Digital systems and basics of electronics

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Microprocessors and embedded systems - lecture 12

Microcontrollers

Microcontroler - computer implemented in the form of a single integrated circuit, containing a central processing unit (CPU), RAM, generally, program memory and extensive input-output systems.

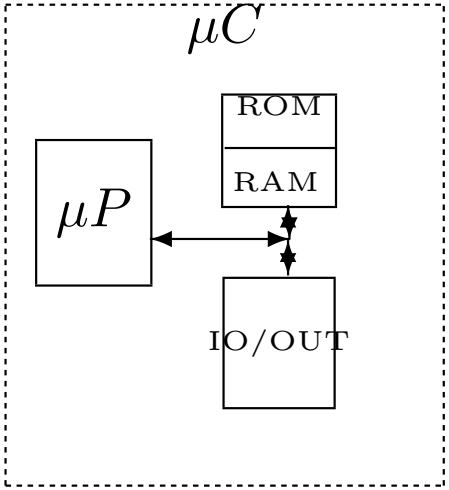
The term microcontroller comes from the main application area, which is control electronic devices.

Construction of microcontrollers

A typical microcontroller includes:

- Arithmetic Logic Unit (ALU) - usually 8-bit,
- Data memory (RAM),
- Program memory,
- Universal input ports - some of these ports can perform alternative functions, selected by software,
- Serial or parallel transmission controllers (UART, SPI, I2C, USB, CAN, etc.),
- Analog-to-digital or digital-to-analog converters,
- Timers,
- Work control system (watchdog)
- Internal sensors of non-electric quantities (e.g. temperature)

Components of the microcontroller μC



Basic components:

- processor from ALU
- computer memory (containing *data* and *program*)
- input-output devices

Microcontroller clocking

The microcontroller system clock can be clocked:

- *external clock signal* (a solution often used in large systems requiring synchronous cooperation of many units),
- *with its own generator*, requiring the connection of external retainers clock frequency (most often it is a quartz resonator and two capacitors),
- *internal timing system*, not requiring connection of additional elements

The clocks of modern microcontrollers reach frequencies up to several hundred MHz, however, in most applications, the timing can be much slower.

Programming languages μP

- High order languages (eg. VB, C, Java)
- Assembler

Programming methods μC

ROM memory can be programmed in three ways:

1. *High voltage Programming* or programming method introduced over several dozen years ago to program EPROM memory using 12V signals - requires a programmer.
2. *ISP (In-System Programimg)* which does not require removing memory from the system in which it works.
3. *Bootloader* - after the μC reset, the program located in the Bootloader section is launched, which through a link (e.g. serial port) connects to the parent computer, downloads the program code and places it in the designated ROM memory area.

Review of current microcontrollers

The most popular microcontrollers include:

1. The unquestioned standard for the mass market was imposed by *Intel*, which introduced the microcontroller *8051* to the market,
2. it AVR microcontrollers by *Atmel* are also very popular - laboratory classes will be based on them,
3. *PIC* from *Microchip Technology*,
4. other.

Embedded systems - **definitions**

- The general definition of *embedded systems* defines them as devices used to control, monitor or support the operation of devices and machinery. The term "built-inżefers to the fact that they form an integral part of the system in which they work. In many cases, the presence of *embedded systems* may not be obvious to inexperienced observers.
- Embedded system - a special-purpose computer system that becomes an integral part of the equipment it supports.

Embedded systems

- The embedded system meets certain requirements defined for the tasks it is to perform,
- A typical embedded system is based on a microprocessor (or microcontroller), programmed to perform specific tasks,
- Some embedded systems contain an operating system.

Characteristics of embedded systems

- *Program* - the tasks that the program is to perform are known a priori,
- *Static* planning and allocation of system resources,
- *Real-time systems* - a compromise between the hardware and software used, handling exceptional situations,
- *Interaction* between the embedded system and the external environment,
- *Behavior hierarchy* - behavior sequence, competitive behavior scenarios.

Embedded systems and PCs

- Simple user interface (display, port, diode, buttons),
- The port in which the embedded system works, not the embedded system itself, can be diagnosed using the port,
- Program tasks may not be directly visible (program written for specific applications).

