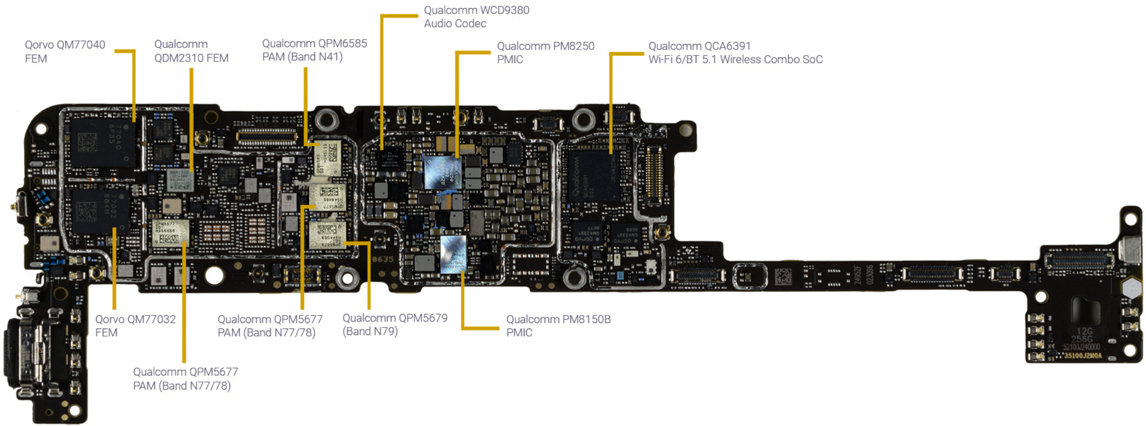


Introduction to ATmega328P MCU

Kizito NKURIKIYEYEZU, Ph.D.

Introduction to AVR microcontrollers

- Initially designed by two students at the Norwegian Institute of Technology
- AVR was developed in the year 1996 by Atmel Corporation[1]
- Available in three categories[2]:
  - TinyAVR—General purpose microcontrollers with up to 16K Bytes Flash program memory, 512 Bytes SRAM and EEPROM.
  - MegaAVR —High performance microcontrollers with Hardware Multiplier. Up to 256KB Flash, 4K Bytes EEPROM and 8KB SRAM.
  - XmegaAVR —Advanced peripherals, high, performance, DMA and Event system
  - AVR32 UC3—High performance, low power 32-bit AVR32 flash microcontrollers. Up to 512 KBytes Flash, 128 KB SRAM.
  - AVR32 AP7—High performance, low power, 32-bit CPU, and up to 32KB SRAM.
- AVR are faster, consume less power compared to some other 8-bit MCU such as PIC and intel 8051

[1] https://en.wikipedia.org/wiki/AVR_microcontrollers

[2] https://www.engineersgarage.com/avr-microcontroller-all-you-need-to-know-part-1-46/

AVR MCU Packaging[3]

