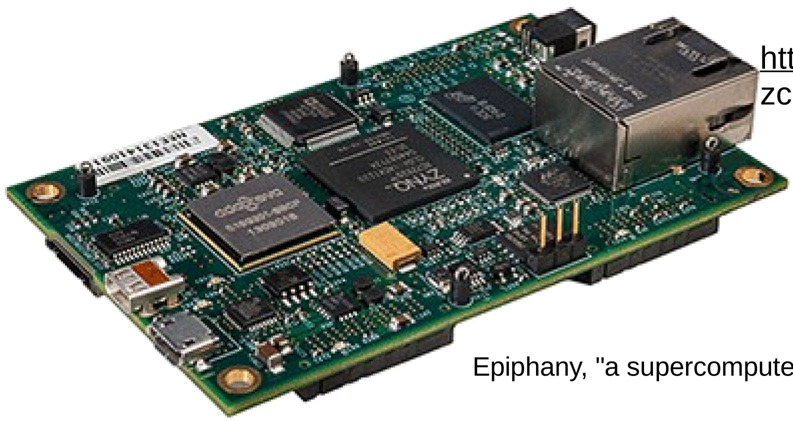
An IBM z mainframe computer



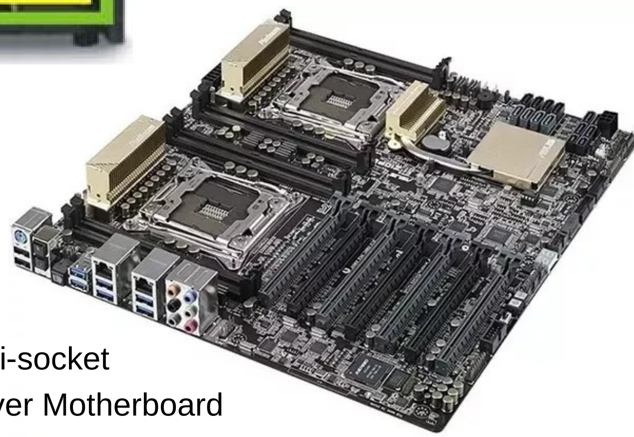
An IBM z mainframe Computer: Internals

https://www.ibm.com/docs/en/zosbasics/com.ibm.zos.zcourses/zcourses_MFHWinternals.pdf

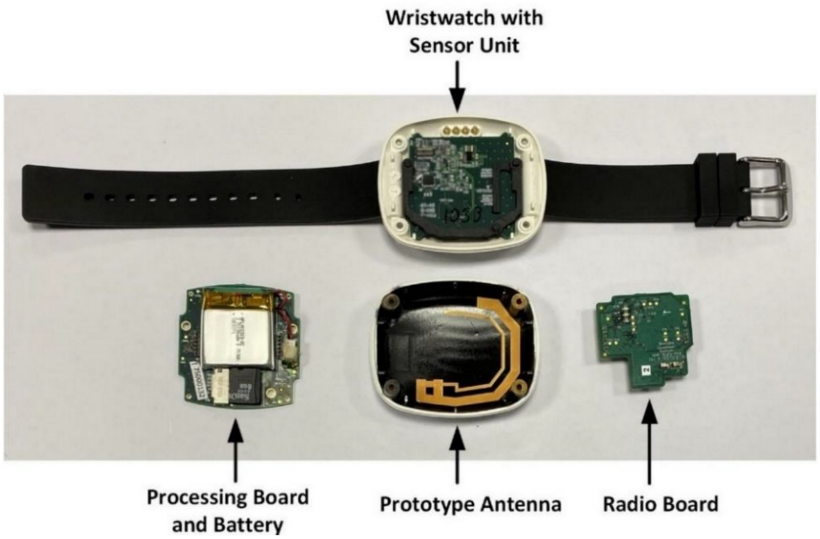
Workstation

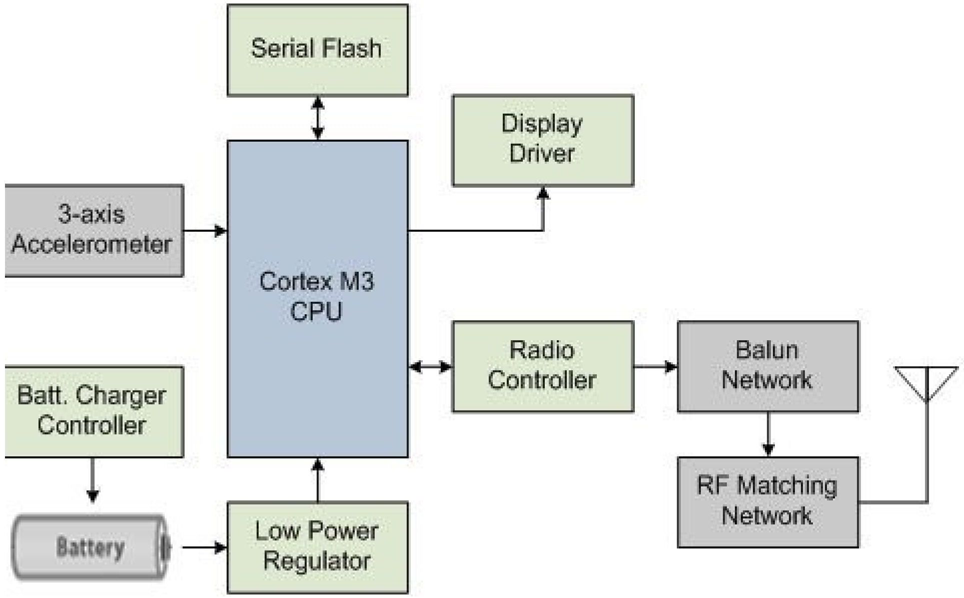


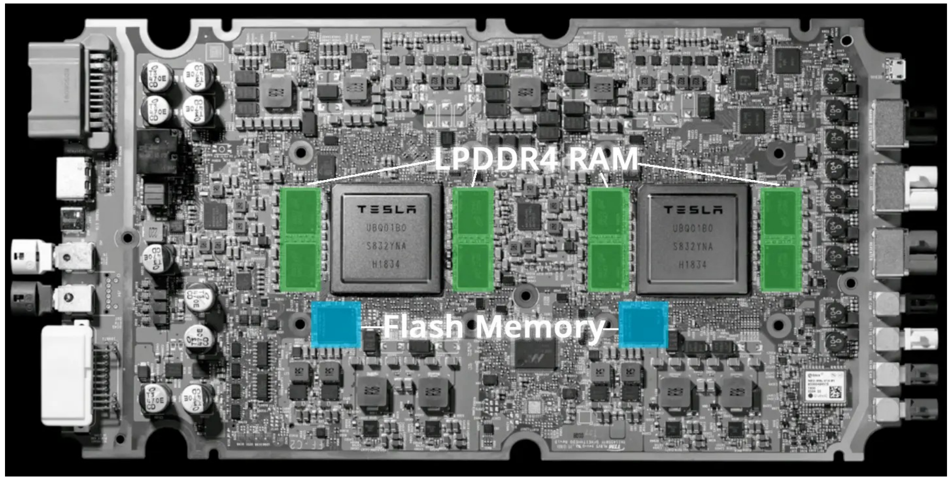
Epiphany, "a supercomputer for everyone”



