Budapest University of Technology and Economics
Faculty of Transportation Engineering and Vehicle Engineering
Department of Control for Transportation and Vehicle Systems

I + C Technologies
Embedded Systems

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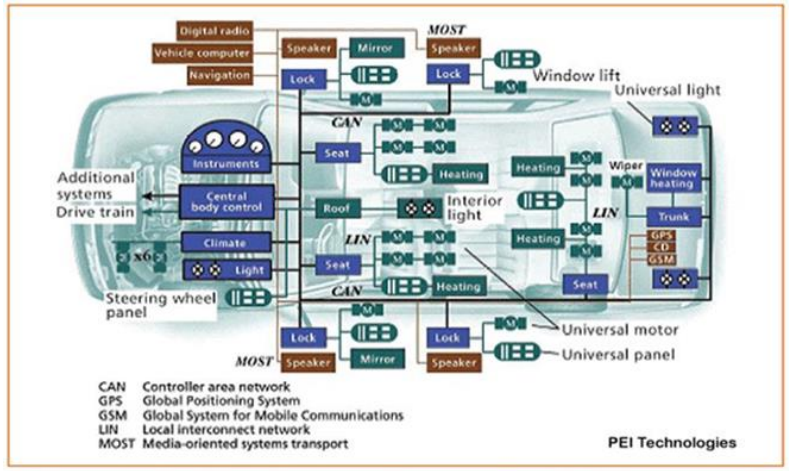
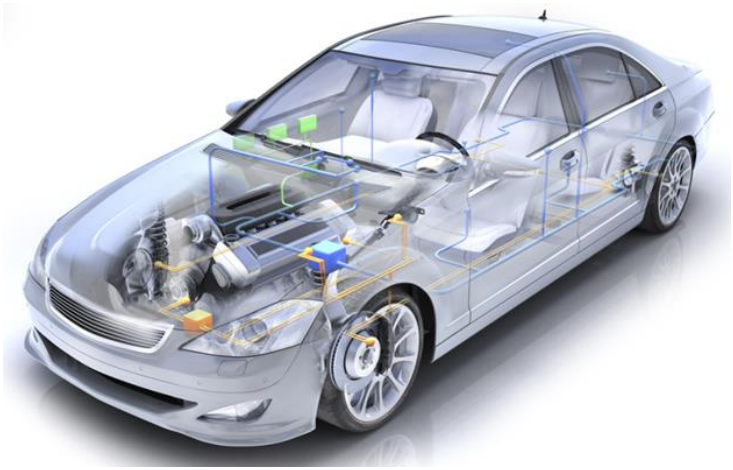
General Introduction

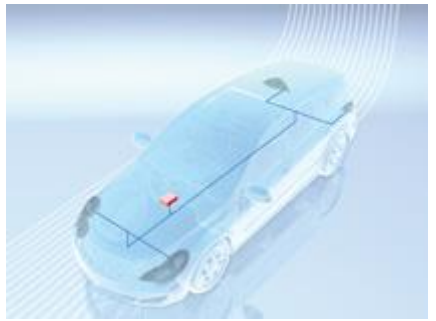
- Embedded System: An embedded system is a computer system with a **dedicated function.**
  - traffic lights and measuring systems (road traffic);
  - railway interlocking systems, train controlling systems, controlling units of trains;
  - flight control units of aircrafts;
  - industrial process control;
  - vehicle systems;
  - etc…



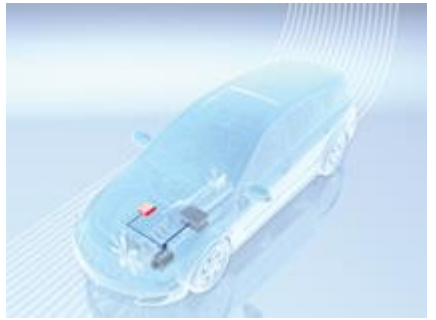


General Introduction

- ratio of electronic parts in a car: about 25%,
  - e.g. in a high level car, the average number of electronic control units (ECU) is 80;
  - e.g. in a modern aircraft more, than 700 ECUs are working in the same time;
- generally the ECUs constitute networks.