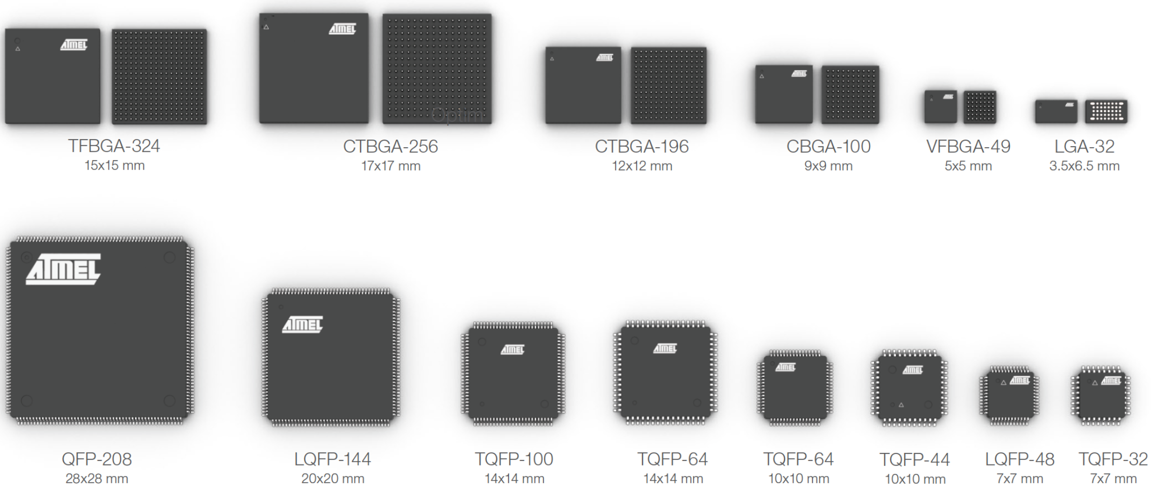


FIG 1. Surface Mount Packages

[3] https://www.engineersgarage.com/ic-packages-types/

AVR MCU Packaging

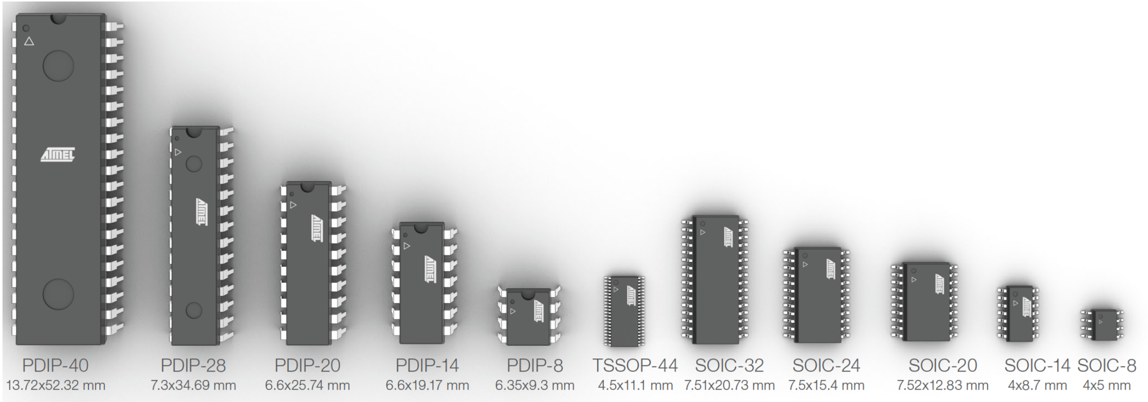


FIG 2. Dual In-line Packages

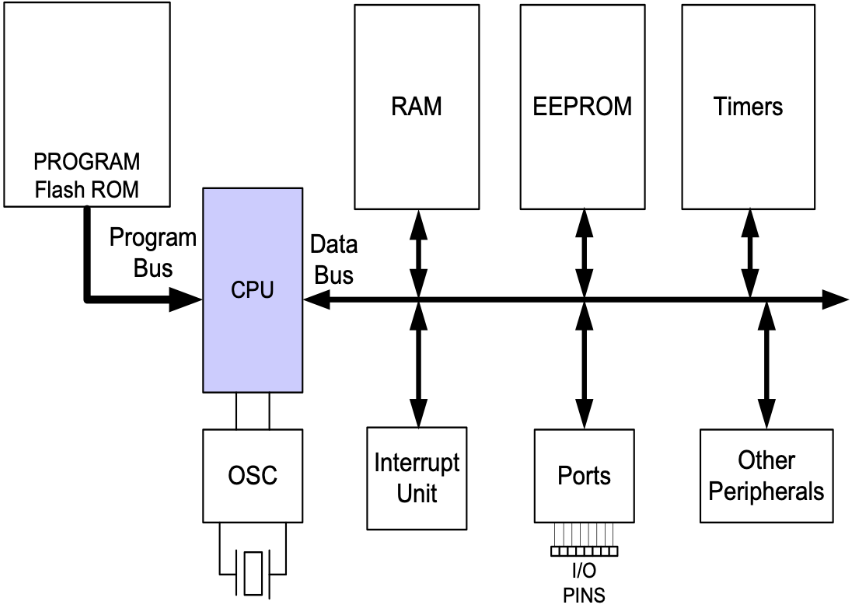


FIG 3. Simplified View of an AVR Microcontroller