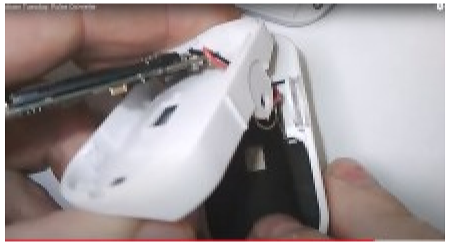
Multi-socket Server Motherboard

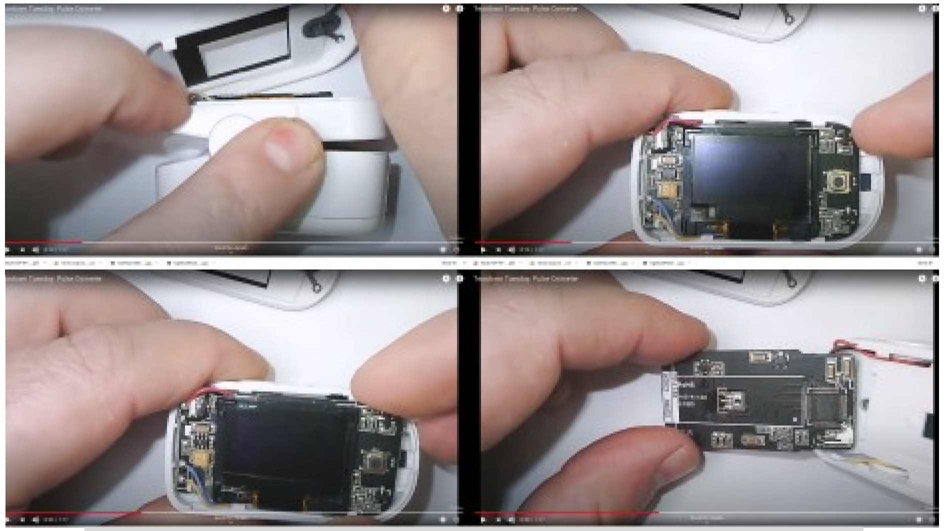




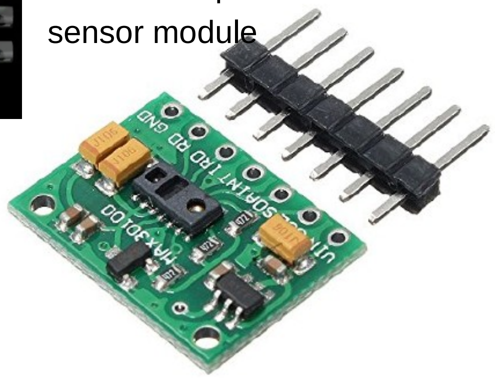


Teslas New HW3 Self-Driving Computer. Its A Beast

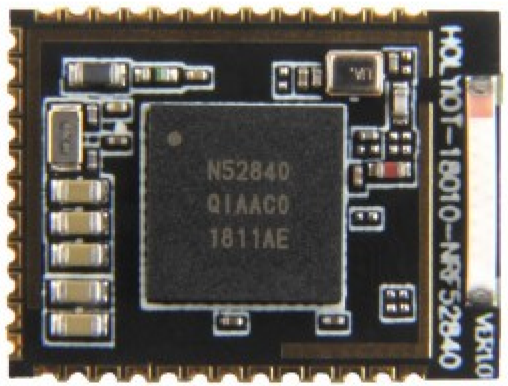


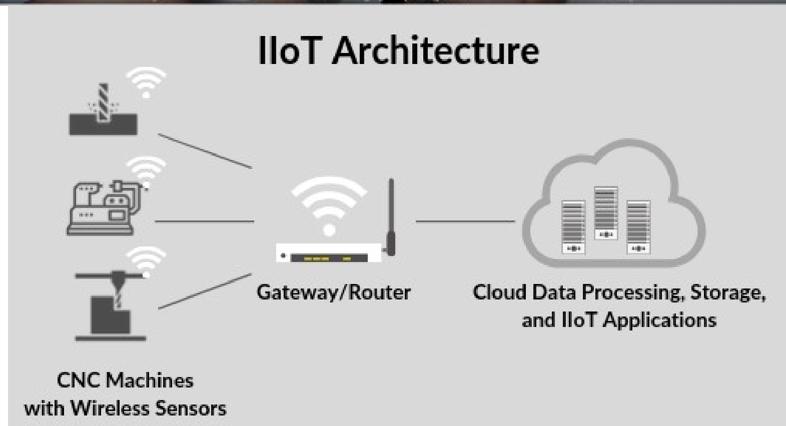


MAX30100 pulse oximeter
sensor module



nRF52840 low power
BLE module with ceramic
antenna



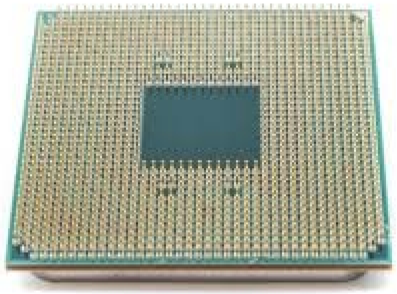


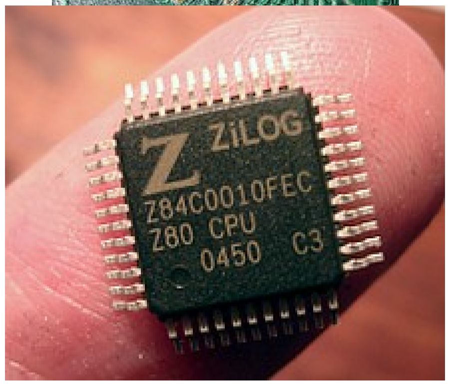
Wearable --> IoT --> Microcontroller --> Micro-computer --> workstation --> server -->
main frame computer --> super computer

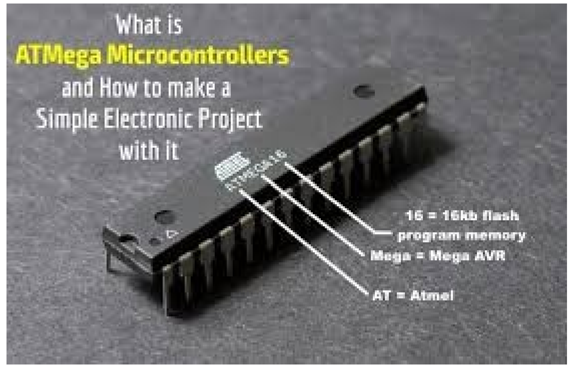
Microprocessors & Microcontrollers

- ➢ Also called CPU

Intel 4004 (1971)







Companies Manufacturing Microprocessors

Companies Manufacturing Microcontrollers

life.augmented

intel

Texas Instruments

zilog

An IXYS Company

SILICON LABS

DALLAS SEMICONDUCTOR

freescale semiconductor

RENESAS

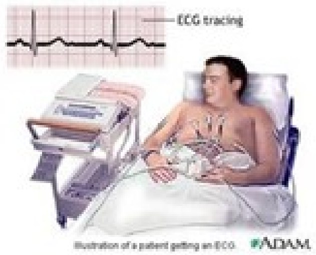
MICROCHIP

FUJITSU

Atmel

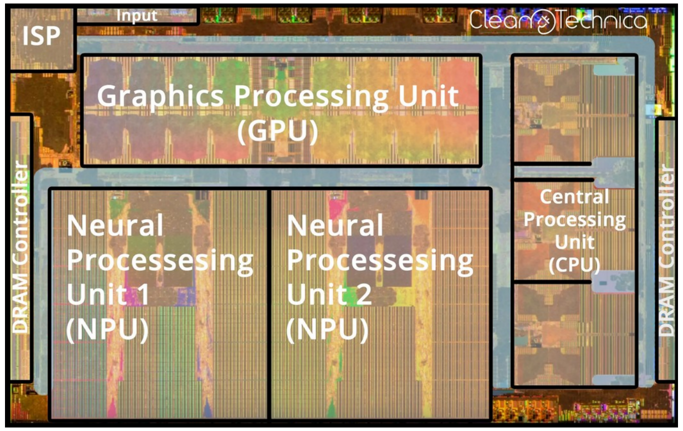
Enabling Unlimited Possibilities

Applications of Microcontrollers



Complementary CPUs (Microprocessors)

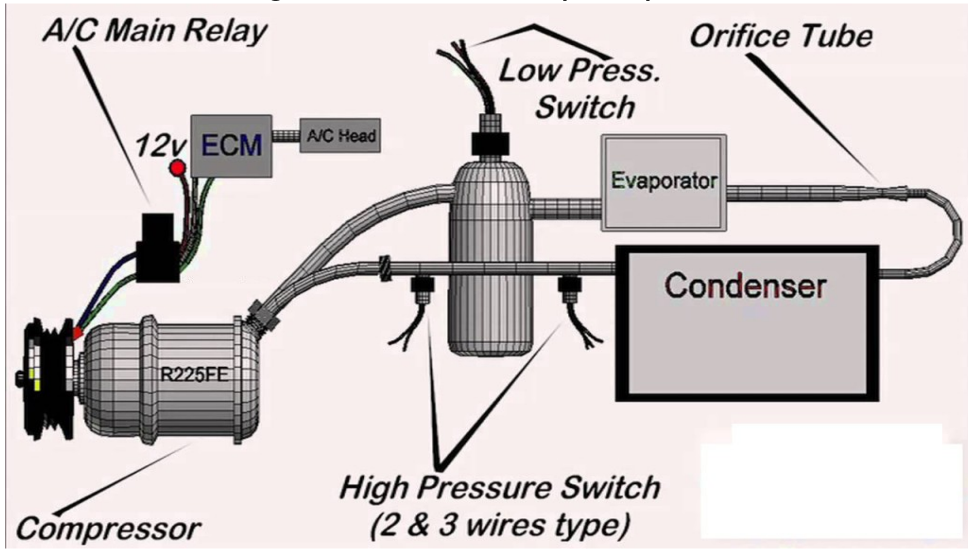
- Central Processing Unit (CPU)
  - General purpose
- Specific Processing Units
  - Graphics Processing Unit
    - Processes graphics only
  - Neural Processing Unit (NPU)
    - Machine learning processor
  - Tensor Processing Unit (TPU)
  - Floating Point computation Unit (FPU)
  - Accelerated Processing Unit (APU) – AMD
    - CPU + GPU
  - Vision Processing Unit (VPU)
    - Same as GPU ~ similar
  - Parallel Processing Unit (PPU)
  - Digital Signal Processor (DSP)
    - Hardware engines specifically do the basic signal processing routines