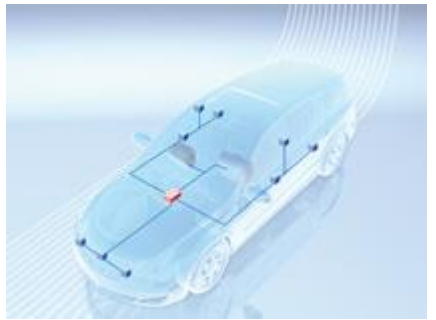
intelligent lighting



engine control

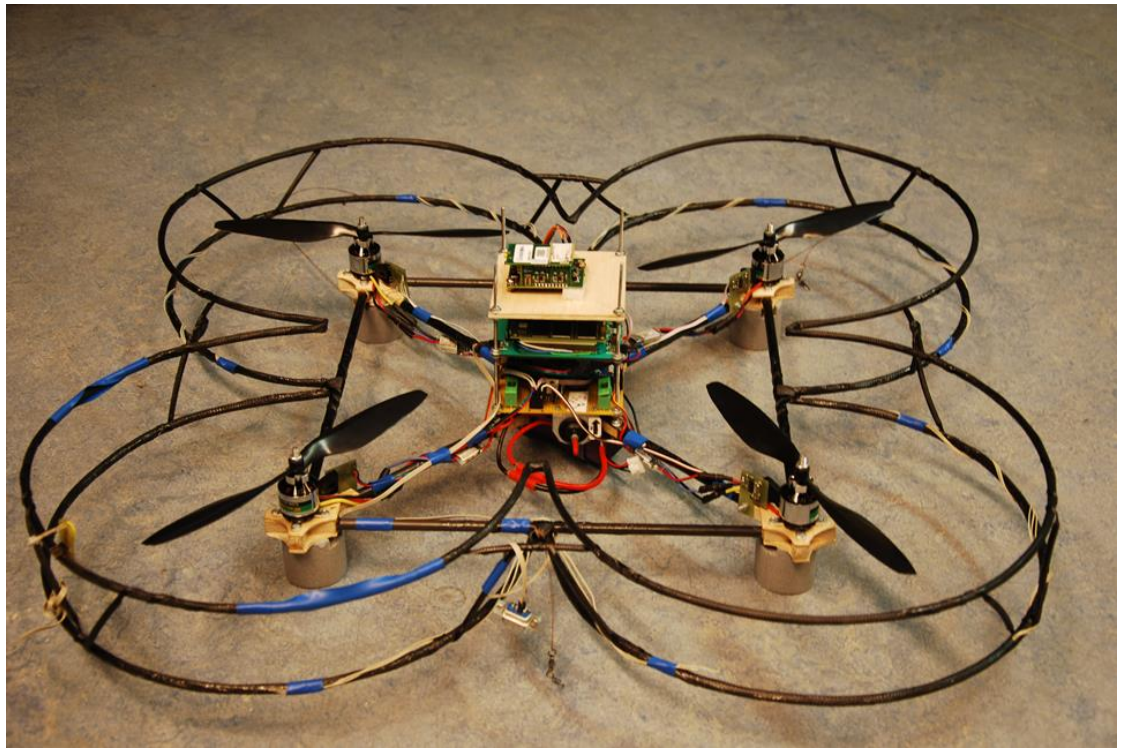
automotive sensors

safety



General Introduction

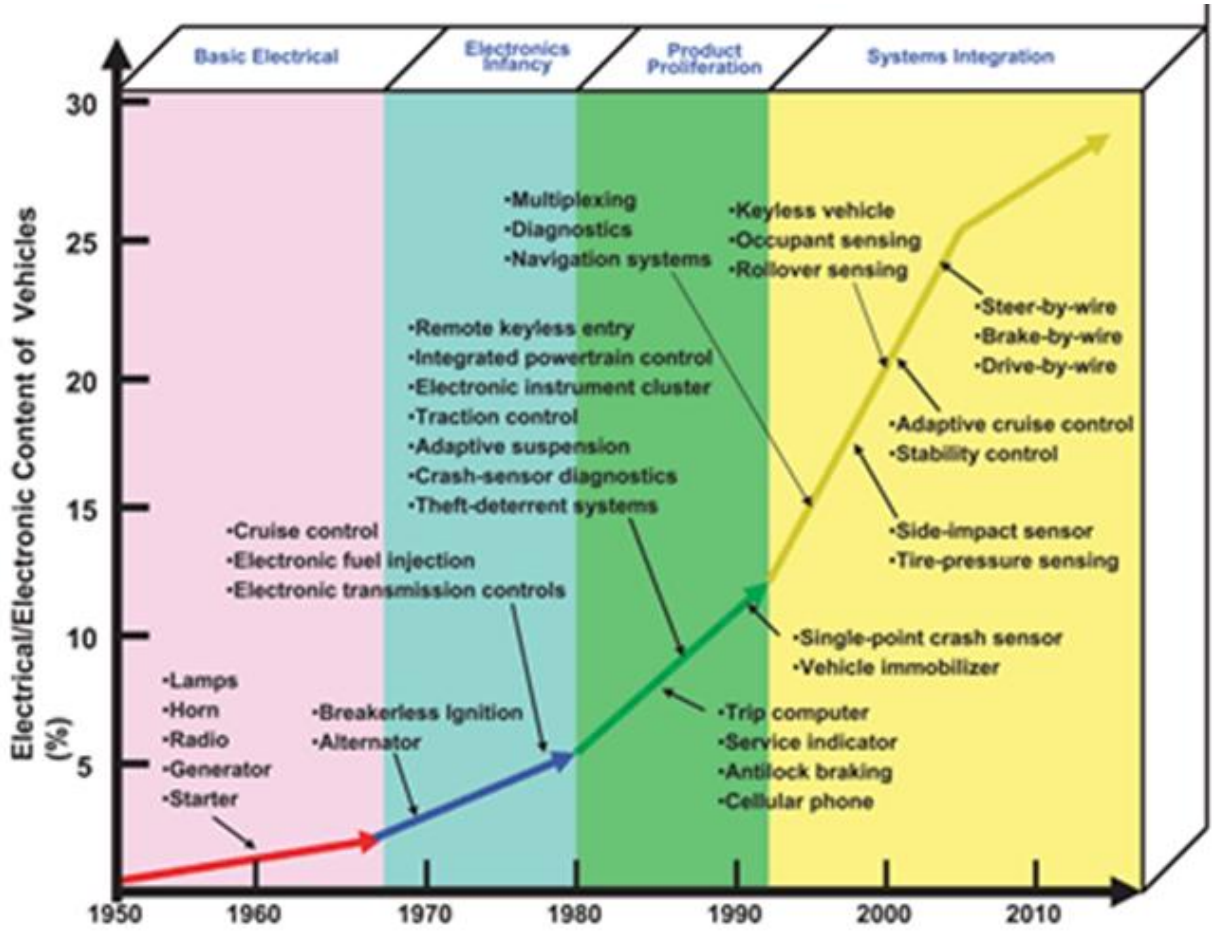
CAN controlling system
- Freescale MC9S12XDT512



UAV – unmanned aerial vehicle

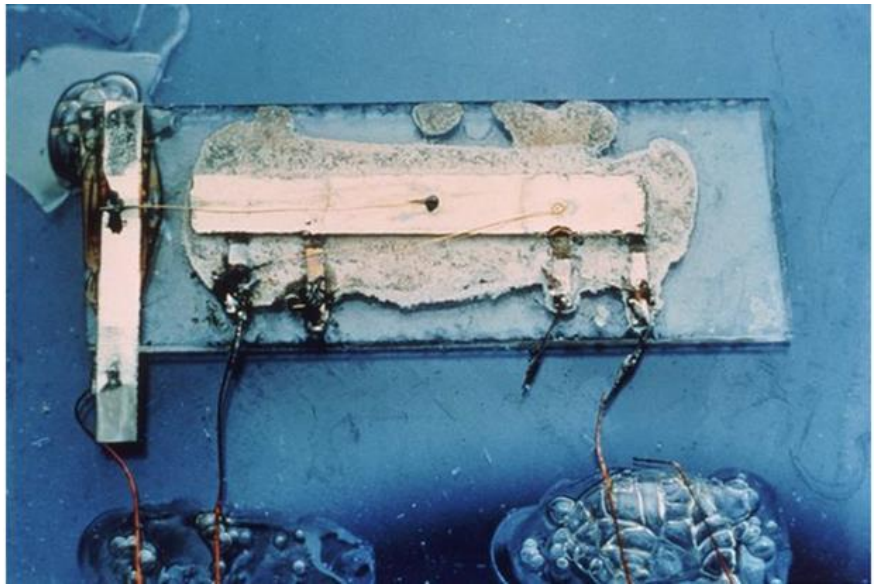
General Introduction

- The first microprocessor controllers have appeared at the end of 1970.
- In 2000: ~15 processors in an average vehicle.
- In 2010: ~60 processors in an average vehicle.



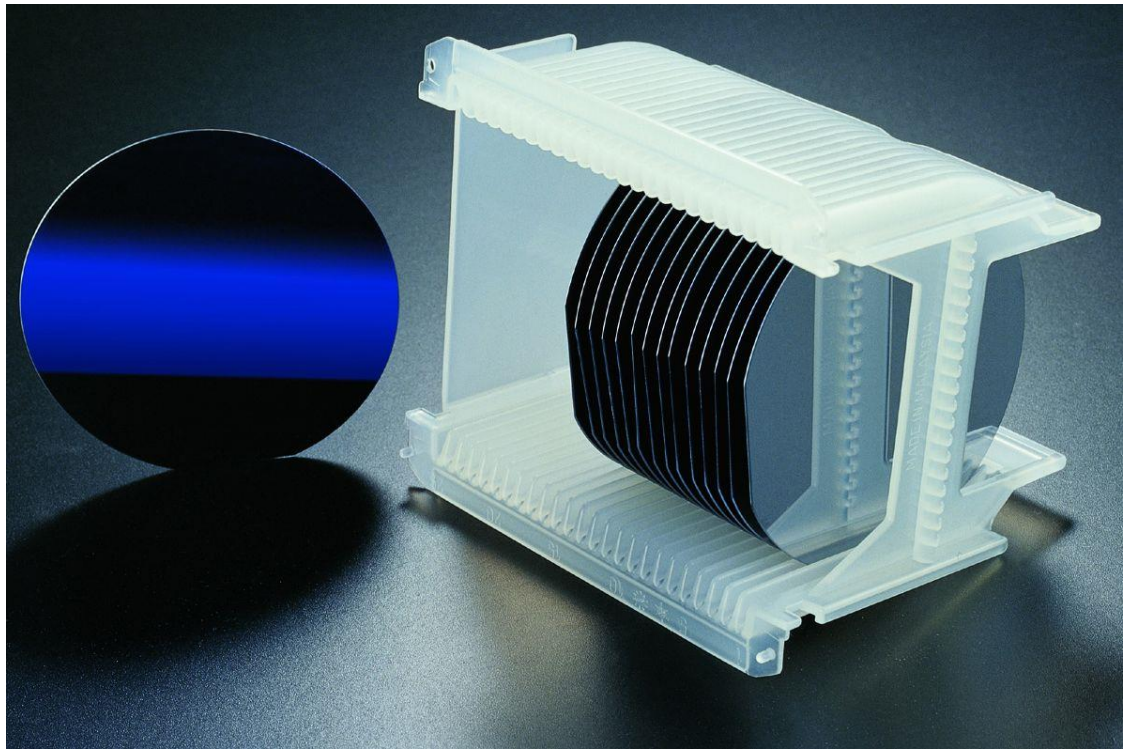
IC – Integrated Circuit – Technology

- Integrated Circuit: An integrated circuit (IC, a chip, or a microchip) is a set of electronic circuits on one small flat piece (or "chip") of semiconductor material, normally silicon.
- First IC had created by Jack Kilby – researcher of Texas Instruments - in 1958.
- Basic elements of ICs:
  - resistor,
  - capacitor,
  - diode,
  - transistor.

