Ecodesign of Electronic Devices

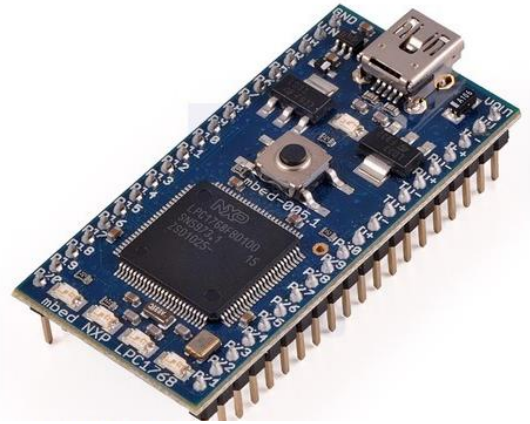
UNIT 8: Microcontroller systems part 1

Funded by the Erasmus+ Programme of the European Union

Ecoinnovation Skills for European Designers, Project number: 562573-EPP-1-2015-1-SI-EPPKA2-SSA.

Introduction to microcontroller systems

- Today's microcontroller production reaches billions of pieces yearly with numerous different manufacturers. Today's electronic systems are hard to imagine without a microcontroller, and their use is constantly rising. Here are a few groups of devices that use microcontroller systems:
  - Household appliances (microwaves, washing machines, coffee machines, etc..).
  - Telecommunication (telephones, smartphones, modems, routers, etc..).
  - Consumer electronics (television sets, music and video players, gaming consoles, etc..)
  - Industry (management and control of devices and production processes).
  - Automotive industry (engine control, safety driving system, etc..).
  - Space technology.



Funded by the
Erasmus+ Programme
of the European Union

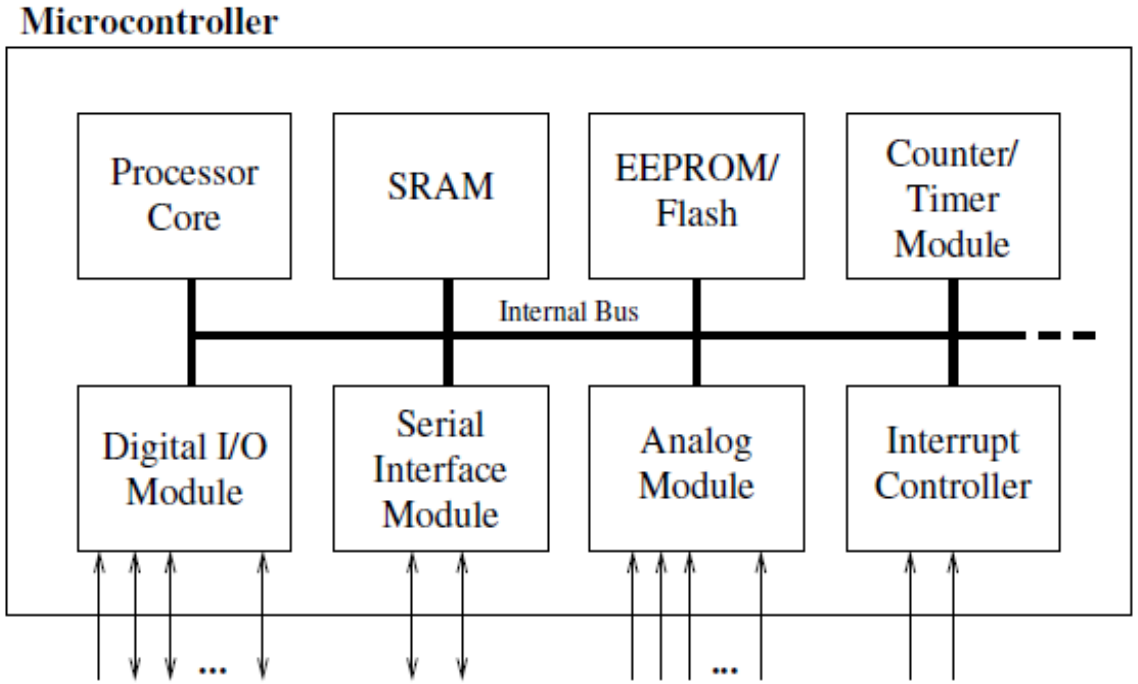
Advantages of microcontroller systems

- Microcontroller systems have flourished and are a great substitution for analog systems and circuits. With the inclusion of microcontroller systems into device design we can greatly decrease device sizing, increase efficiency, reliability and make the upgrade easier.
- From the ecological perspective, devices with microcontroller system are significantly more economical, use of materials is lower, and recycling is easier.
- Modern microcontrollers contain basic peripheral units (RAM, FLASH, I/O, communication modules) and also separate units which we can use to enable lower energy consumption when we do not use the system, or it is inactive (standby mode, wake-up mode, etc.). with a good understanding of microcontroller architecture and the concept of program in the system, we can develop an efficient system or device that is environmentally friendlier.
- Ecodesign has an important role in microcontroller systems as there are many options how to provide reliable functioning, low consumption, and low material use.