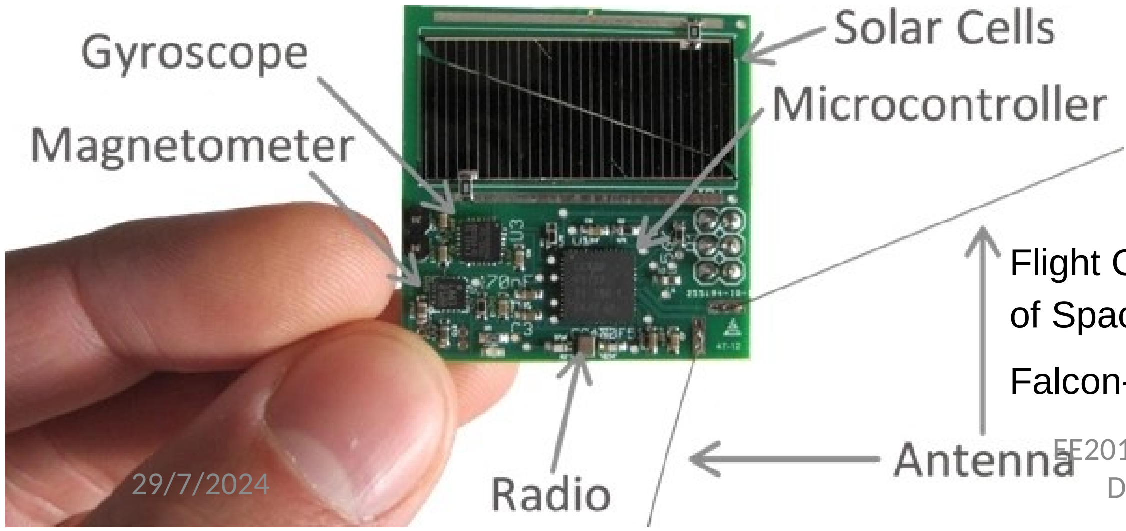


Applications of Microcontrollers

Market	Embedded Device
Automotive	Ignition system Engine control Brake system
Consumer electronics	Digital and analog televisions Set-top boxes (DVDs, VCRs, Cable boxes) Personal digital assistants (PDAs) Kitchen appliances (refrigerators, toasters, microwave ovens) Automobiles Toys/games Telephones/cell phones/pagers Cameras Global positioning systems
Industrial control	Robotics and controls systems for manufacturing Sensors
Medical	Infusion pumps Dialysis machines Prosthetic devices Cardiac monitors
Office automation	Fax machine Photocopier Printers Monitors Scanners


Tata Nano Engine Control Unit (ECU)

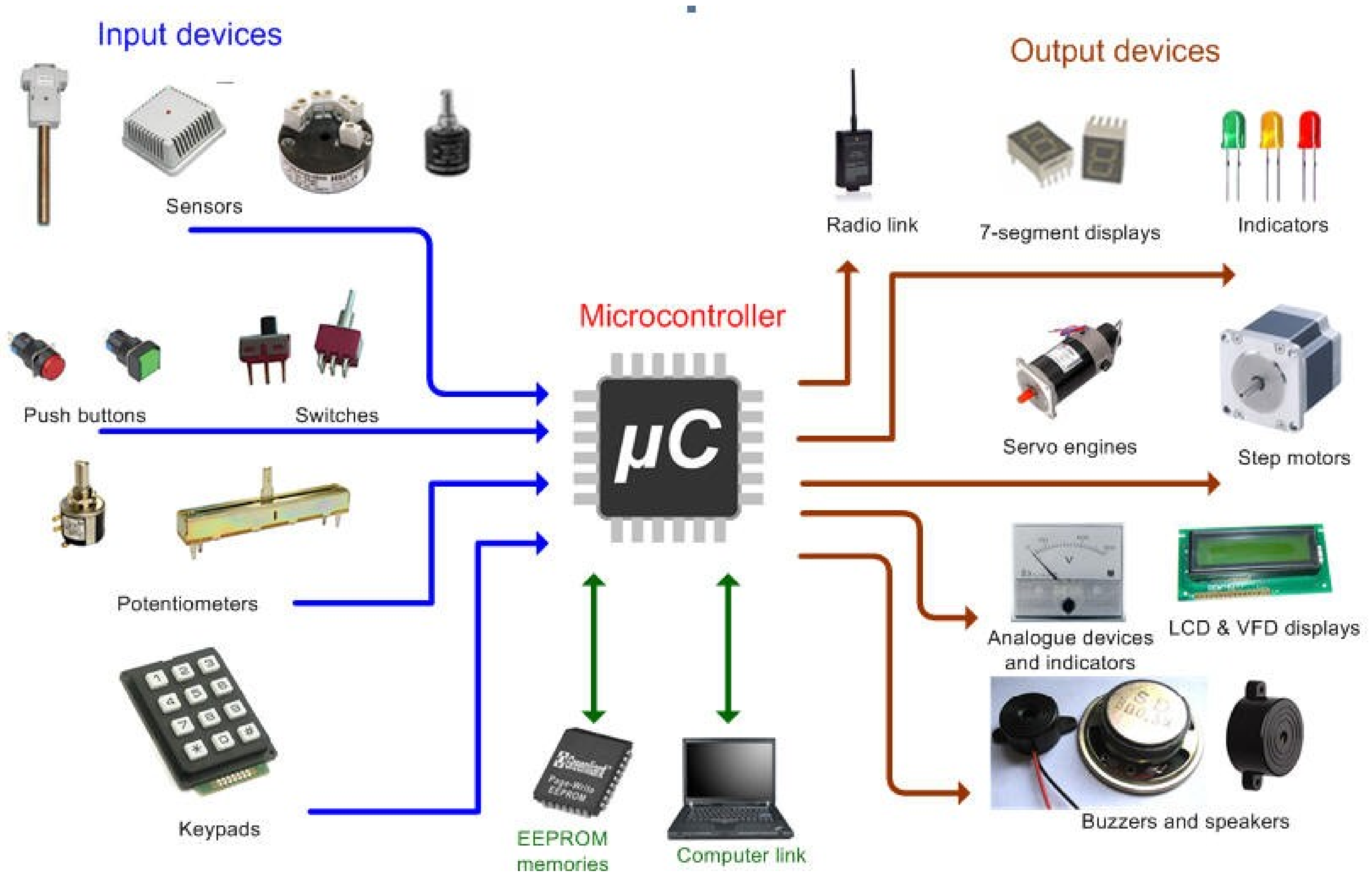




Flight Control Unit of SpaceX's

Falcon-9

Xn+1 = Xn + rho_n
s.t |Xn+1 – X0| is minimized


Input devices
Sensors
Push buttons
Switches
Potentiometers
Keypads
Microcontroller
µC
EEPROM memories
Computer link
Output devices
Radio link
7-segment displays
Indicators
Servo engines
Step motors
Analogue devices and indicators
LCD & VFD displays
Buzzers and speakers

Applications of Microcontrollers: Process the Data from Sensor Modules & control

Temperature sensor module

Vibration switch module

Hall magnetic sensor module

Key switch module

Infrared emission sensor module

Laser sensor module

Small passive buzzer module

3-color full-color LED SMD modules

Photo interrupter module

2-color LED module

Active buzzer module

Temperature sensor module

Temperature & humidity

sensor module

3-color LED module

Mercury open optical module

Photo resistor module

5V relay module

Finger measuring heartbeat module

Tilt switch module

Mini magnetic reed modules

Infrared sensor receiver module

XY-axis joystick module

Linear magnetic Hall sensors

Reed module

Flame sensor module

Magic light cup module

Temperature sensor module

5mm red and green LED (common cathode) module

Knock sensor module

Obstacle avoidance sensor module

Automatic flashing colorful LED module

Analog Hall magnetic sensor module

Metal touch sensor module

Sensitive small microphone sensor module

Sensitive Big microphone sensor module

Microcontroller Applications: Example

Remote control software program flowchart   Receiver side software program flowchart