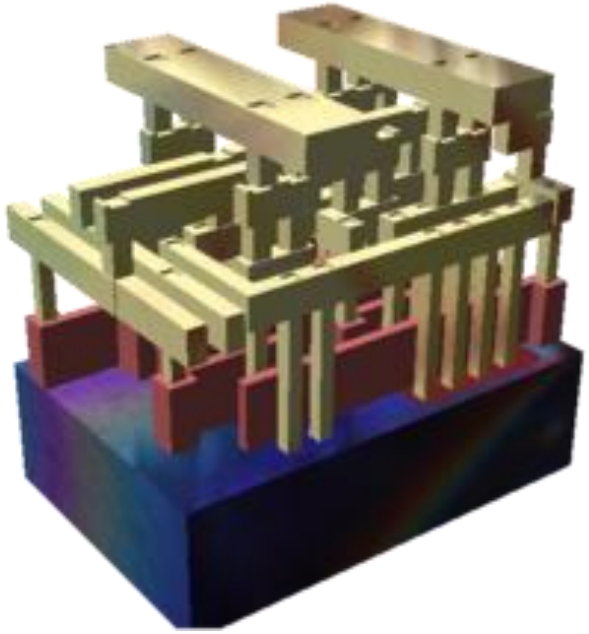


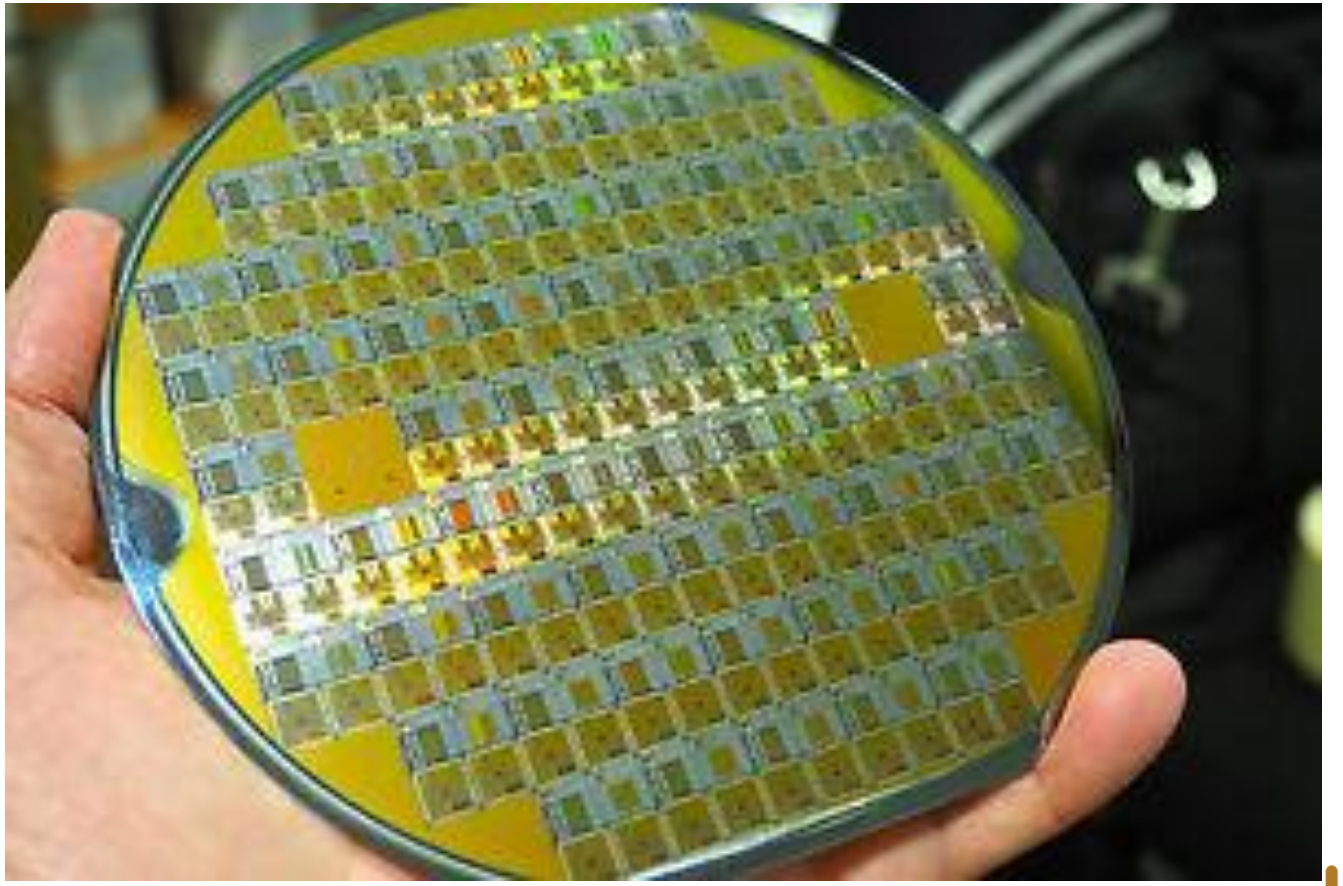
IC – Integrated Circuit – Technology

- Digital integrated circuits can contain anywhere from one to billions of logic gates, flip-flops, multiplexers, and other circuits in a few square millimeters.
- Planar process (several times in a row), from slices of a silicon single crystal rod, called wafer:
  - creation of a layer,
  - lithography,
  - doping.