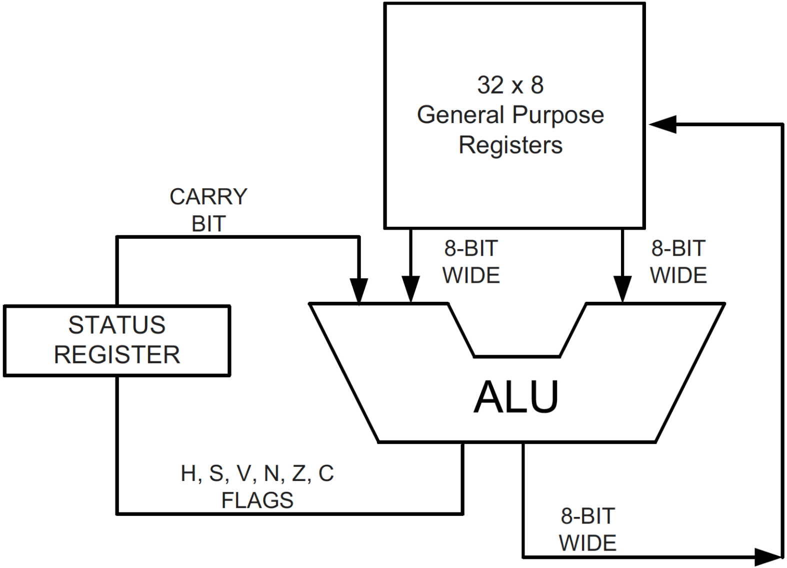


FIG 4. AVR General Purpose Registers and ALU

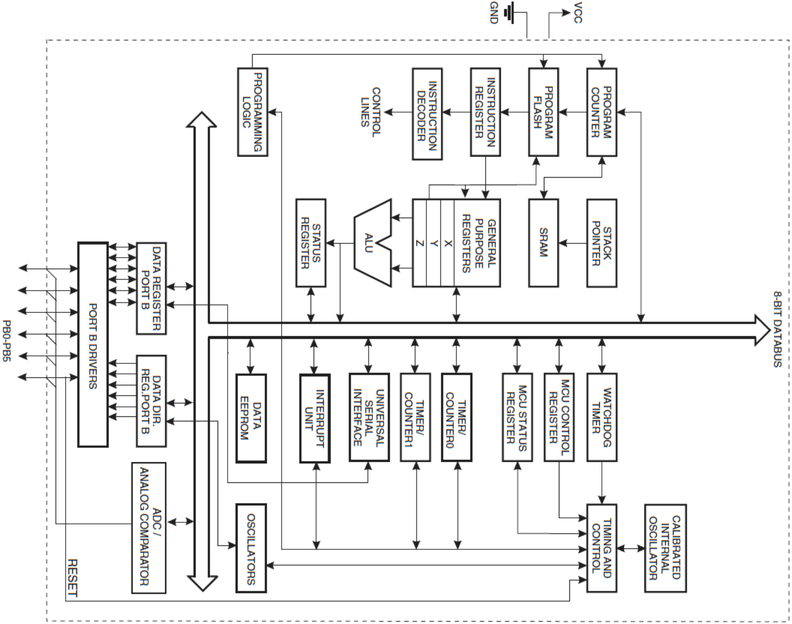


FIG 5. ATtiny25 Block Diagram

Introduction to the ATMega328

It’s the MCU in the Arduino UNO

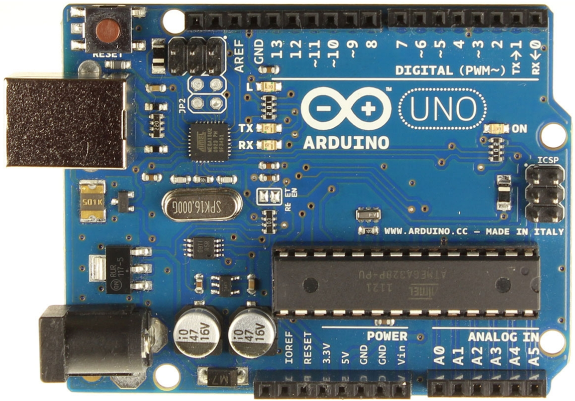