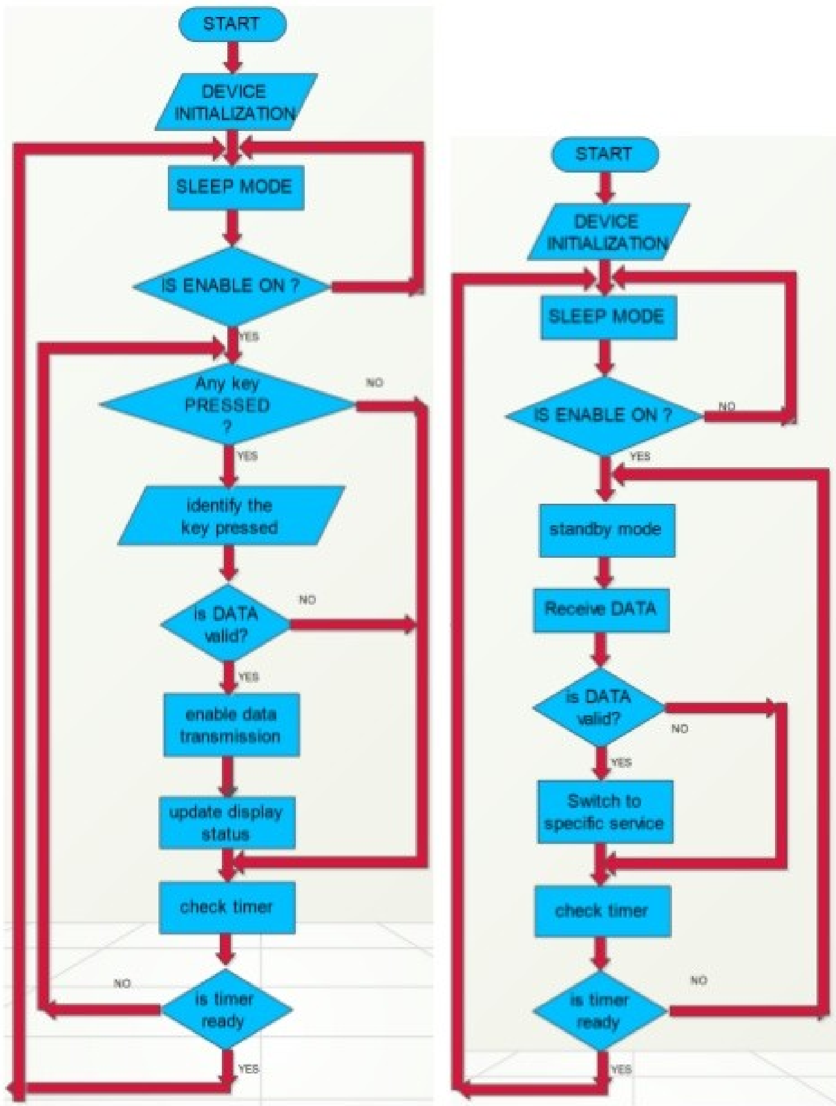
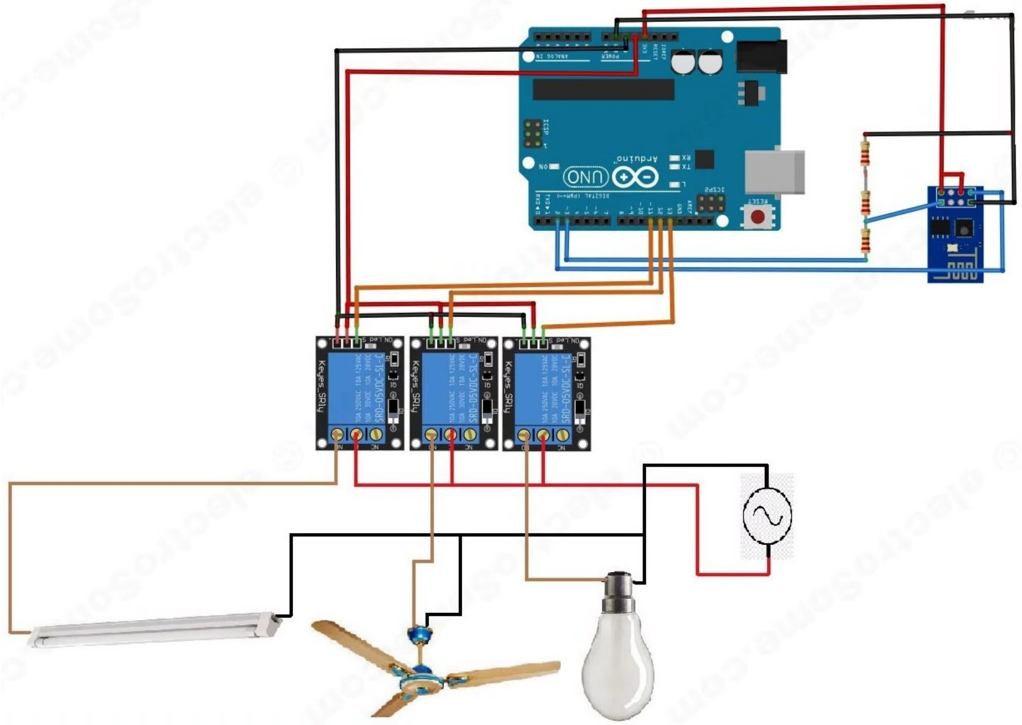
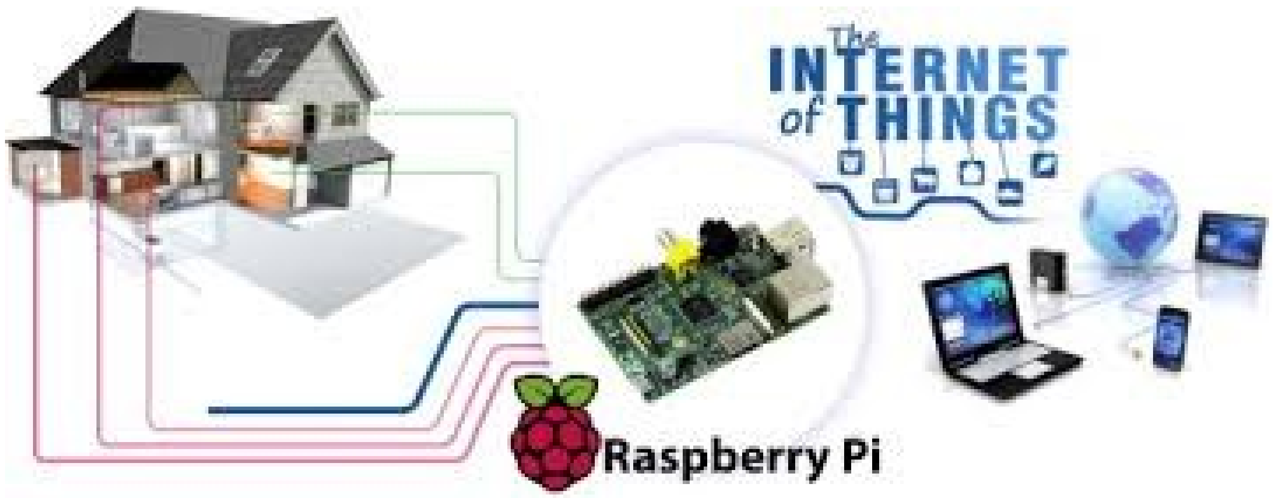


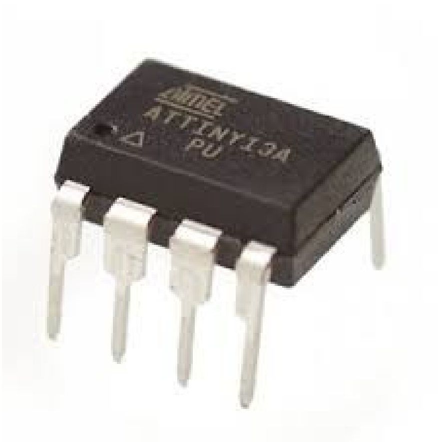
Figure 2 Flow charts for software programs for transmitter and receiver microcontrollers