Funded by the
Erasmus+ Programme
of the European Union

Microcontroller structure

- The current development of microcontroller systems is steep. Currently, the most often used are 16-32 bit systems with clock speed from 10 MHz to 300 MHz. The internal controller structure is the same.



Funded by the Erasmus+ Programme of the European Union

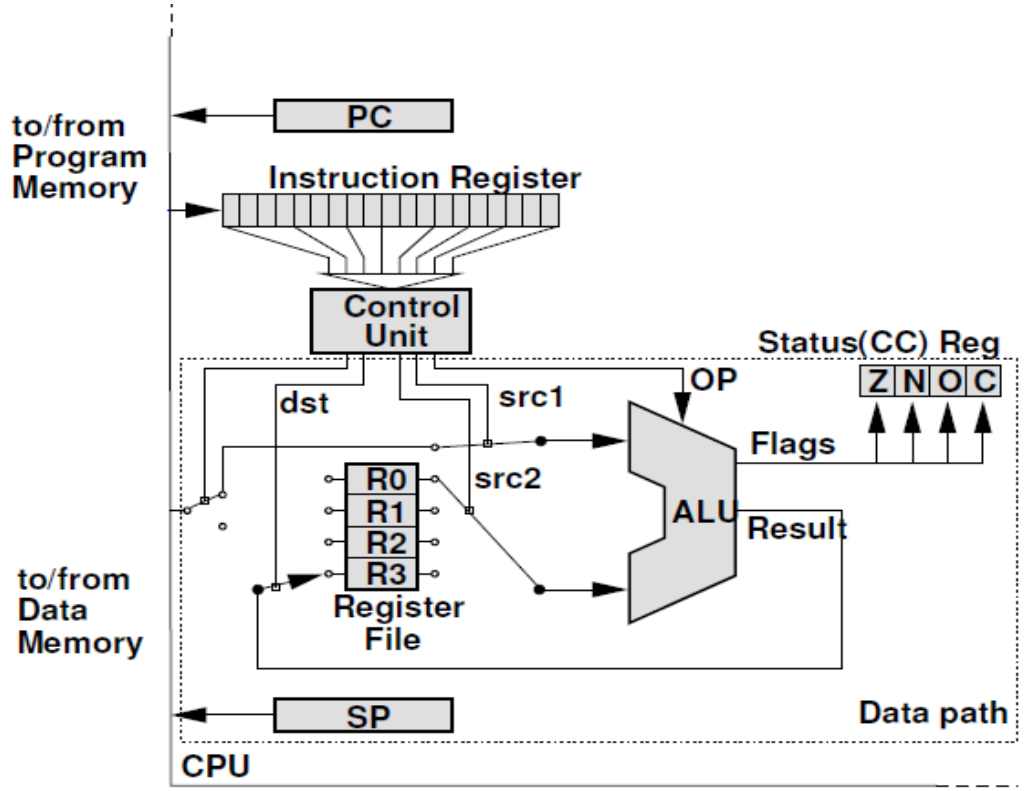
Microcontroller structure

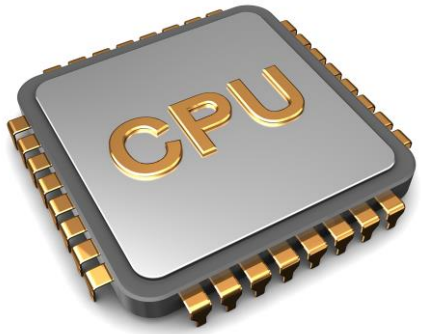
- The typical modules that are common in most microcontrollers are:
  - Processor CPU
  - Memory
  - Interrupt controller
  - Counters and timers
  - Digital inputs/outputs, Analog inputs/outputs
  - Communication interfaces
  - Debugging unit

Funded by the
Erasmus+ Programme
of the European Union

Processor Core

- Processor core CPU is the main part of each microcontroller. Image 4 presents the basic processor structure.





Funded by the
Erasmus+ Programme
of the European Union

Processor Core

- The core of the CPU consists of a data path (Data path), which executes the instructions from the control unit. The control units control the data path.
- The core of the CPU is an arithmetic logical unit - an ALU capable of performing only basic computational operations such as; addition, subtraction and essential complement.
- The task control unit (Control Unit) is to perform the instruction and determine which instruction will be performed at a given moment. The control unit also stores the instruction index in the program counter-PC (Program Counter) and the contents of the instruction in the Instruction Register (IR).
- The instruction determines which value from the registry will be sent to the ALU and where it will be stored.

Funded by the
Erasmus+ Programme
of the European Union

Processor Core

Depending on the control unit structure, we know two architectures:

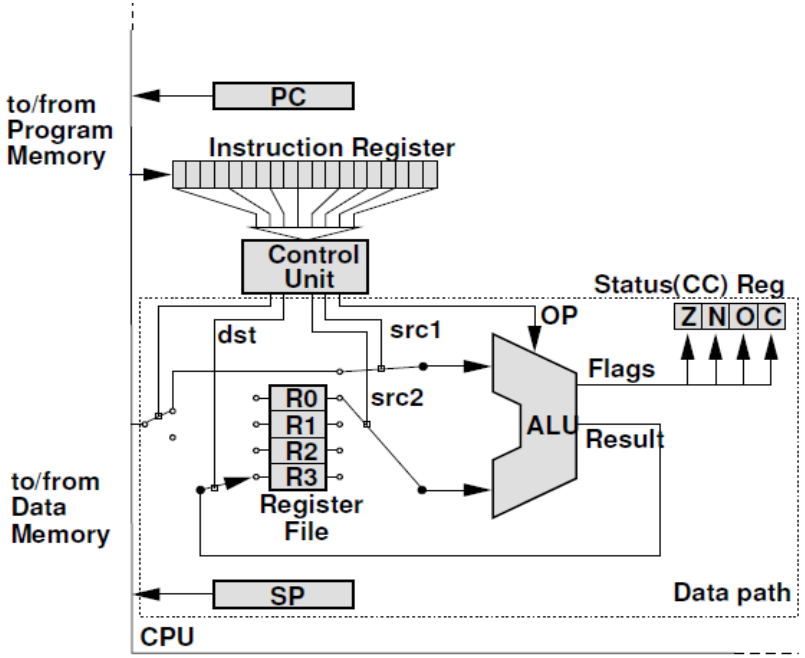
- **RISC:** Reduced instruction set computer architecture is simpler because the execution only takes a few hour cycles. The advantages of RISC systems are that they use a certain length of micro-code for addressing and instructions. As a result, the instructions are executed quickly but are fairly small.
- **CISC:** Complex instruction set computer is a structure that is managed by complex microcoded instructions. Such instructions need several hour cycles for the execution. The instruction has variable length and enables many efficient instructions in comparison to the RISC structure.

Funded by the
Erasmus+ Programme
of the European Union

Processor Core

Depending on whether the memory is separate or common, we differentiate two types of processor architecture:

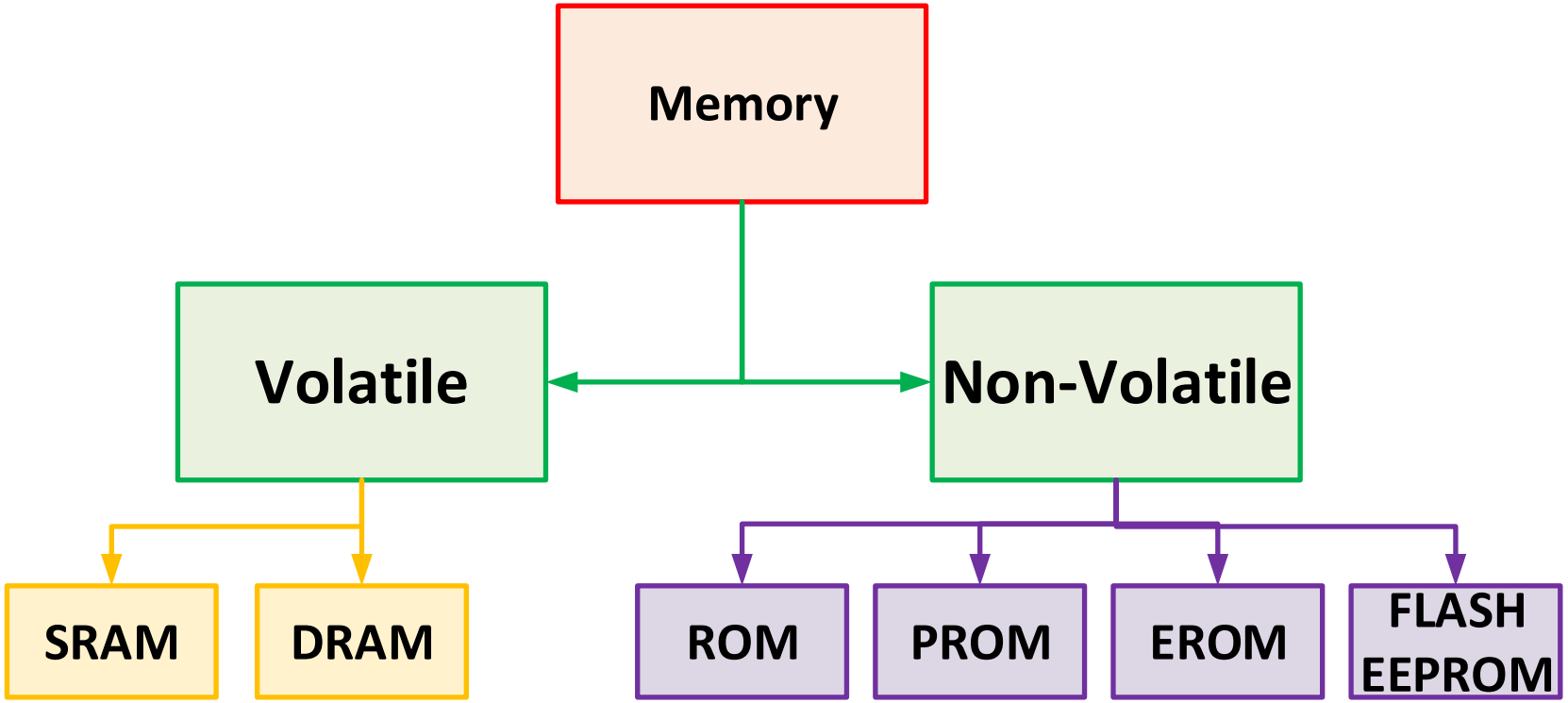
- **Von Neumann architecture:** In this architecture, the instruction and data memory is common. The bus that is used to access the memory is also common. Unfortunately, in this architecture, it can lead to a conflict between the instruction and data which can cause unwanted system delay. This disadvantage is generally known as Von Neumann bottleneck.
- **Harvard architecture:** In this architecture, the memories, as well as bus, are separate. The conflict between data and instruction is not possible which consequently improves processor efficiency. The system's disadvantage is that the architecture needs several components, such as double memory, double bus and a unit that enables simultaneous access to data and instruction memory.