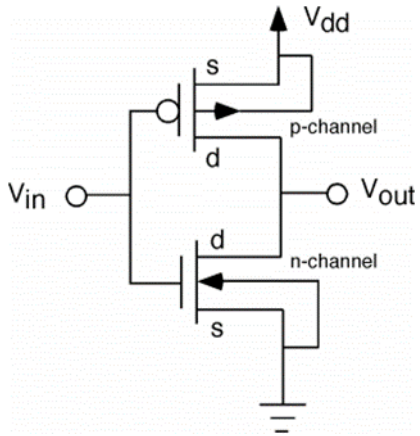
IC – Integrated Circuit – Technology

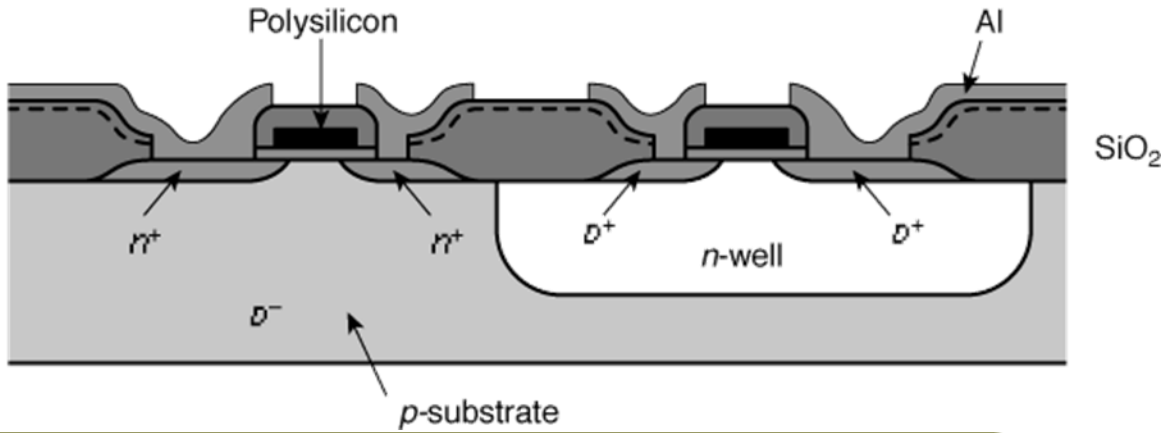




IC – Integrated Circuit – Technology

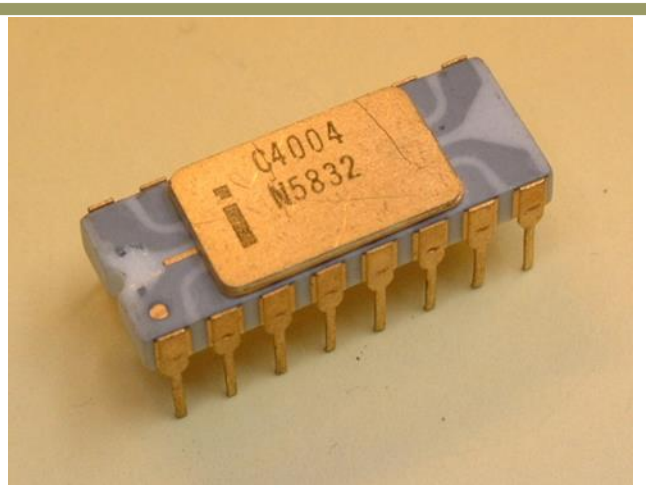
- CMOS type inverter:
  - p and n type layers by masks – these are the layers of the source and the drain of the transistors, with aluminum outlet,
  - gate of the transistor is made by polycrystalline silicon, beneath a thin layer of SiO_2, above it is also a thicker insulating layer.





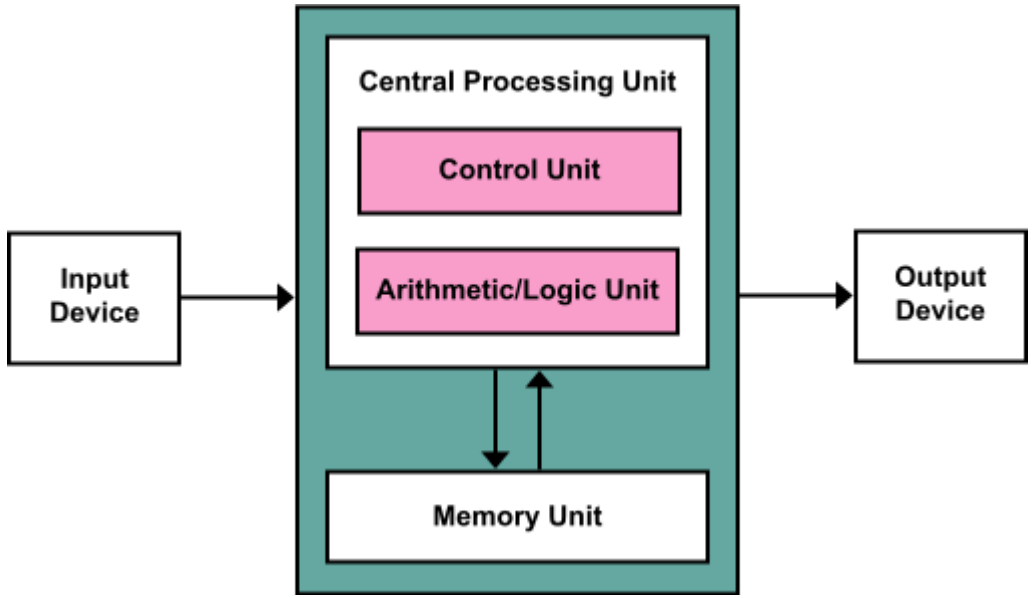
IC – Integrated Circuit – Technology

- Generation of ICs:
- ICs – number of transistors:
  - SSI (Small-Scale Integration): 10x
  - MSI (Medium-Scale Integration): 100x
  - LSI (Large-Scale Integration): 10000x
  - VLSI (Very Large-Scale Integration): 100000x
  - ULSI (Ultra Large-Scale Integration): 1000000x
  - SoC (System on Chip): a „whole computer" integrated in a single IC. (E.g.: motherboard of smart phones)
  - Intel 4004 (1971): 2300
  - Intel Core i7 (2008): 781 million
- Wire width in the chip:
  - Intel 4004 (1971): 10 μm
  - Intel Core i7 (2008): 45 nm



Architectures of Computers

- Von Neumann Architecture (1945):
  - using the binary numeral system,
  - common used memory to store both instructions (code) and data,
  - universal usability.
- Harvard Architecture (1944):
  - separated code (instructions) and data memory,
  - generally used by microcontrollers (MCUs).



Memories

- Memories:
- Volatile:
  - RAM (Random – Access Memory):
    - Dynamic RAM,
    - Static RAM.
- Non – Volatile:
  - ROM (Read-Only Memory),
  - PROM (Programmable ROM),
  - EPROM (Erasable Programmable ROM),
  - EEPROM (Electrically Erasable Programmable ROM),
  - Flash.

Memories

- RAM:
  - Dynamic RAM:
    - one cell consists of one transistor and one capacitor,
    - it has to refresh time to time, because the capacitor is discharged due to the trickle current,
    - slow, smaller size, cheap.
  - Static RAM:
    - one cell consists of more transistors (flip-flop),
    - it stores the data for any length of time, if there is a power supply,
    - fast, small energy consumption, expensive.

Memories

- ROM
  - Programmed by the manufacturer, the user can only read it.
- PROM
  - User can program it once, than he can only read it.
- EPROM
  - Cleared by UV light, programmed by special equipment.
- EEPROM
  - Programmed and cleared by special equipment.
- Flash
  - Type of EEPROM, programmed and cleared by the computer.

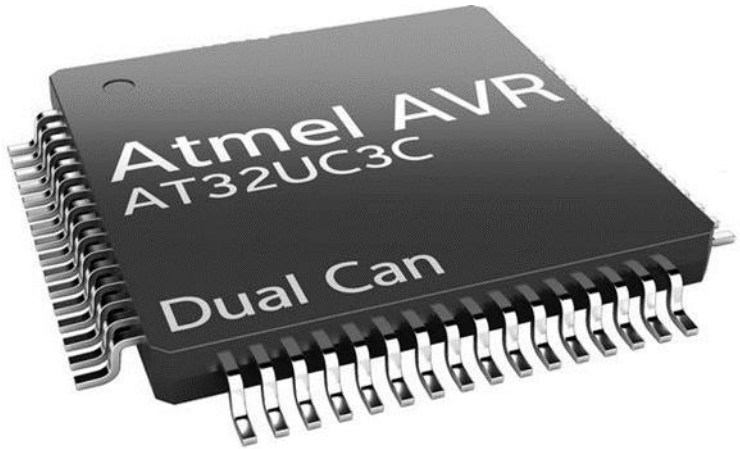
CPU vs. MCU

- **C**entral **P**rocessing **U**nit:
  - large, generally used instruction set and other special instruction sets*,
  - complex memory management,
  - it requires a complex additional circuit, itself is inoperable,
  - capable to doing complicated calculating performing it in a high-speed,
  - capable to running complex operating systems.

*:by performing the basic arithmetic, logical, control and input/output (I/O) operations specified by the instructions.

CPU vs. MCU

- **M**icro **C**ontroller **U**nit:
  - CPU and:
    - RAM, ROM,
    - digital I/O ports,
    - timers/counters,
    - clock generator,
  - lower computing capacity,
  - suitable for industrial control tasks,
  - not capable to running complex operating systems,
  - hardware based on MCU is called **„Embedded System”.**



MCU

- General properties of MCUs:
  - register width (word): 8, 16, 32 bits:
    - expected distribution in 2017:
      - 8 bits – 28 %, 16 bits – 34 %, 32 bits – 38%,
    - 16 and 32 bits are used generally in the automotive industry,
  - frequency: 2 – 100 MHz,
  - size of the memory:
    - RAM: 128 bytes – 64 Kbytes,
    - ROM: 2 Kbytes – 256 Kbytes;
  - power supply:
    - voltage level: 5 V, 3,3V;
    - energy consumption: 10x mA.