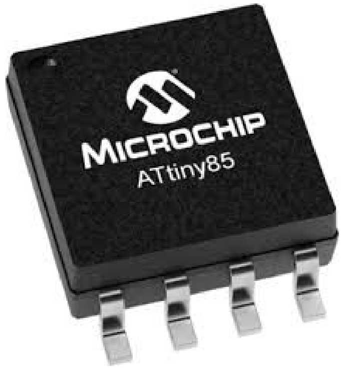
WIRELESS HOME AUTOMATION
USING PIC MICROCONTROLLER
BASED ON RF-MODULE

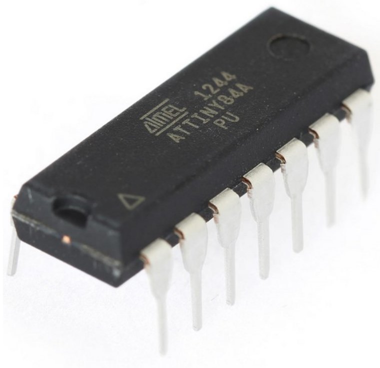


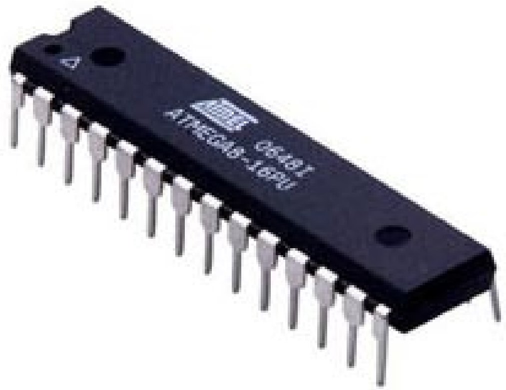


Atmel AVR Processors

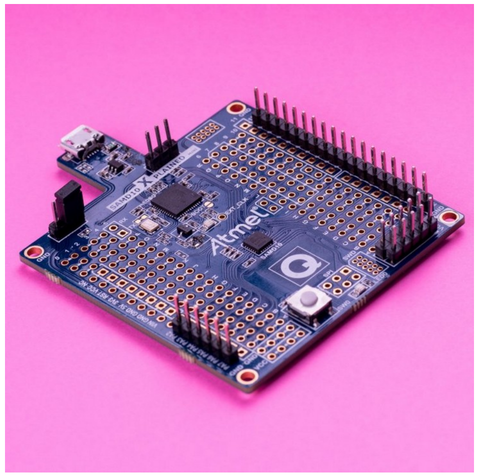


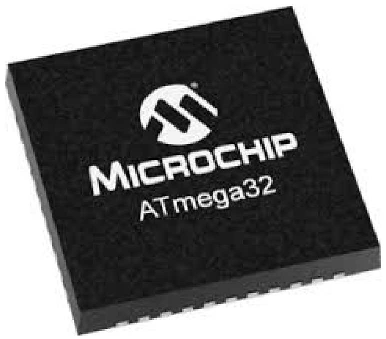






Amazing 1$ Microcontroller



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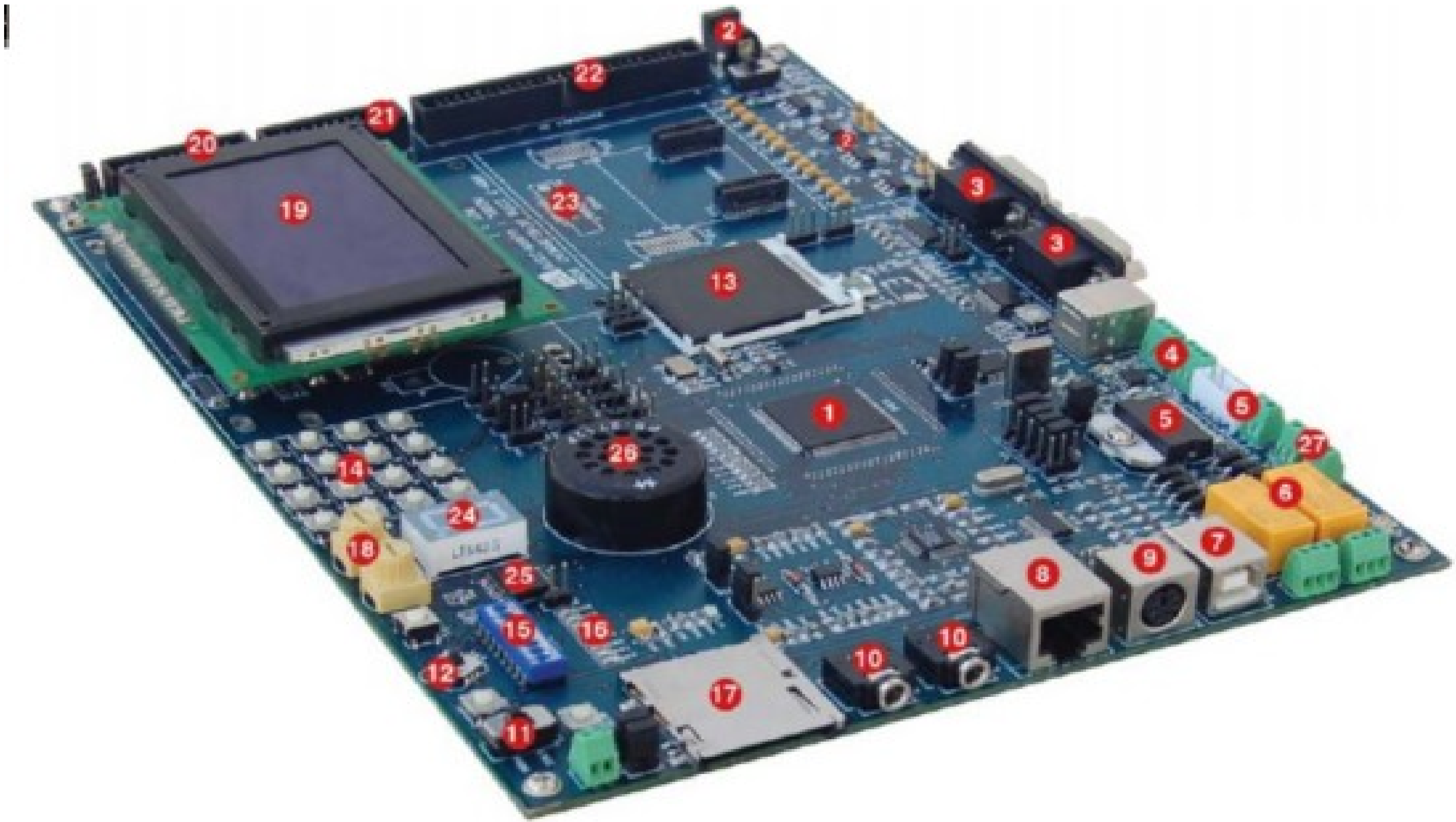
Vi Microsystem's ViARM LPC2378 Development Board

ViARM2378 ARM Development Board



In our lab ViARM2378 TFT LCD is not provided

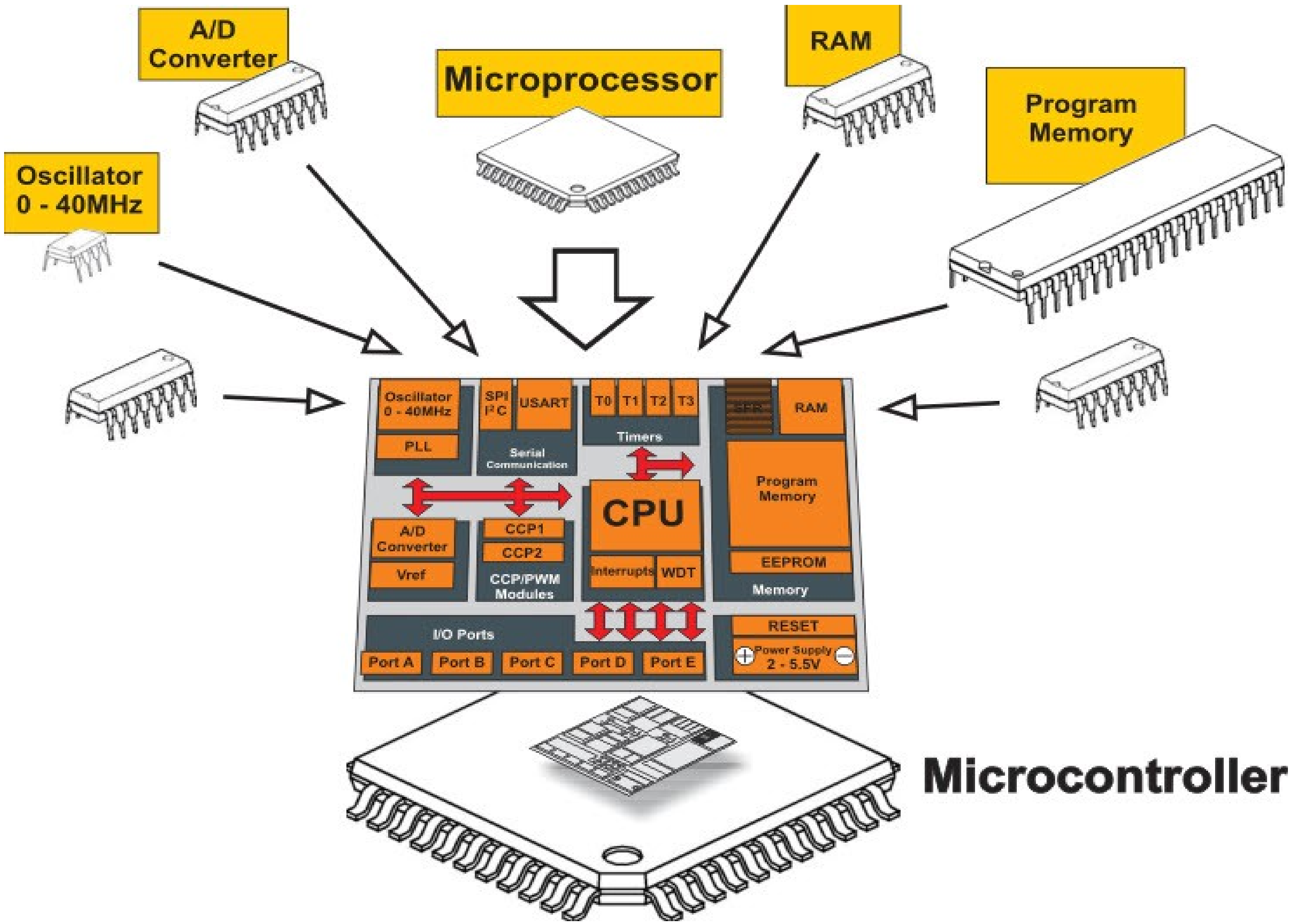
1. NXP LPC2378 Micro controller (TQFP-144 Packaging).
2. Power supply section.
3. UART.
4. CAN Port.
5. Stepper Motor.
6. Relay.
7. USB 2.0 Device Conne
8. 10/100 Base T Ethernet Connector.
9. PS2- Keyboard connector.
10. Stereo Jack for USB Audio Device.
11. Prog/Exec Switch.
12. Joystick.
13. TFT LCD.
14. 4 x 4 Matrix Keypad.
15. 8 Way DIP switch.
16. LED.
17. SD Card Socket.
18. Analog input Trimmer.
19. 128 x 64 Pixels Graphics LCD.
20. Jtag Connector.
21. ADC, DAC and PWM Expansion slot.
22. 50Pin Expansion Header.
23. J-Trace.
24. Seven Segment Display.
25. Serial EEPROM.
26. Speaker.
27. Temperature Sensor