Funded by the Erasmus+ Programme of the European Union

Memory

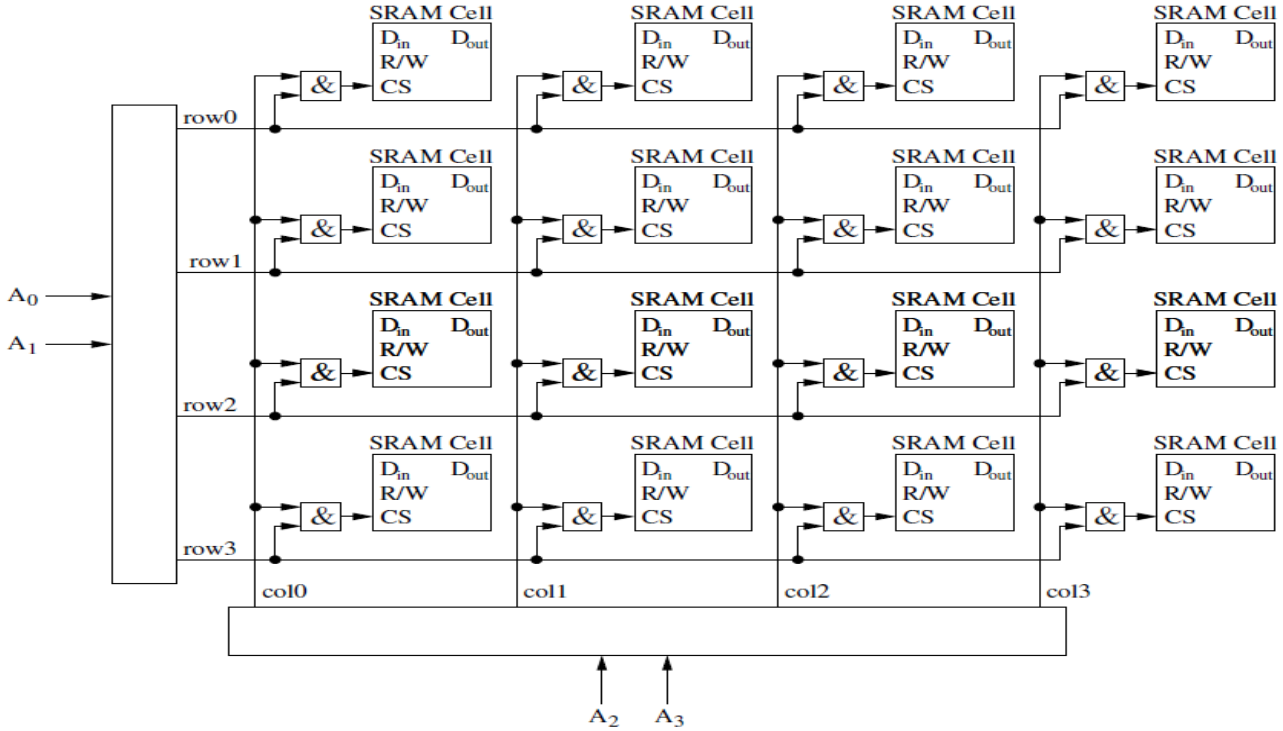
- Memory types:



Funded by the
Erasmus+ Programme
of the European Union

Volatile memory

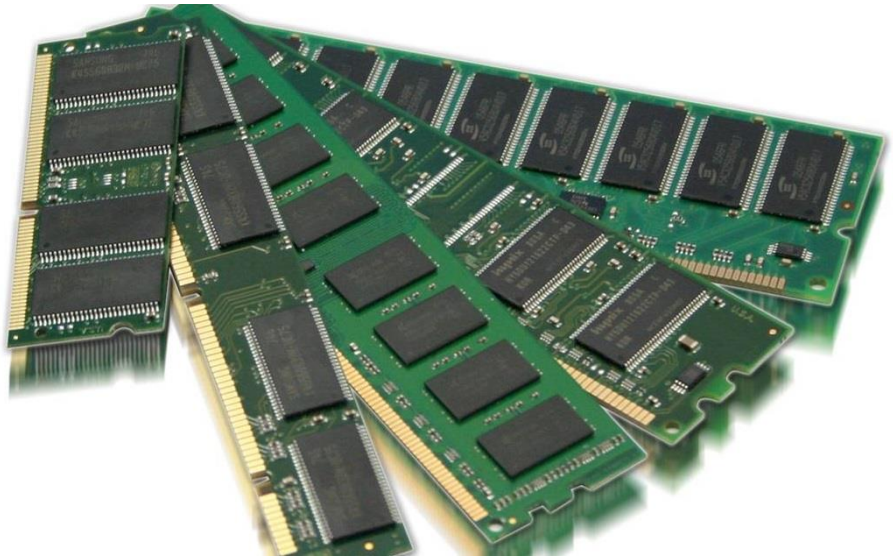
- **Static RAM-SRAM:** Word RAM comes from the term random access memory, which means that we can access the memory locations randomly. SRAM memory for saving uses D-flip-flop cells. D-flip-flop is composed of at least six transistors. Each D-flip-flop cell can save one bit (0 or 1), and each cell has address.