FIG 6. Arduino Uno SMD R3

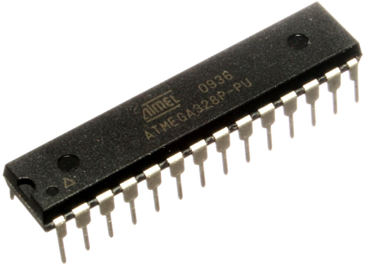


FIG 7. ATmega328P in dual in-line package

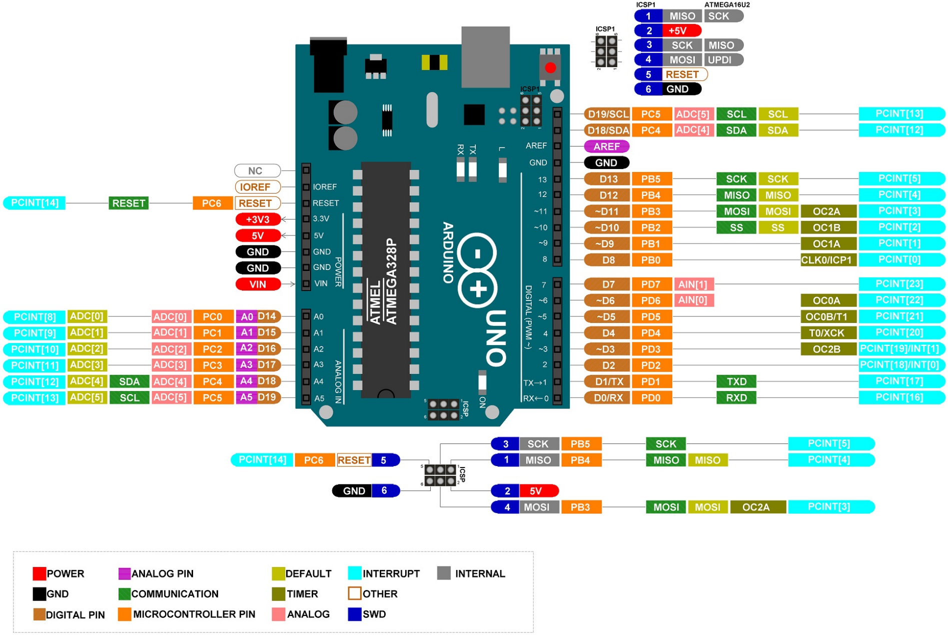


FIG 8. ATmega328P-Arduino Pin Mapping

Atmega 328 architecture

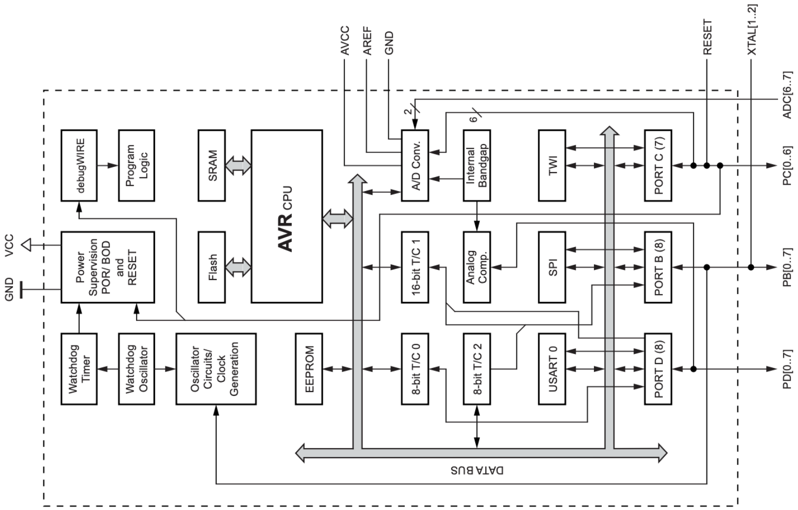
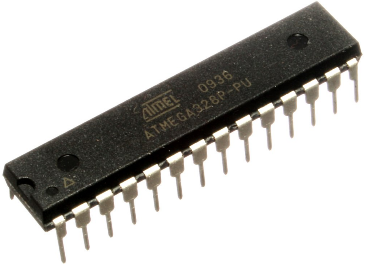