Week 2

3rd Class (1.8.2022)

MicroController Architecture

- Microcontroller



Oscillators, RF front-end & digital Receiver, Serial communication Technologies: SPI / I2C & USART, A/D & D/A converter, I/O ports (including watch dog timer (WDT) & interrupts), Timers, Memory (RAM, EEPROM)

CCP – Capture, Compare & PWM Module

PWM – Pulse Width Modulation

Microprocessor Vs Microcontroller

- **Microprocessor**
  - Provides mainly the CPU
  - Without RAM, ROM and peripherals
  - General purpose computation: could be used for anything from simple to more memory / computationally intensive applications
  - Typically consumes more power than microcontroller – needs power outlets
- **Microcontroller**
  - A complete computer despite designed optimally for a specific task
    - This means I/O modules, RAM & ROM / EPROM are all built-in
  - Metal oxide semiconductor technology --> cheaper
  - General processing speed lower – but optimized (sometimes through hardware accelerator) for the targetted application & hence the speed is acceptable in the real-time, real-world targetted application.
  - Power consumption is lesser – often battery operated.
- **Closely related terms:**
  - Embedded processor, wearables, CoM, SoM, ASIC, SoC, FPGA etc

Microprocess versus Microcontroller

S No	Property	Microprocessor	Microcontroller
1	Hardware	Provides mainly CPU. This alone is useless.	A complete computer despite designed for specific application. Contains microprocess -or within
2	Hardware	Without RAM, ROM and peripherals	Includes RAM, ROM, I/O, peripherals like oscillator, PLL, A/D, D/A, timers & interrupts
3	Purpose	General purpose computation: If interfaced could be used for anything from simple to more memory / computationally intensive applications	Specific targetted application, by & large ONLY one program in ROM
4	Power requirements	Requires larger power. Needs power outlets. Few hundred watts	Power requirements are low: Battery operated. Milli-Watts to a watt
5	Mobility	Not mobile. Can be portable. Laptops work on battery once charged. MuPs are interfaced	Typically mobile. Battery operated – battery need not be chargeable.
6	Processing speed	Typically processing speed higher.	Typically the ‘embedded’ microprocessor speed is lower. But, the customized hardware in microcontroller makes the ‘custom task’s’, computational time less and comply to even real-time application requirements.
7	Power dissipated	Power dissipated culminates in the form of heat generated. Hence, heat sinks are required	Power dissipated is not perceivable. Hence heat sinks are not needed typically.
8	Programs	A program is edited, compiled, tested – design & development stage. Next program is taken for des -ign & development. So on ... general purpose PC	Post deployment stage (Single program – permanently burnt in ROM – No change possible till the life of the product).
9	Hardware	(Program + data) both in RAM – main memory [BIOS ROM & secondary storage are non-volatile]	ROM for program, RAM for data
10	Hardware	Van Neumann model	Harvard model

Architecture Versus Organization

- Microcomputer architecture
  - Attributes of computing system which are explicit during the logical execution of the program
  - Attributes visible to a programmer
  - Eg: multiplier instruction – MULT();
- Microcomputer organization
  - How the above (architectural) attribute / instruction is realized internally using hardware
  - Multiplier instruction realization
  - Either dedicated hardware (eg Booths algorithm)
  - Or using “Addition” hardware repeatedly

Architecture Versus Organization

- Decision based on
  - Anticipated frequency of use of the multiply instruction
  - Relative speed of two approaches (latency)
  - Cost & physical size (foot print)
- Different computer models with the same architecture (but with different organization)
  - Cost & performance (cheaper slower model, upgrade to expensive, faster models)
    - Same ISA (but, different underlying digital circuits, technology used 60 nm or 45 nm or 10 nm?)
      - » 10 nm indicates the channel width in FIN-FET CMOS technology
    - Same program (compilers, IDE, softwares are same) would work for upcoming models also
  - Models changing with changing technology
    - Slower or faster models (celeron or core i9?)

Minaturization and Moors Law

➢ Miniaturization

– Pack more transistors in the same area

– Reduce interconnect (metal) pitch and contacted gate pitch

➢ Moore’s law

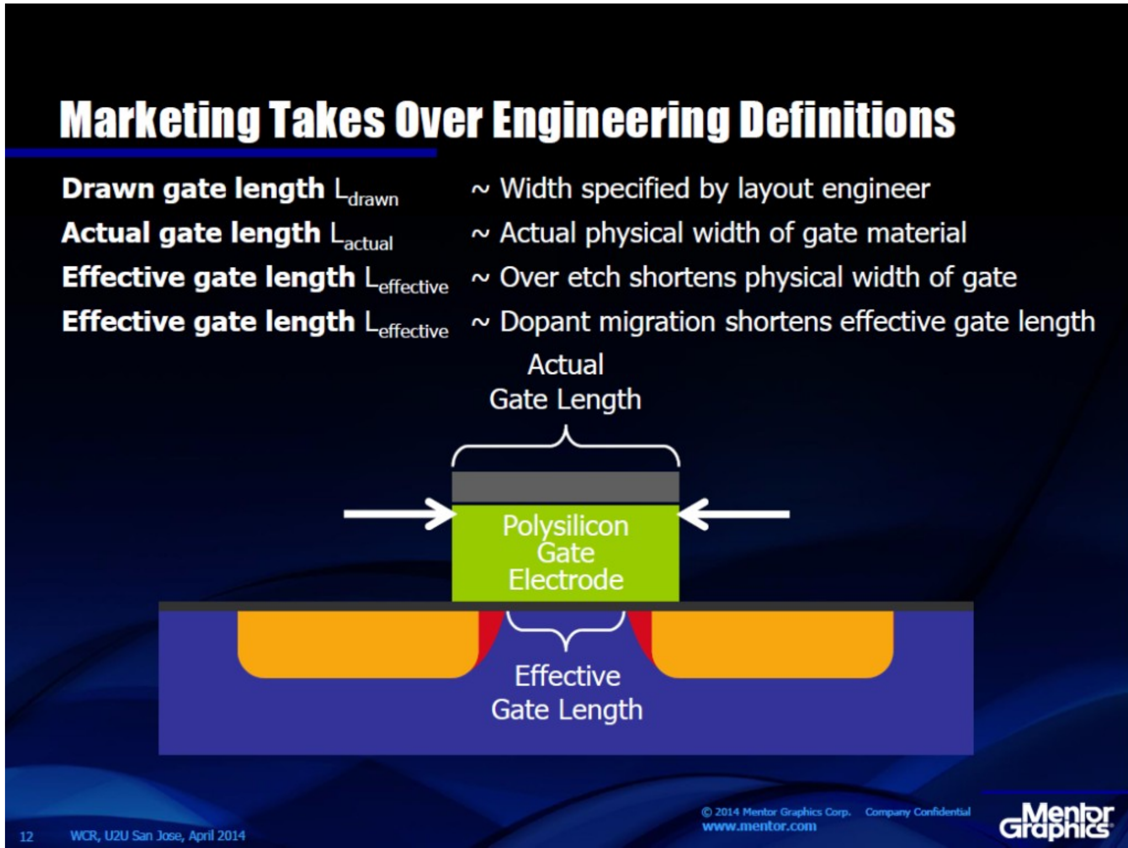
– Moore's Law states that the number of transistors on a microchip doubles every two years