Funded by the
Erasmus+ Programme
of the European Union

Volatile memory

- **Dynamic RAM – DRAM:** In comparison to SRAM, dynamic RAM reaches significantly higher capacities. Now we know that SRAM needs at least six transistors for saving 1 bit. For the higher capacity of SRAM, we need more cells which significantly increases the physical chip size and price. If the memory can be reduced, we can use a simple way of saving bit value. DRAM saves data in electric charge storage (capacitor). This way the number of elements for saving one bit is reduced and consequently the capacity of memory is increased at significantly smaller chip size. DRAM slower than SRAM.



Funded by the
Erasmus+ Programme
of the European Union

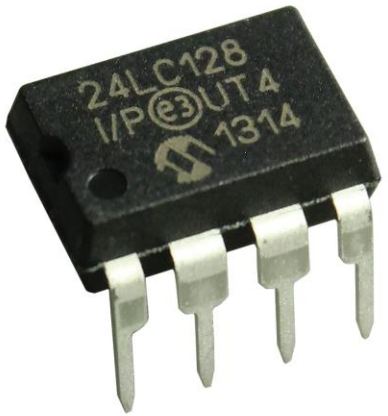
Non-Volatile memory

- **ROM:** ROM stands for read-only memory. Read-only means that we cannot save any data. ROM usually contains data saved by the manufacturer and are key for device functioning. In ROM is saved BIOS for personal computers or register values for microcontroller settings.
- **PROM:** ROM is used only in mass production because its production for smaller quantities or pilot research is too expensive. PROM (programmable read-only memory) is an alternative for ROM. It can be programmed only once because it contains a fuse that prevents repeated writing. PROM is also known as OTP (one-time programmable memory). It is not suitable for development when memory content and the program often change.

Funded by the
Erasmus+ Programme
of the European Union

Non-Volatile memory

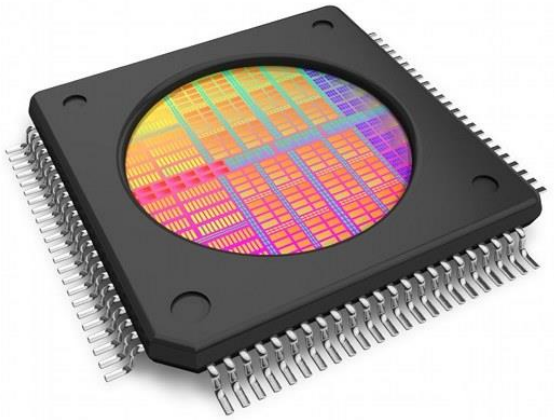
- **EPROM:** EPROM is an erasable programmable read-only memory. Programming of EPROM requires a complex procedure. Hence it usually cannot be deleted by the microcontroller. Value of EPROM is saved in FET (field effect transistors) that is managed by pin-gate. High voltage in pin-gate closes the transistor. When these gates are closed, they stay closed until they are not under voltage anymore. This way we can save digital values 1 or 0. Due to issues in FET, the gates can open over time.
- **EEPROM:** EEPROM is electrically erasable and programmable ROM, meaning it is an electronically programmable memory. Essentially, EEPROM works the same way as EPROM; the only difference is that for memory deletion we do not need any special external high voltages and UV light. High voltage for the awakening of FET is built-in inside chip and is known as charge pump. Generally, EEPROM has, same as EPROM, a lifecycle that is often limited to 100.000 deletion cycles.

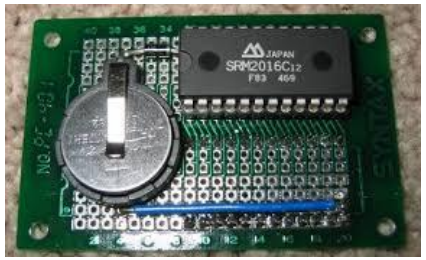


Funded by the
Erasmus+ Programme
of the European Union

Non-Volatile memory

- **FLASH:** FLASH is a limited version of EEPROM memory and works the same way as EEPROM. The difference between FLASH and EEPROM is that we cannot delete each cell separately, but only complete memory of a certain sector. The reason for the implementation of FLASH memory is the high price of EEPROM memory. FLASH also has a limited number of sign-ins, same as EEPROM.
- **NVRAM:** NVRAM (non-volatile RAM) is a combination of volatile and non-volatile memory. This memory has the same working principle as SRAM, but it has added power supply battery. We also know a version of memory, where EEPROM and SRAM memory are joined in the same chip.