MCU

- Instruction set:
  - **R**educed **I**nstruction **S**et **C**omputer,
    - few, simple instructions,
    - uses more registers,
    - fewer addressing mode,
    - instructions take one cycle time,
    - emphasis on software.
  - **C**omplex **I**nstruction **S**et **C**omputer
    - many, complex instructions,
    - less registers,
    - more addressing mode,
    - instructions take a varying amount of cycle time,
    - emphasis on hardware.

MCU

- e.g. an excerpt of the CISC of Intel 8051

Table 10. 8051 Instruction Set Summary (Continued)

Mnemonic		Description	Byte	Oscillator Period
ARITHMETIC OPERATIONS (Continued)				
INC	DPTR	Increment Data Pointer	1	24
MUL	AB	Multiply A & B	1	48
DIV	AB	Divide A by B	1	48
DA	A	Decimal Adjust Accumulator	1	12
LOGICAL OPERATIONS				
ANL	A,Rn	AND Register to Accumulator	1	12
ANL	A,direct	AND direct byte to Accumulator	2	12
ANL	A,@Ri	AND indirect RAM to Accumulator	1	12
ANL	A,#data	AND immediate data to Accumulator	2	12
ANL	direct,A	AND Accumulator to direct byte	2	12

Mnemonic		Description	Byte	Oscillator Period
LOGICAL OPERATIONS (Continued)				
RL	A	Rotate Accumulator Left	1	12
RLC	A	Rotate Accumulator Left through the Carry	1	12
RR	A	Rotate Accumulator Right	1	12
RRC	A	Rotate Accumulator Right through the Carry	1	12
SWAP	A	Swap nibbles within the Accumulator	1	12
DATA TRANSFER				
MOV	A,Rn	Move register to Accumulator	1	12

MCU

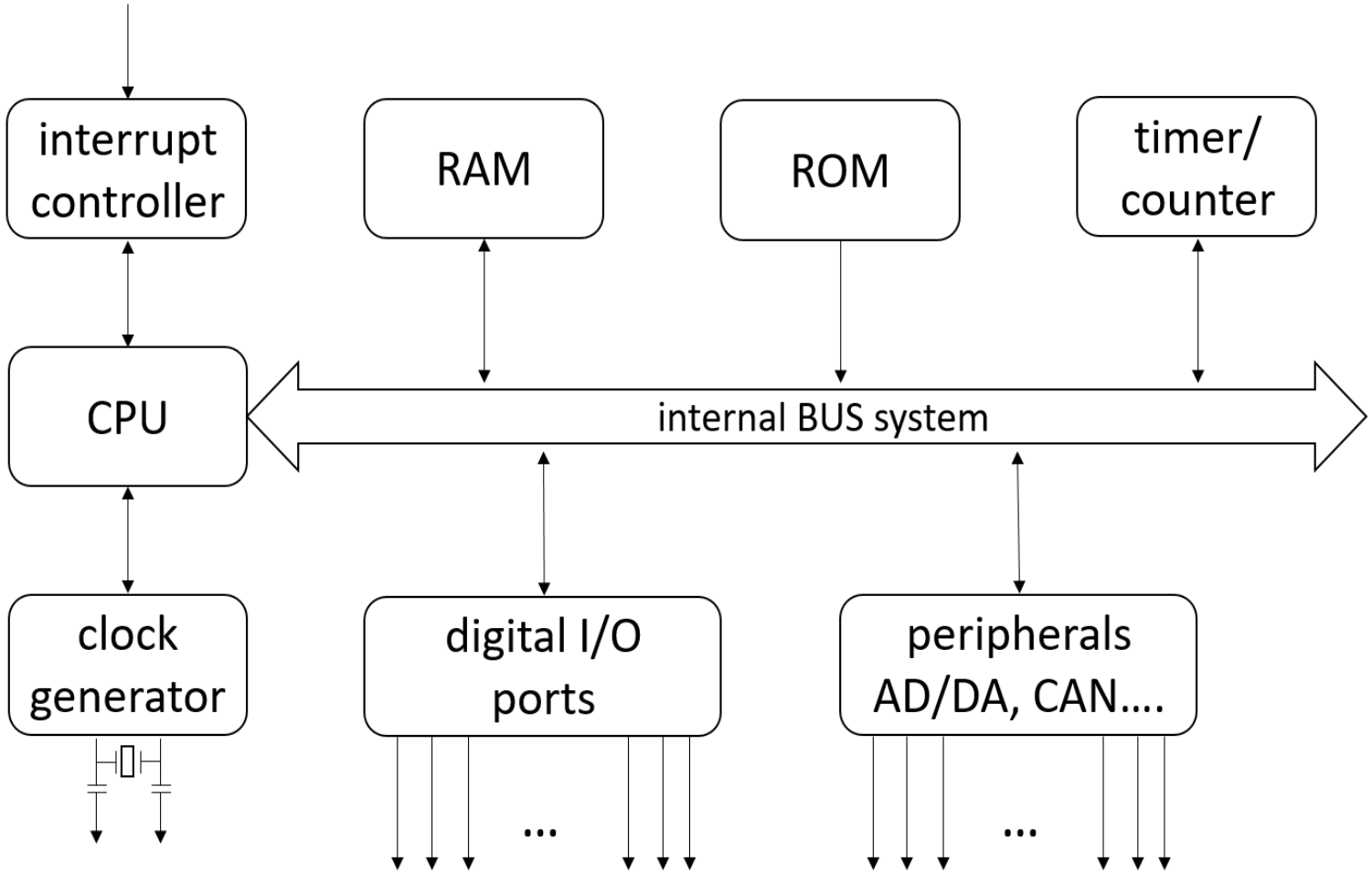
- Programming, e.g. (IDE).
  - C, C++

```
while(1) {
  P5=((numpad()<<4)|0x0F);

if(LEP==1){
  LEP=0;
  masodperc++;
  if(masodperc==60){
      masodperc=0;
      perc++;
  }
  if(perc==60){
      perc=0;
      ora++;
  }
  ASCII_factory(20,ora);
  LCD_DataWrite(':');
  ASCII_factory(23,perc);
  LCD_DataWrite(':');
  ASCII_factory(26,masodperc)
}
```

  - assembly

```
loop:
jb TILT, lefagy
jnb SEC,vege2
  clr SEC
  jb VAR, lefagy
  setb VAR
  mov a,R3
  orl a,#0x0F
  mov P5,a
  mov a,R3
  rl a
  mov R3,a
  jnb VAR,vege2

    nyugta:
    jb SEC,loop
      mov a,P5
      anl a,#0x0F
      mov r1,a
      xrl a,#0x0F
      jz nyugta
      mov r7,#0
      prell: djnz
```

MCU


interrupt controller
RAM
ROM
timer/ counter
CPU
internal BUS system
clock generator
digital I/O ports
peripherals AD/DA, CAN....
...
...