➢ C-MOS Technology

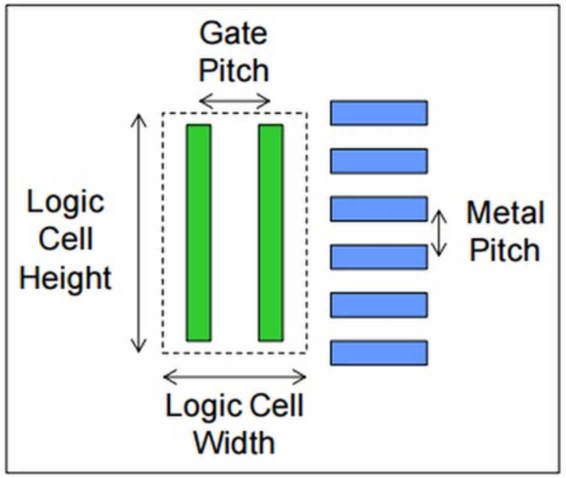
– a 5 nm node is expected to have a contacted gate pitch of 51 nanometers and a tightest metal pitch of 30 nanometers

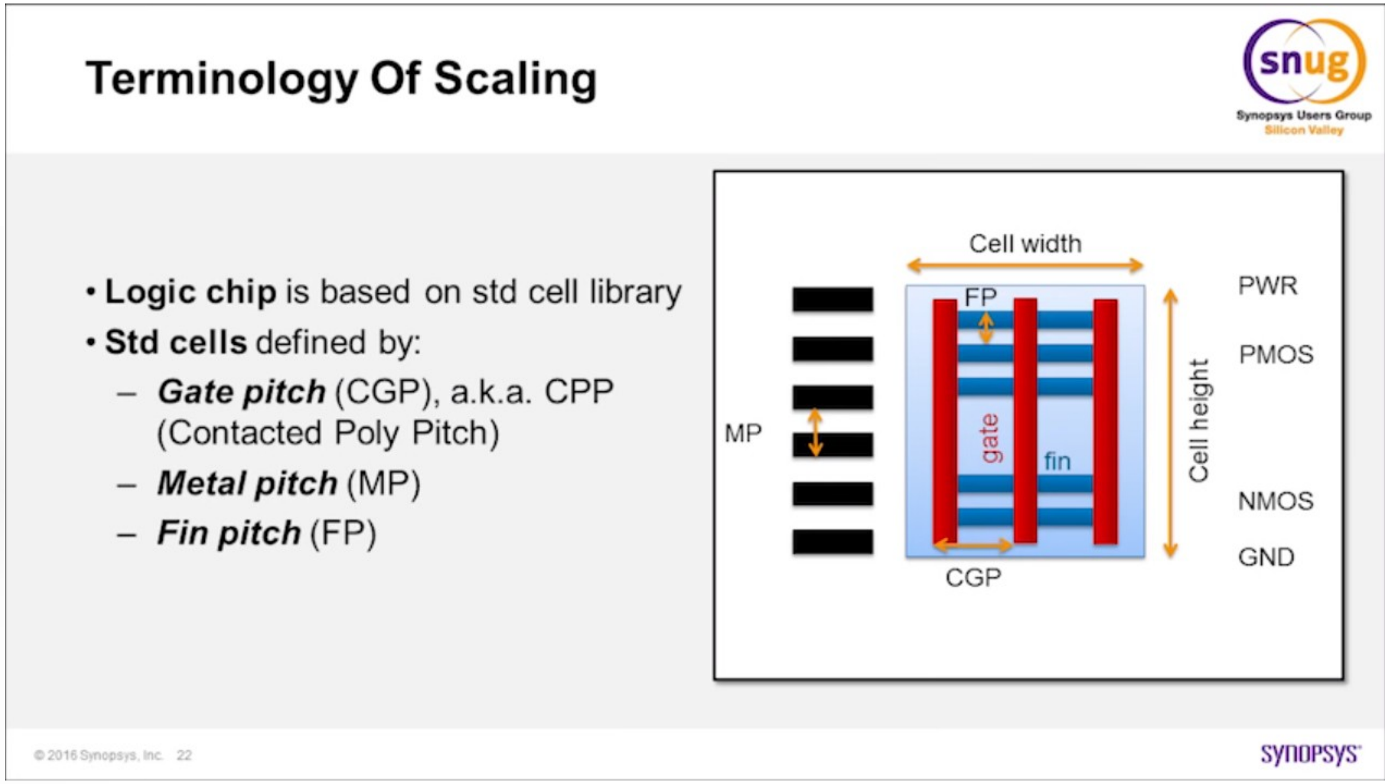
➢ Fabrication Process / Technology

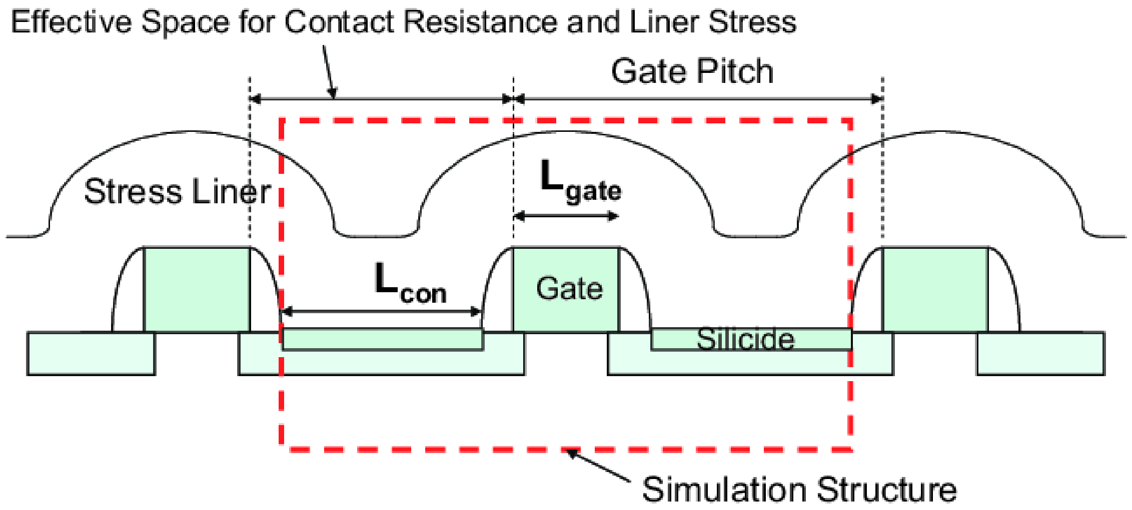
Process	Gate pitch	Metal pitch	Year
5 nm	51 nm	30 nm	2020
3 nm	48 nm	24 nm	2022
2 nm	45 nm	20 nm	2024?