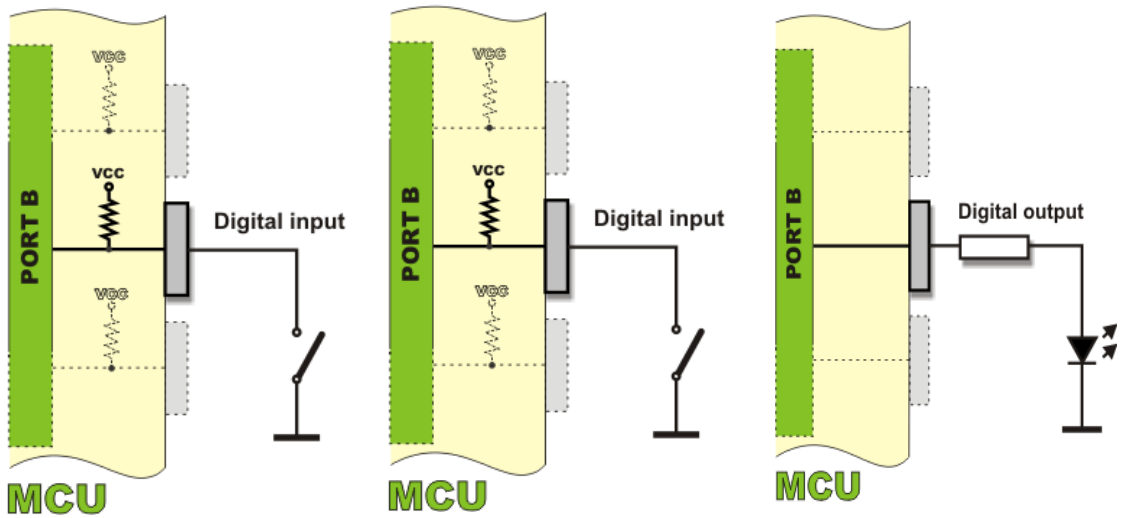




Funded by the
Erasmus+ Programme
of the European Union

Peripheral units-Digital inputs and outputs

- Digital inputs and outputs – I/O are used for controlling and management of external devices and are the main units inside the microcontroller.
- Digital inputs and outputs are often grouped into ports. Each port can contain 8, 16 or 32 I/O pins.
- Most often all I/O pins are two-way, meaning they can be used as inputs or outputs.

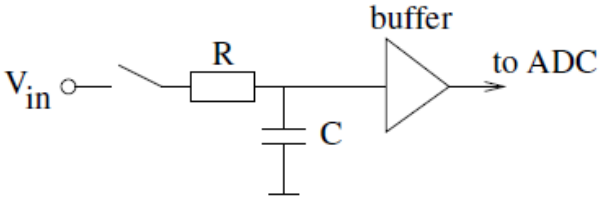


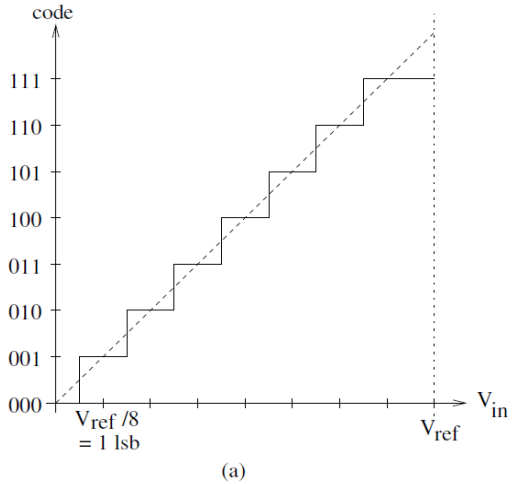
Funded by the
Erasmus+ Programme
of the European Union

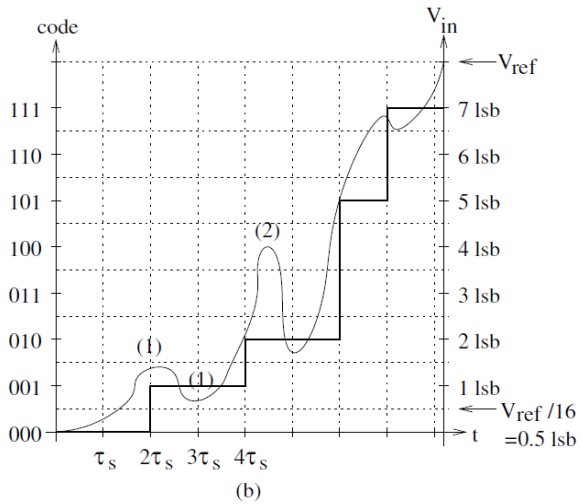
Peripheral units- Analog inputs

Analog inputs:

- In comparison to the digital inputs and outputs, it is possible to read or process different voltage levels with analog inputs/outputs.
- Reading of analog values is related to ADC peripheral unit in the controller. The basic data of ADC converter are resolution, conversion speed, and conversion type.
- Capturing of ADC signal is divided into three phases.
  - **sample & hold**
  - **Kvantization**
  - **Coding**