MCU

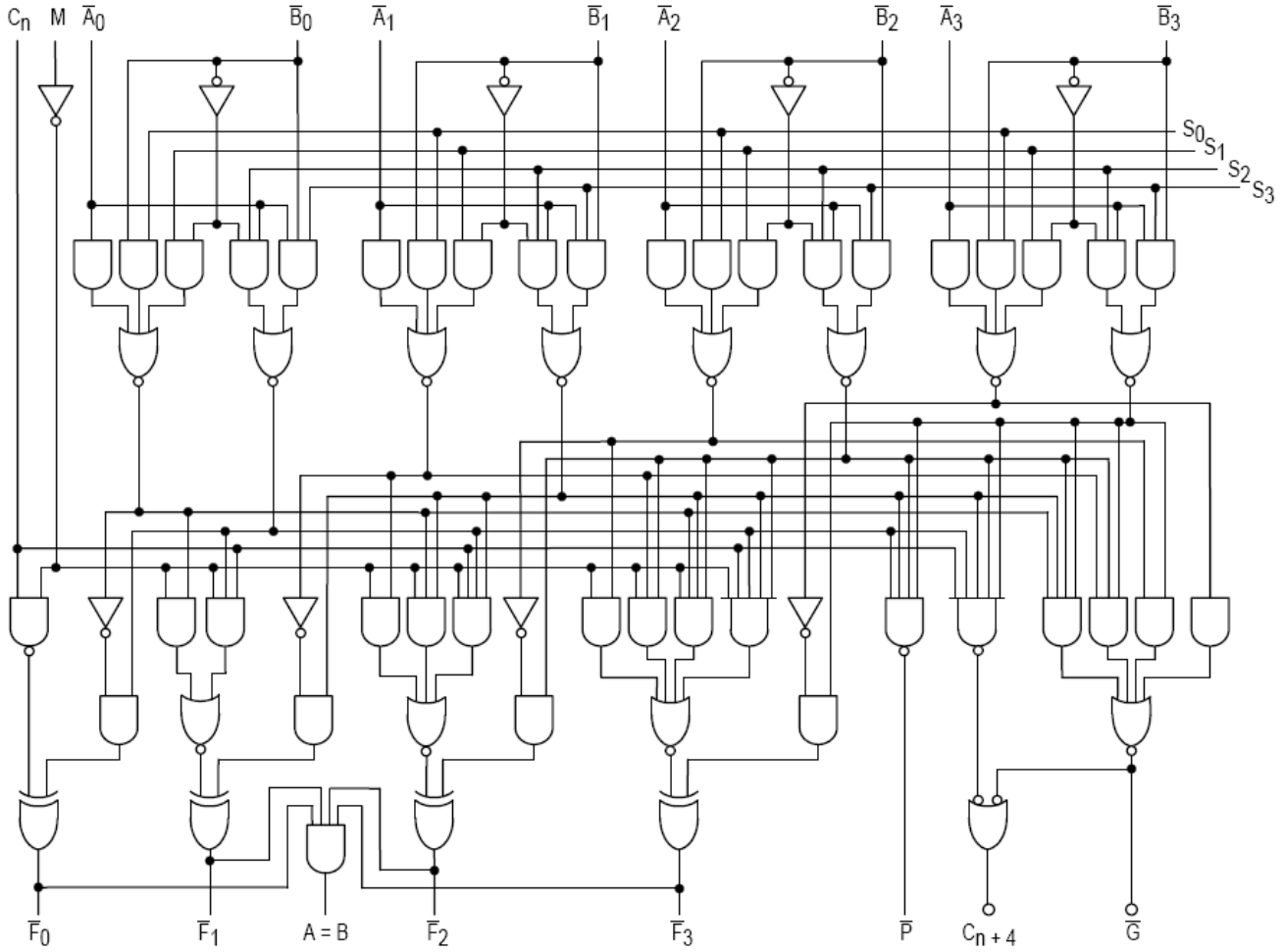
- CPU:
  - **A**rithmetic **L**ogic **U**nit:
    - performs arithmetic and bitwise operations on integer binary number,
      - AND, NOT, OR, XOR,
      - addition, subtraction, multiplication, division (in 2's complement code),
      - shift, rotate.
  - **C**ontrol **U**nit:
    - it tells the computer's memory, arithmetic/logic unit and input and output devices how to respond to a program's instructions.
    - it directs the operation of the other units by providing timing and control signals.
  - **A**ddress **G**eneration **U**nit:
    - calculates addresses used by the CPU to access main memory.

MCU

- Registers:
  - a processor register is a quickly accessible location available to a digital CPU, size: 1-2 words (e. g. in an 8 bits controller: 1- 2 bytes),
  - data register, to store the data,
  - address register, suitable for memory addressing,
  - general purpose register, suitable for store data or address,
  - special function register:
    - suitable for running and tracking of the program (code);
    - or suitable for handling other hardware modules.

MCU

- E.g. combinational logic circuitry of the type 74181 IC, which is a simple four-bit ALU.



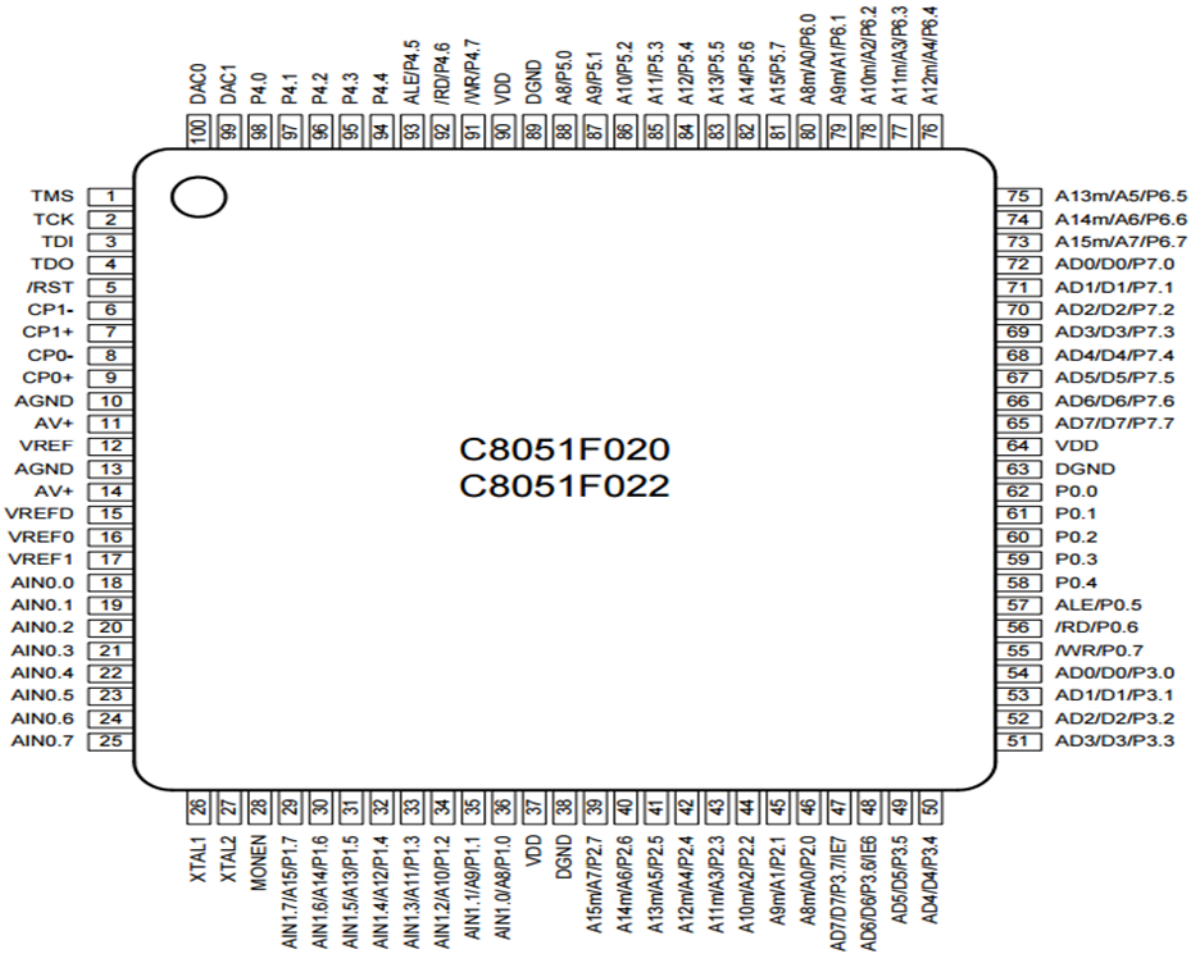
MCU

- Input/Output ports (I/O, GPIO):
  - multifunctional, bidirectional interface between peripherals (sensors, actuators) and other MCUs.
- Interrupt:
  - is signal to the processor emitted by hardware or software indicating an event that needs immediate attention;
  - an interrupt alerts the processor to a high-priority condition requiring the interruption of the current code the processor is executing;
  - can be a hardware or software interrupt.