Operating System Properties in Embedded Systems

- *small* - minimum memory used,
- *open* - many interfaces, protocols and standards,
- *modularity* - easy integration of components,
- *portable* for various devices,
- *Real-time* supports hardware deadline, task synchronization,
- *power consumption* - integrated,
- *resistant* exceptions, CRC, ...,
- *configurable* depending on your needs.

Embedded systems with operating systems

The following memory resources are required for *operating systems* used in *embedded systems*:

- *QNX:* has the smallest requirements from around $10KB$,
- *Windows CE:* requires a minimum of $350KB$,
- *Linux:* requires $125 - 256KB$ for a sensible kernel configuration,
- *VxWorks:* a few kilobytes of the simplest embedded system.

Fields of application of embedded systems

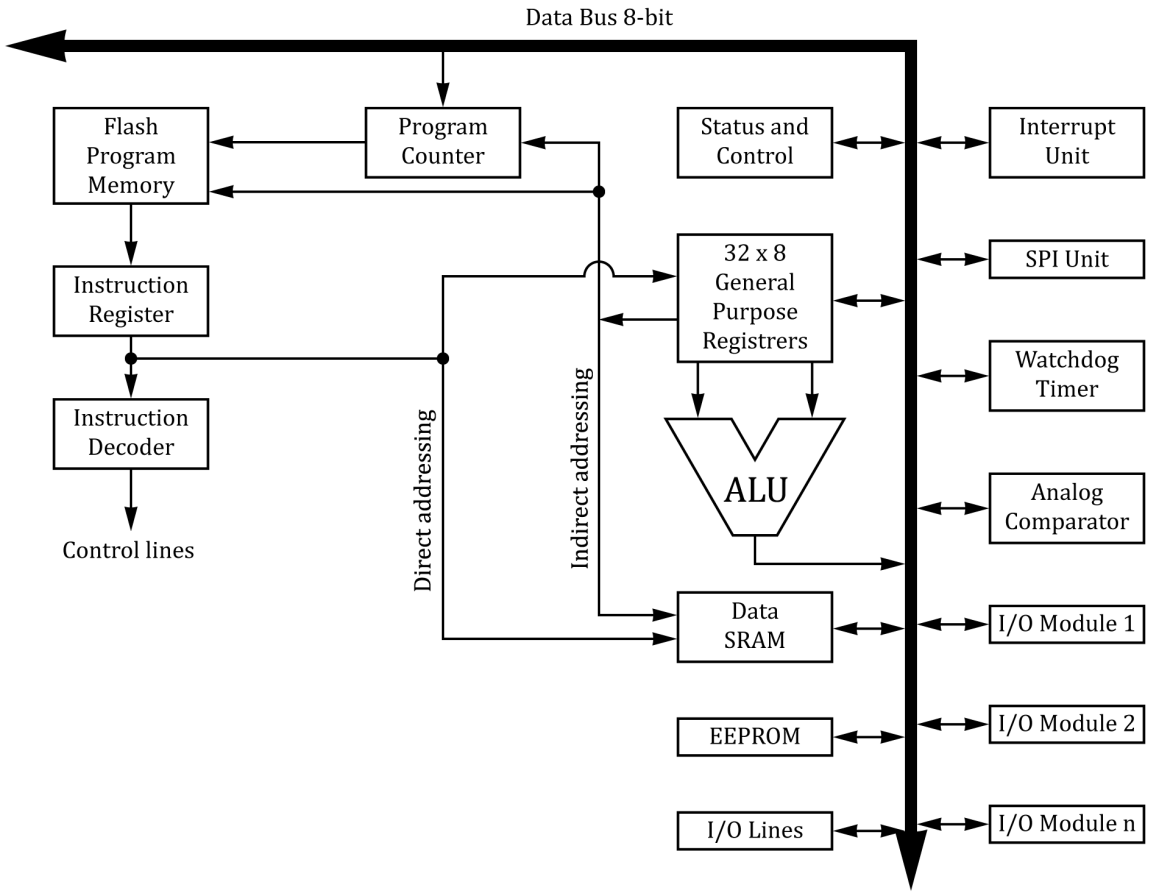
- *Automotive* - car engine and ABS control systems, on-board computers,
- *In industry* to control and control production processes and machines,
- *Drivers* for all kinds of mechanical robots,
- *Alarm and monitoring systems* to protect people and property, e.g. anti-theft, fire,
- *Cell Phones* and it telephone exchanges,
- *Office equipment* - printers, photocopiers, calculators
- *Medical equipment* e.g. holter monitors,
- *Measuring equipment* e.g. oscilloscopes, spectrum analyzers,