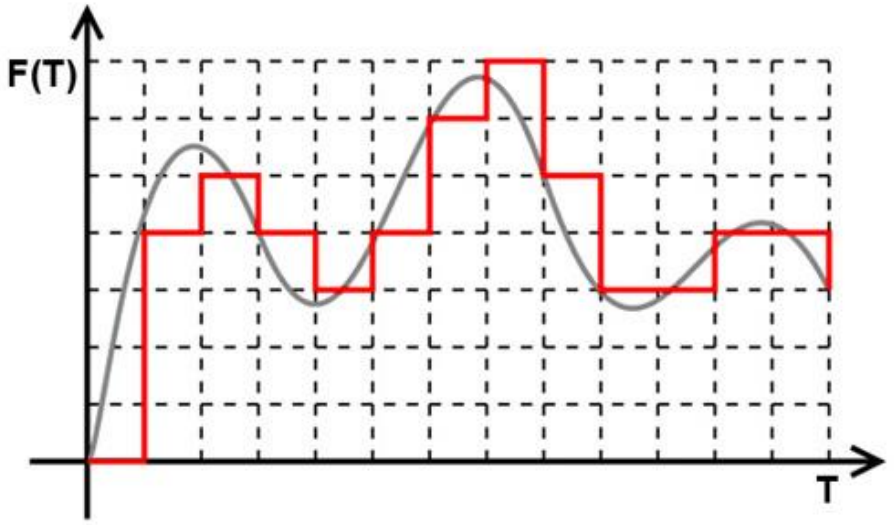


Funded by the
Erasmus+ Programme
of the European Union

Peripheral units- Analog outputs

Analog outputs:

- The function of digital-analog converter DAC is to convert the binary value to analog signal. DAC is most often used for processing of any output signals from the controller. DAC has similar characteristics than ADC.
- DAC resolution is defined by resolution (bit number) and samples per second speed.



Funded by the
Erasmus+ Programme
of the European Union

Peripheral units- Interrupt routine

- Programs that are executed on microcontroller systems have to react to given events. The events differ by duration, whether they repeat and by complexity.
- The controllers have to react to each potential change on the input pin, as well as receiving or transmission of data through communication interfaces.
- Some most common interrupt routines:
  - **Timer interrupt**
  - **Counter interrupt**
  - **External interrupt**
  - **Receive interrupt**
  - **Transmit interrupt**
  - **ADC interrupt**
  - **DAC interrupt**
  - **Sleep mode interrupt**

Funded by the
Erasmus+ Programme
of the European Union

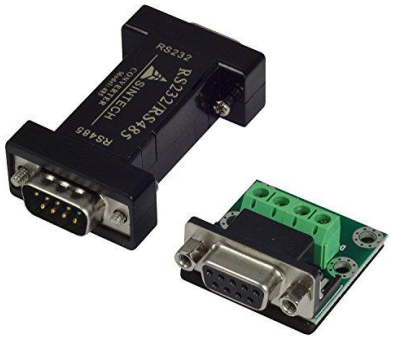
Peripheral units- Counters and timers

- Counters and timers are key peripheral units of each microcontroller that are often connected to other units. Timers are used for different tasks, such as delay, measurement of time, measurement of frequency. The most basic use of timers is use of the counter only. The timers can generate different events, interruption or process modulated PWM signal.
- Main timer parameters:
  - **Clock:** Timer clock is determined by the speed of peripheral bus for the given timer. The speed of peripheral bus is determined by controller's system settings.
  - **Scaling factor (prescaler):** Scaling factor determines timer clock split. With this factor, we determine timer increment and duration of counting when we count until the end of counters data register. Timer increment i time resolution that determines how precisely we measure time.
  - **Period:** Timer period determines counting time frame. This means that the longest period equals the length of the counter data register. Counter data length is determined by a number of bits in the timer.

Funded by the Erasmus+ Programme of the European Union

Peripheral units- Communication interfaces

- Communication interfaces enable communication between the microcontroller and other external devices, such as other controllers, PCs, sensors, etc.
- Communication interfaces differ by different characteristics, such as parallel or serial interface, synchronous or asynchronous communication, point-to-point or network mode, half-duplex or full-duplex mode, wire or wireless mode.

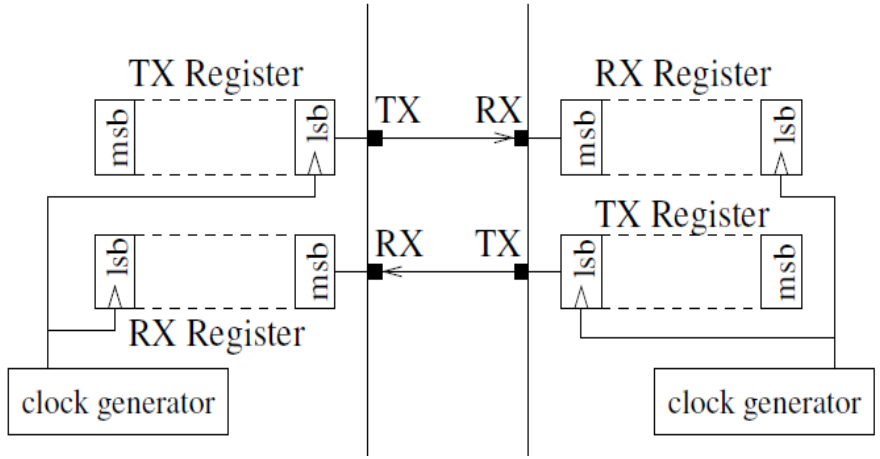


Funded by the
Erasmus+ Programme
of the European Union

Peripheral units- Communication interfaces

- ***USART*:** It is a serial connection (universal synchronous asynchronous receiver transmitter) that uses only two lined for communication. One line is for transmitting Tx and other for receiving Rx. The difference between USART and UART is that USART needs a separate line for clock. UART has a preset clock with which are familiar all other devices in the communication path. In USART the receiving device uses sender's clock. Image 13 presents UART communication interface.