MCU

- Main types of MCU architectures:
  - MCS-51 (Intel 8051): from 1980's, (e. g. Infineon XC 800 in the automotive industry);
  - ARM: from 1983's, Acorn Ltd., generally used in the RISC type MCUs;
  - Freescale: generally used in the automotive industry, (e.g. Qorivva series MPC55 and 56, with float-point arithmetic);
  - PIC: to general purposes,
  - Atmel AVR: in 1996, by two Norwegian students, the firs MCU, that used flash memory to store the code.

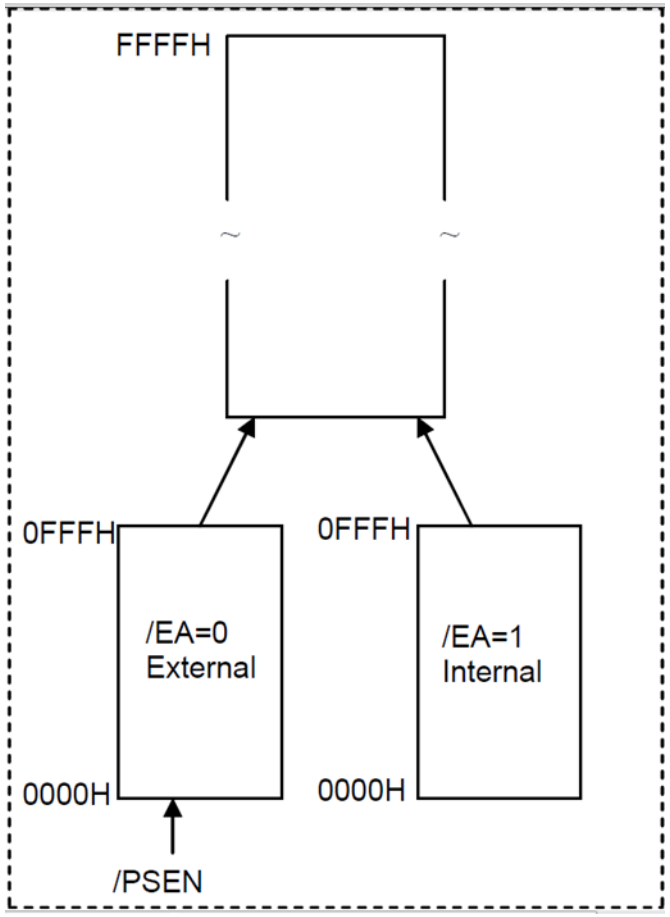
Short Presentation of MCU Intel 8051



Short Presentation of MCU Intel 8051

FLASH ROM

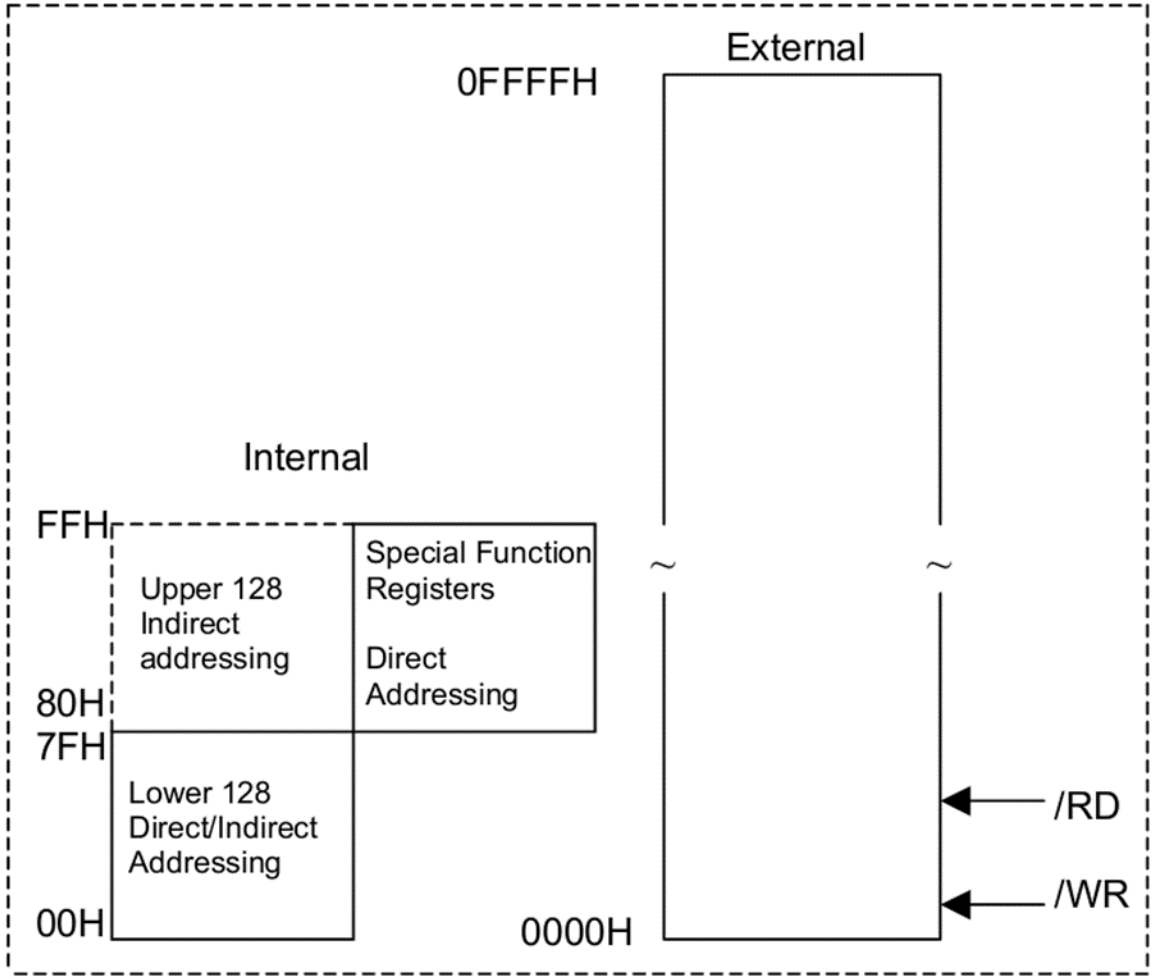
4 kB + 64 kB



Short Presentation of MCU Intel 8051

RAM

384 B + 64 kB



Short Presentation of MCU Intel 8051

RAM
lower 128 B

Byte Address	Bit Address							
7F	General Purpose RAM							
30								
2F	7F	7E	7D	7C	7B	7A	79	78
2E	77	76	75	74	73	72	71	70
2D	6F	6E	6D	6C	6B	6A	69	68
2C	67	66	65	64	63	62	61	60
2B	5F	5E	5D	5C	5B	5A	59	58
2A	57	56	55	54	53	52	51	50
29	4F	4E	4D	4C	4B	4A	49	48
28	47	46	45	44	43	42	41	40

27	3F	3E	3D	3C	3B	3A	39	38
26	37	36	35	34	33	32	31	30
25	2F	2E	2D	2C	2B	2A	29	28
24	27	26	25	24	23	22	21	20
23	1F	1E	1D	1C	1B	1A	19	18
22	17	16	15	14	13	12	11	10
21	0F	0E	0D	0C	0B	0A	09	08
20	07	06	05	04	03	02	01	00
1F	Bank 3							
18								
17	Bank 2							
10								
0F	Bank 1							
08								
07	Default Register Bank for R0 – R7							
00								