- *Home appliances* - dishwashers, microwaves, washing machines, thermostats, air conditioners,
- *Computer hardware* - hard disk drivers, optical drives, routers, servers,
- *Multimedia equipment* - gaming consoles and machines, televisions, DVD players, cameras digital video recorders etc.
- *ATMs* and other ATM devices
- *Military technique* - control of aircraft, missiles, etc.

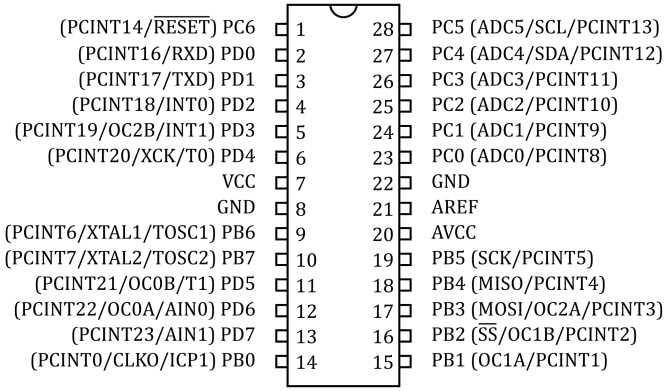
Features of μC ATmega328

1. RISC architecture - 131 processor instructions (executed in one clock cycle), 32×8 -bit general purpose registers,
2. Non-volatile program and data memory - $32kB$ program memory, ISP, with Bootloader option, 1024 bytes of EEPROM data memory, $2kB$ internal SRAM memory,
3. Peripherals - 8-bit and 16-bit timers / counters with prescaler option, four PWM channels, $8 \times 10 - bit$ ADC transducers, Two-wire interface, programmable Serial USART, interface Master / Slave SPI, programmable Watchdog, analog comparator,
4. Other features - internal RC generator, internal and external interrupt sources, energy saving systems, power supply $3.3 - 5.5V$, clock frequency up to 16MHz.

Block diagram of ARV ATmega328



Pinout of μC AVR ATmega328



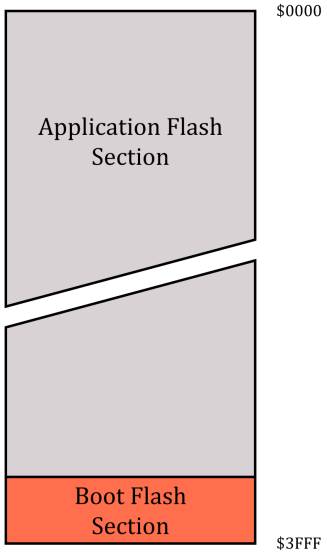
- **VCC** - Supply,
- **GND** - Ground,
- **Port B** ($PB_7 \ldots PB_0$) - Bidirectional I / O ports with internal pull-up resistors,
- **Port C** ($PC_6 \ldots PC_0$) -Bidirectional I / O ports with internal pull-up resistors, or ADC, Reset,
- **Port D** ($PD_7 \ldots PD_0$) - Bidirectional I / O ports with internal pull-up resistors,
- **XTAL1, XTAL2** - external generator (clock) inputs,
- **AREF** - AC converter external reference input,

Registers of μC AVR ATmega328

- **Status Register** - register of flags monitoring the status of ALU operations (meaning of bits in documentation),
- **General purpose registers**
- **Stack Pointer** - Two 8 -bit registers SPH, SPL indicating current place on the stack (top of the stack) - is decremented.
- **Registers X, Y and Z** - general purpose registers, additionally used for indirect addressing in the data space:
- **Registers EEARH, EEARL, EEDR and EECR** - registers enabling access to EEPROM data memory. Registers' meanings: EEARH and EEARL - address, EEDR - data entered or read out, EECR - control register.