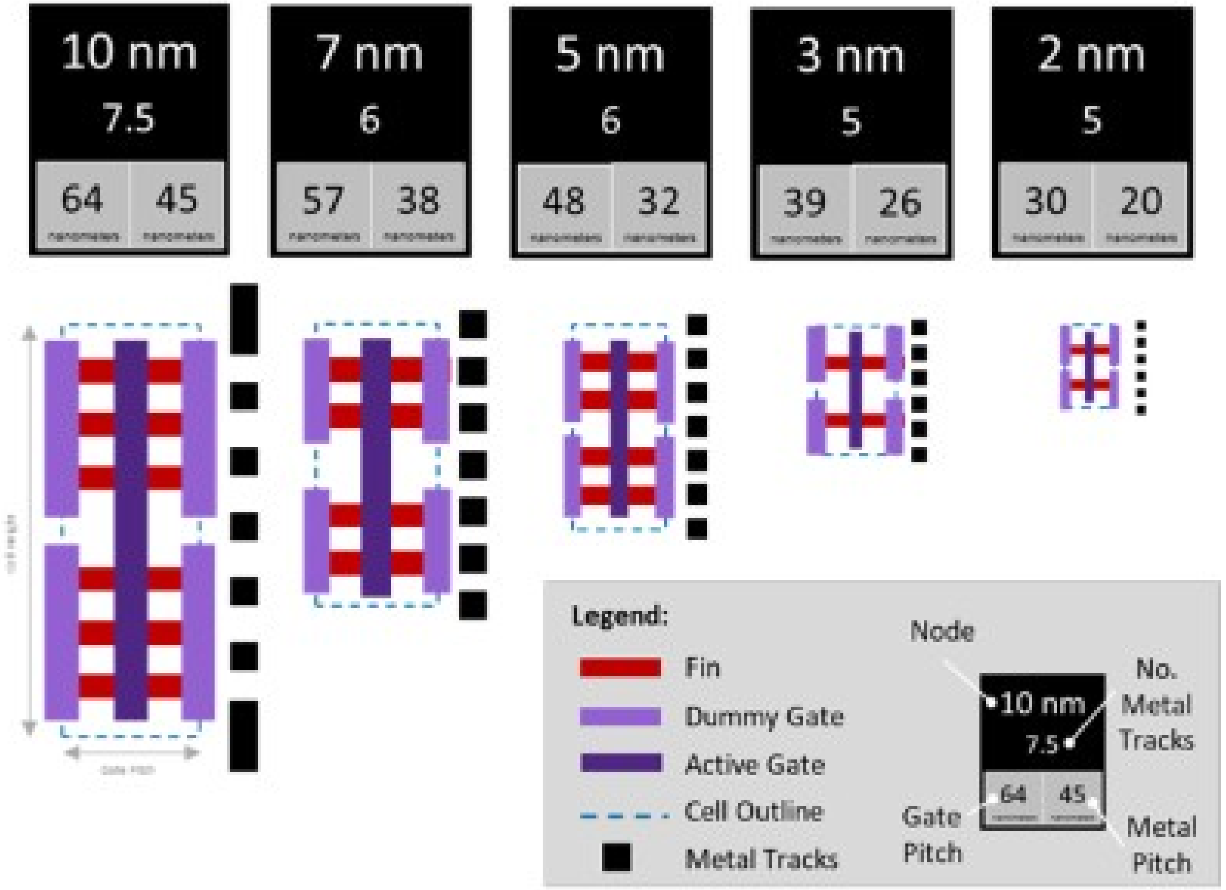


Interconnected (metal) pitch & contacted gate pitch







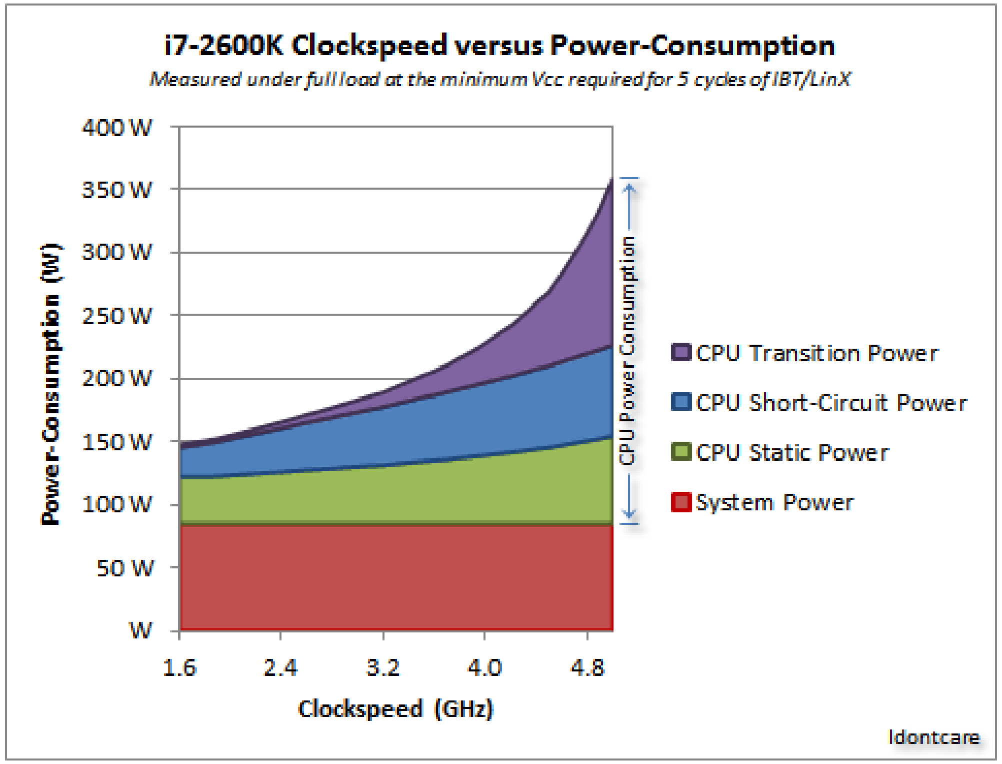


Frequency versus Power Dissipated

- Microprocessor Frequency
  - Clock speed
  - Basic (smallest) interval of time, any digital event can happen in a processor
  - More the frequency, more the operations per sec --> computational speed of processor
  - More number of switching per sec
- Microprocessor power
  - Inside LSI muP, digital (both combinational & sequential) circuitry have some capacitance
  - Reactive power increases when frequency increases
  - Ideally capacitor consumes zero real power
  - But, as frequency increases, (ac) current increases and in reality there is some real power consumed (small stray resistance in the branch of capacitance)

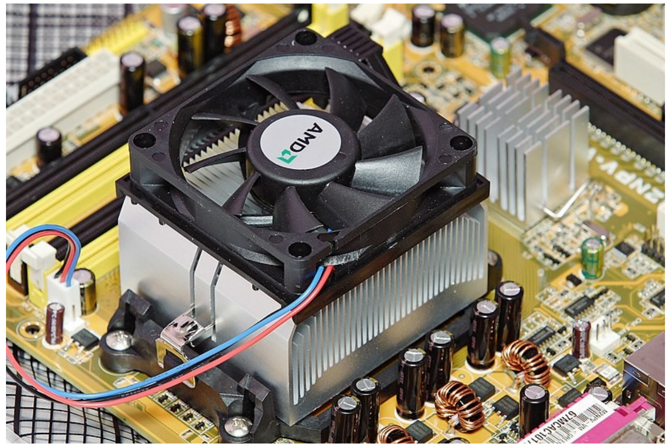
Frequency versus Power Dissipated

- Power Consumed by Capacitor
  - a practical capacitor has an imperfect dielectric,
  - a small amount of power --> dielectric loss.
  - dielectric loss is almost negligible in most electrostatic capacitors.
  - In electrolytic capacitors, the dielectric loss can go from a low if 1.6 % to as high as 15 % of its reactive power for different types.
  - Stray resistance adds to real power dissipated



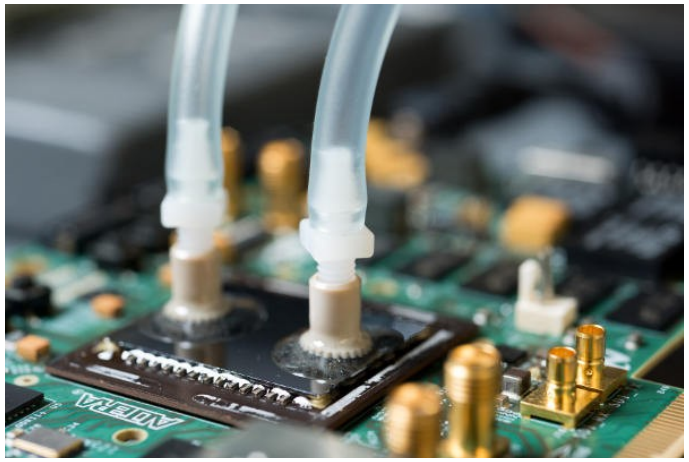
- Power dissipated --> heat generated
  - Dielectric loss + I^2 R loss --> heat

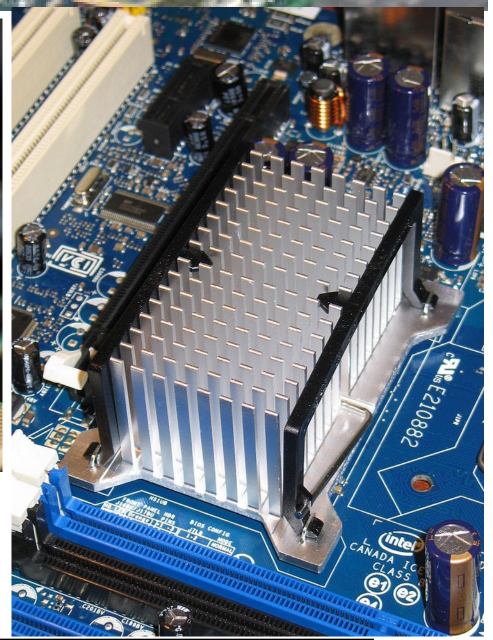
Frequency versus Power Consumed



- Heat is generated
  - If not thrown away
    - temperature rises
    - --> component misbehaves
    - --> leads to glitch
      - o/p --> garbage

- Heat dissipating mechanisms
  - Fan
  - Al sink
  - Water cooling
  - Mineral oil immersion
    - Thermally conductive, but not electrically conductive





Classification by Model for Microcomputer

- Classification by Instruction Set Architecture (ISA)
  - Complex Instruction Set Computer (CISC) or Reduced Instruction Set Computer (RISC)
- Classification by microcomputer model
  - Van Neumann Model
  - Harvard Model

Microprocessor Vs Microcontroller

- Atmel Atmega8 is a microcontroller while ARM is a microprocessor
- ARM is a microprocessor architectural design
  - (not a physical processor, its called core) which ARM holdings inc, gives licence to others.
  - Manufacturer could fabricate either a microprocessor or microcontroller.
- Main Organizational (Hardware) Difference
  - Microcontrollers are based on Harvard model where program memory and data memory are separate.
    - Programs are stored in program memory in ROM and for throughout the life of the equipment / embedded system it is undisturbed (eg, ECU in a car), while RAM is used to store the data (eg. speed of car, temperature of running engine, coolant temperature, RPM, etc).
  - While general purpose PC (with separate microprocessor chip) are based on Von Neumann model where program and data are stored in same memory module.
    - This is developmental phase or general application wherein the program itself is continuously edited which requires RAM (volatile)
      - » may be a softcopy is stored in the secondary memory (HDD - non-volatile)