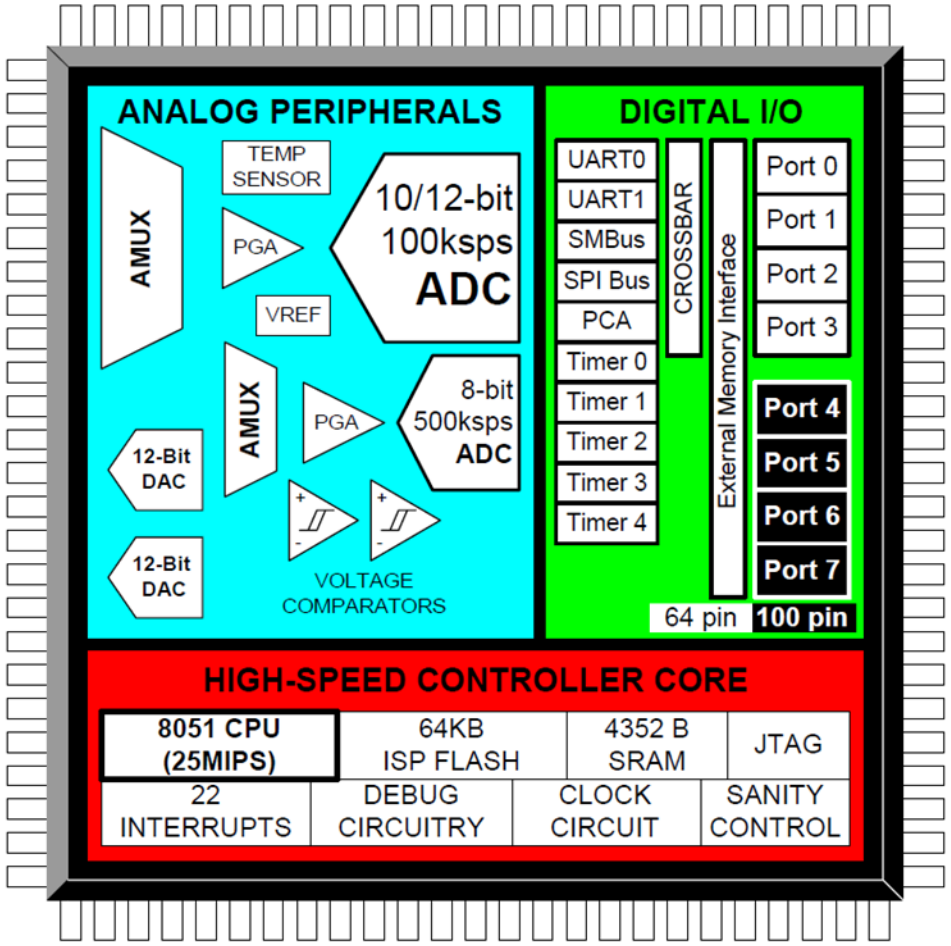
Short Presentation of MCU Intel 8051

RAM
SFR

Byte Address	Bit Address								
FF									
F0	F7	F6	F5	F4	F3	F2	F1	F0	B
E0	E7	E6	E5	E4	E3	E2	E1	E0	ACC
D0	D7	D6	D5	D4	D3	D2	-	D0	PSW
B8	-	-	-	BC	BB	BA	B9	B8	IP
B0	B7	B6	B5	B4	B3	B2	B1	B0	P3
A8	AF	-	-	AC	AB	AA	A9	A8	IE
A0	A7	A6	A5	A4	A3	A2	A1	A0	P2

99	Not bit-addressable								SBUF
98	9F	96	95	94	93	92	91	90	SCON
90	97	96	95	94	93	92	91	90	P1
8D	Not bit-addressable								TH1
8C	Not bit-addressable								TH0
8B	Not bit-addressable								TL1
8A	Not bit-addressable								TL0
89	Not bit-addressable								TMOD
88	8F	8E	8D	8C	8B	8A	89	88	TCON
87	Not bit-addressable								PCON
83	Not bit-addressable								DPH
82	Not bit-addressable								DPL
81	Not bit-addressable								SP
80	87	86	85	84	83	82	81	80	P0

Short Presentation of MCU Intel 8051



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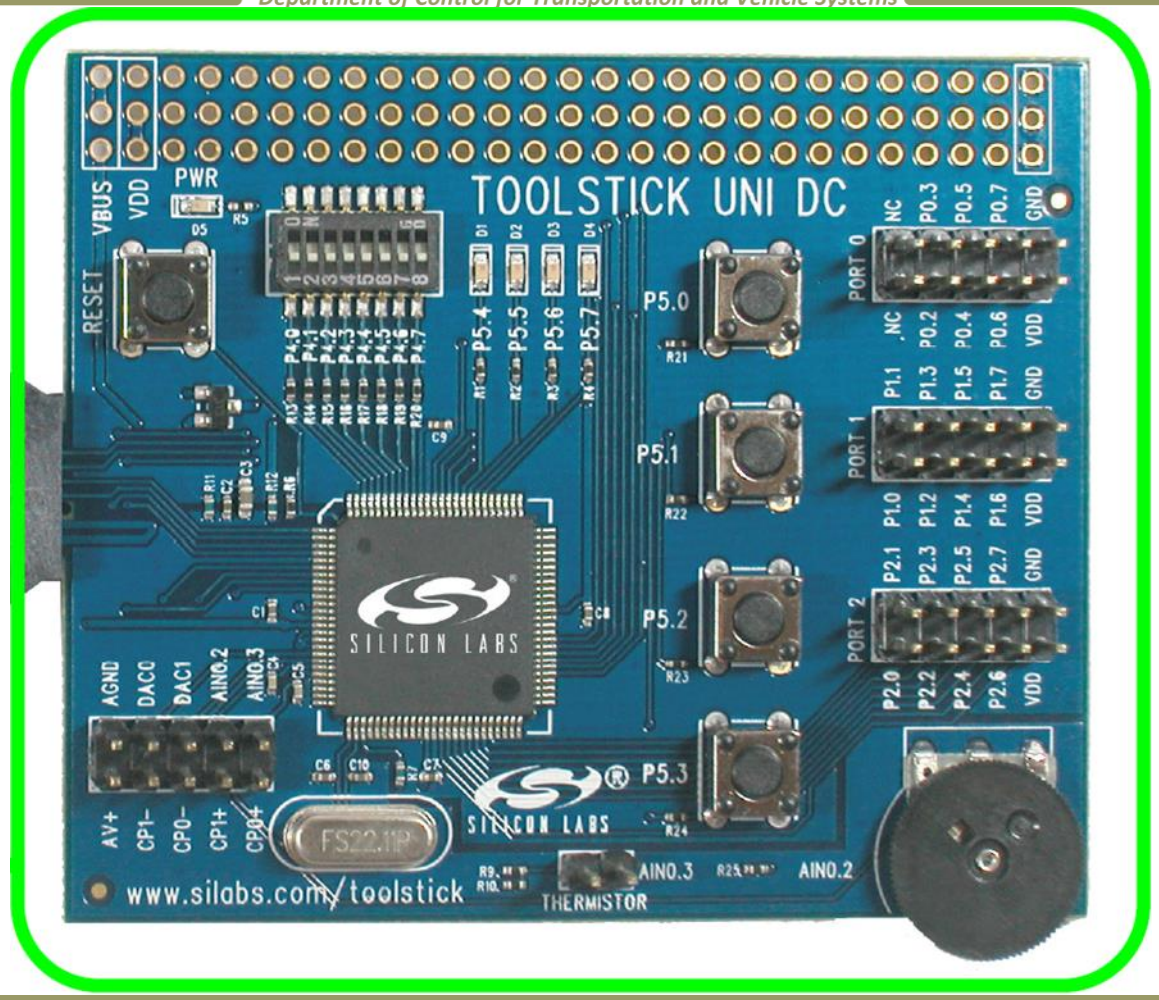

Short Presentation of MCU Intel 8051

- Live presentation:
  - 8051 with ASM;
  - 8051 with C;
  - small electric motor controlling task.

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