Program memory μC AVR ATmega328P

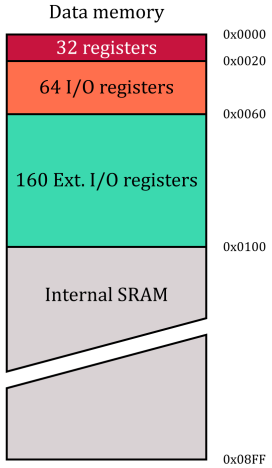
- $32kB$ Flesh memory for storing the $16k \times 16$ program. AVR instructions are 16 or 32 bit. The program counter (PC) is 14 bit, allows addressing $2^{14} = 16kB$ memory cells.
- The program memory is divided into two areas - *application section* and *bootloader section*.



- The FLASH memory is designed for 10,000 write / delete cycles.

Data memory SRAM μC AVR ATmega328P

- The youngest 2144 memory cells contain *general purpose registers* (32), *input / output registers* (64 cells) and internal SRAM memory (2048 cells),



- There are five different addressing modes: Direct, Indirect, Indirect with offset, intermediate with pre and post increment. Indirect addressing is done using registers X, Y and Z,
- Any SRAM memory cell can be referenced in any addressing mode.

Non-volatile data memory EEPROM μC AVR ATmega328P

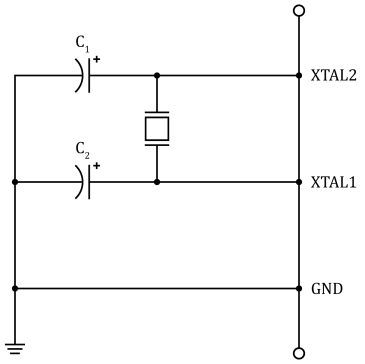
- μC AVR ATmega328P contains 1024 bytes of non-volatile data memory, organized in a separate address space.
- Individual bytes can be written or read in this space,
- EEPROM data memory is provided for 100,000 write / delete cycles,
- Access to this memory is possible via registers **EEARH, EEARL, EEDR and EECR**. These registers perform the following functions: EEARH and EEARL - address, EEDR - data entered or read out, EECR - control register,
- The EEPROM data memory is protected against damage which may cause too low supply voltage V_{CC}.

Memory of input / output devices μC AVR ATmega328P

- μC AVR ATmega328P refers to all peripherals using I / O registers located in the same address space as *general purpose registers* and SRAM memory,
- When using the IN or OUT mnemonics, use the addresses $\$00 - \$3F$, if you refer to them using the LD and ST mnemonics $\$20_{HEX}$, i.e. 32_{10} to their address (because they are preceded by 32 general purpose registers).
- Some I / O registers, depending on their function in peripheral devices, are write-protected. Some registers can be referenced only after setting the appropriate flag (see documentation).

Clock signal sources. w μC AVR ATmega328P

- **Internal generator** - does not require any external components. The nominal frequencies obtained are 1, 2, 4 or 8 MHz,
- **External Quartz Resonator**

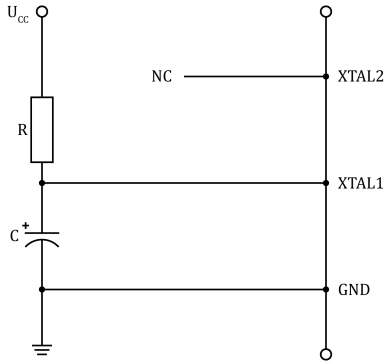


The XTAL1 and XTAL2 inputs are the internal amplifier inputs of the system. The maximum operating frequency is $16MHz$,

- **External low frequency generator** - Quartz should be attached as in the previous case. Internal capacities of $36pF$ are included. The resulting frequency is $32.768kHz$.

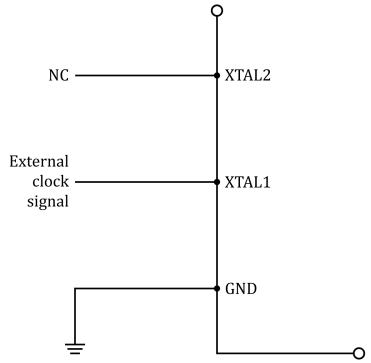
Clock signal sources in μC AVR ATmega328P

- **External generator RC**



The external elements R and C are used to build the generator,

- **External clock**



Provides an external clock signal.