- Adjustable parameters of USART serial interface are:
  - ***Number of data bits:*** Number of data bits determines how many bits will be captured in the sent data.
  - ***Parity bit:*** The user can decide if parity will be used or not. Parity can be an even "1" or odd "0" bit. It is used as simple control over communication regularity.

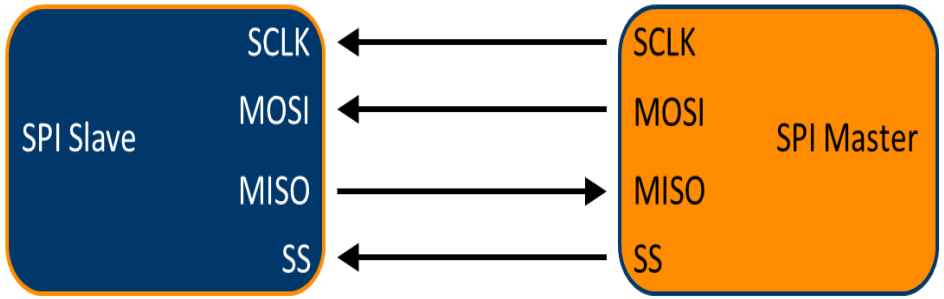


Funded by the
Erasmus+ Programme
of the European Union

Peripheral units- Communication interfaces

- **SPI:** SPI (serial peripheral interface) is a serial connection that is intended for communication between near-by devices. Allowed distances are from only several centimeters to the maximum of one meter. Communication is provided by full-duplex mode between the master and slave. The interface also supports 3,2,1 wire mode.

  - SPI communication in full extent uses four lines:
    - ***MOSI:*** (master out slave in): Connection for transmitting data from master to slave.
    - ***MISO:*** (master in slave out): Connection for receiving data from slave to master.
    - ***SCK:*** (system clock): Generated clock-communication speed.
    - ***SS or CS:*** (slave select or chip select): Addressing device by the master.

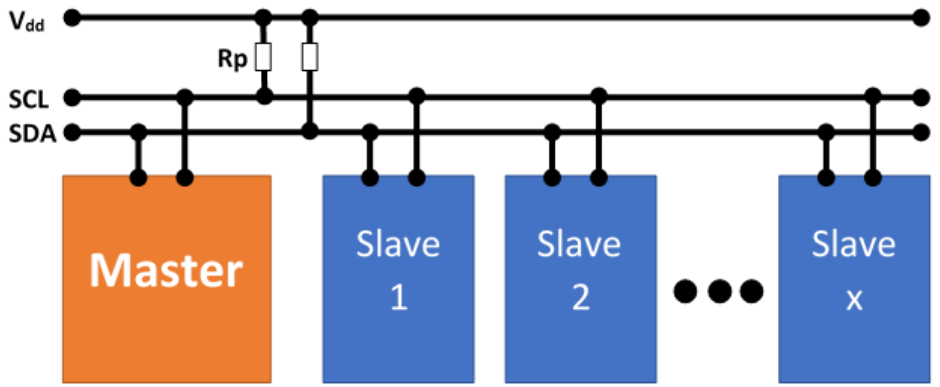


Funded by the
Erasmus+ Programme
of the European Union

Peripheral units- Communication interfaces

- **IIC (I^2C):** Is serial communication that enables half-duplex mode. It also uses principle master-slave. Same as SPI, IIC is also intended for communication between near-by devices. The speed of IIC bus is determined by three factors. The slow mode is 100 kbit/s, fast mode 400 kbit/s and the highest speed 3.4 Mbit/s. The communication interface only requires two lines. One line is data SDA and the second is generated clock SCL by the master.

  - I2C communication parameters:
    - ***SCL:*** Master clock.
    - ***SDA:*** Data line.



Funded by the Erasmus+ Programme of the European Union

Guidelines for low energy consumption of microcontrollers and ecological aspects

- Each controller can be configurated in order to have the lowest possible consumption.
- The first step to ecological design requires choosing a controller depending on its characteristics and chip size. The chip size is directly related to used chip materials, such as housing plastic, metal pins or silicon.
- For each device or application, it is important to evaluate which controller we will use. On the market are several controllers that are intended for low consumption and long autonomy.
- Software and hardware parameters:
  - **Controller clock**
  - **Supply voltage**
  - **Switching off unused modules**
  - **Optimal code design**
  - **Sleep and standby mode**

Funded by the Erasmus+ Programme of the European Union