Reset w μC AVR ATmega328P

- *Power-on Reset* - μC resets by lowering the supply voltage below a certain threshold V_{POT},
- *External Reset* - μC resets as a result of entering a low-level RESET pin for a sufficiently long time,
- *Watchdog Reset* - μC resets as a result of Watchdog exceeding the waiting period (Watchdog must be turned on),
- *Brown-out Reset* - μC resets when the V_{CC} supply voltage drops below V_{BOT} (the Brown-out detector must be turned on),
- *JTAG AVR Reset* - μC resets when it is logical 1 in the Reset Register (can only be detected within the JTAG system).

Interrupt system μC AVR ATmega328P

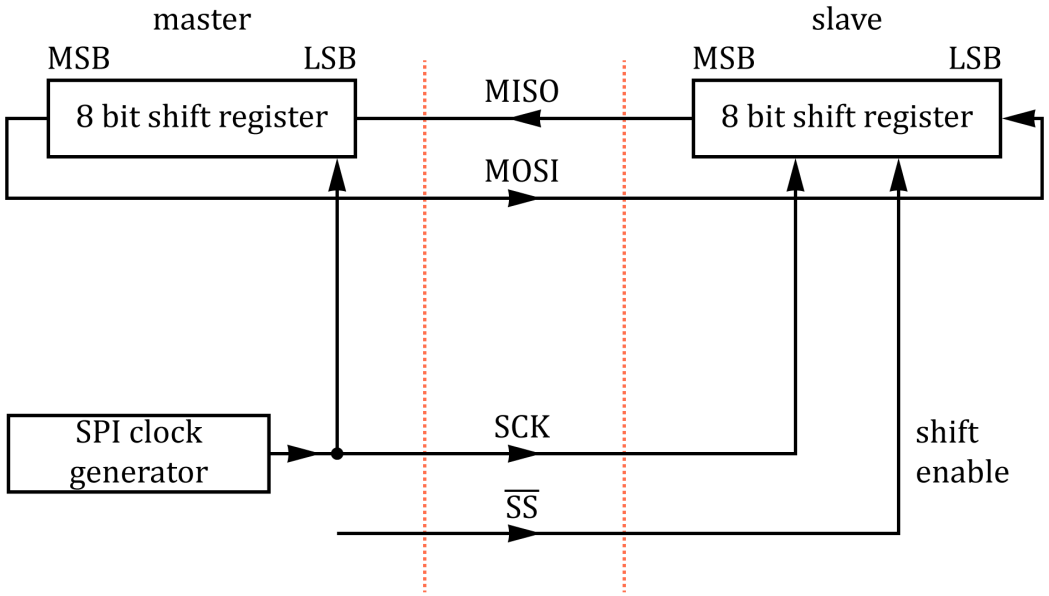
External interrupts

- External interrupts are triggered on pins INT0, INT1, and INT2,
- If the interrupt system is enabled, the INT0, INT1, and INT2 inputs will detect the interrupt, even if the pins are set as outputs - this allows you to use them as program interrupts,
- Interrupts can be triggered by a rising, falling edge or level (INT2 only edge).

Counter and timers- Timer0 i Timer1

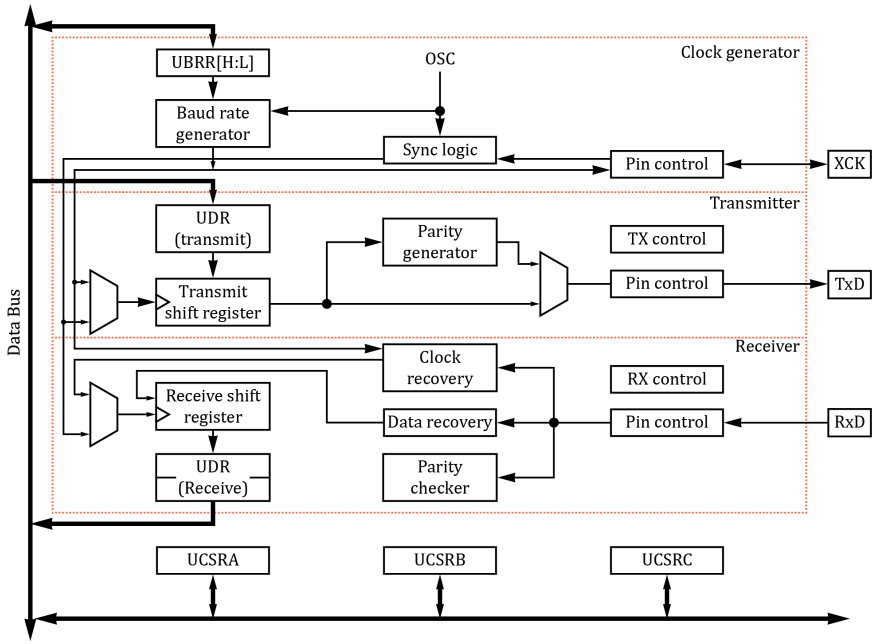
- Possibility of resetting the counters,
- Frequency generator
- Counter of external events,
- Ability to work in PWM mode,
- Clock preskaler $10 - bit$,
- A counter overflow is the source of an interrupt.

Interface SPI - Serial Peripheral Interface



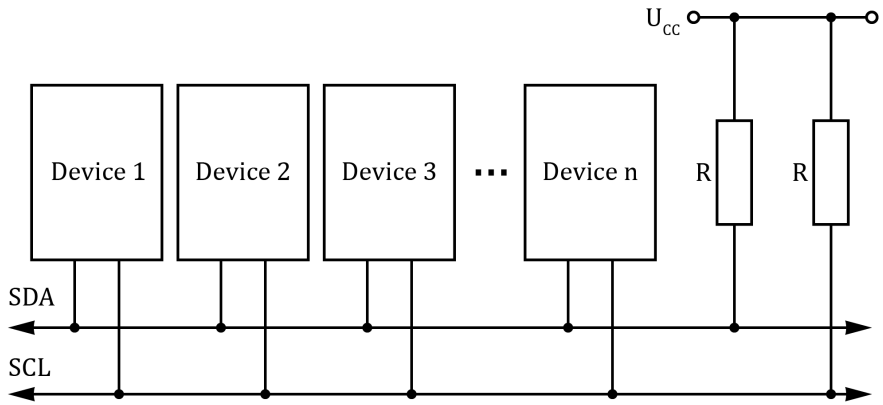
- Full-duplex, synchronous data transfer, 7 programmable transmission speeds,
- The ability to work in Master or Slave mode,
- End of transmission identified by an interrupt flag.

Serial interface USART



- Full Duplex Operation, synchronous and asynchronous transmission,
- 5, 6, 7, 8 or 9 bit data transmission with 1 or 2 stop bits, hardware parity bit, transmission error detection,
- Interrupts: TX Complete, TX Data Register Empty, RX Complete.

Interface Two-wire



- Support for Master and Slave modes, Multi-master arbitration,
- 7-bit address (128 Slave addresses), fully programmable Slave address under General Call Support
- Transmission speed up to $400kHz$

ADC Analog Digital Converter

- Nonlinearity at the level of $\frac{1}{2}$ LSB,
- Absolute accuracy of ± 2 LSB,
- Conversion time $65 \div 260 \mu s$,
- 8 multiplexed channels,
- 7 differential channels,
- 2 differential inputs with a gain of $10\times$ and $200\times$,
- Range of measured voltages $0 \div V_{CC}$,
- Choice of reference voltage: internal $2.56V$ or external,
- In *Single* conversion mode, the transducer works continuously,
- Reported termination after conversion.

Tasks for labs

1. Write a program that will send the message "Hello world"from the AVR via the serial link (after reset),
2. Perform a calculator that performs basic arithmetic operations on two operands in infix notation. Each data (including numbers and characters) should be confirmed by the enter key.
3. Perform a calculator that performs basic arithmetic operations on two operands in infix notation, which loads the entire expression and analyzes it.