FIG 9. Atmega328 block diagram

Atmega 328 architecture

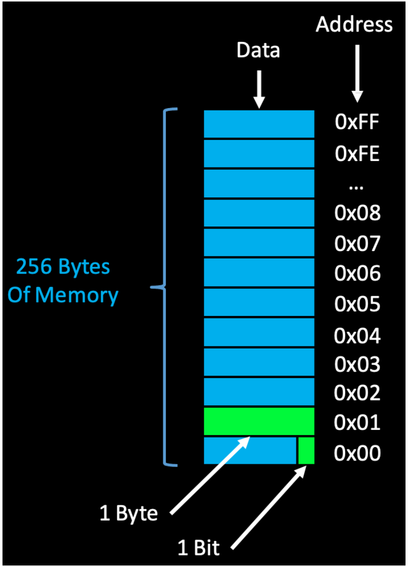
- Harvard architecture
- Programmable memory: 32K flash
- Data memory 2K SRAM
- Long therm memory EEPROM: 1K
- Maximum CPU speed: 20 MHz
- 32 8-bit general purpose registers in SRAM memory space
- 3 8-bit Ports (B, C, D)—Each port controlled by 3 8-bit registers
- Digital Communication Peripherals: 1-UART, 2-SPI, 1-I2C
- Timers: 2 x 8-bit, 1 x 16-bit



Memory system

Review: MCU memory

- Bit
  - Building Block of Memory.
  - Stores 1 piece of Boolean information (0 or 1)
- Byte – 8 Bits. Usually minimum unit for access
- Embedded systems usually have a few kilobytes of memory.
- Memory is one of the limiting factors in embedded systems



Review: MCU memory

- Computer Systems contain a mixture of memories
- Memory considerations Technology:
  - Capacity
  - Power
  - Speed/Latency
  - Price

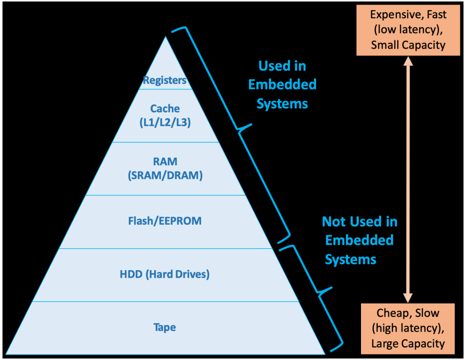
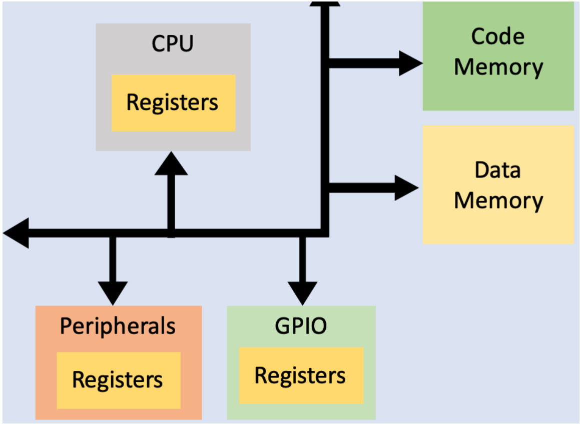


FIG 10. Memory hierarchy
The memory hierarchy separates computer storage into a hierarchy based on response time. Fast memory is usually small and expensive. Embedded systems are usually limited to small memory

Review: MCU memory

- An executable program consists of program code and program data compiled for a particular architecture and platform
- Three types of stoage needed for a program
  - Code Memory
  - Data Memory
  - Runtime State of Program
- The compiler tracks and maps memory from program code and program data into segments
  - Code Segment (Flash)
  - Data Segment (SRAM)



AVR IO port

AVR input/output (I/O) port

- Read-Modify-Write capability, i,.e, you can change pin direction, pin value, or pin pull-up resistor without effecting any other pins in the port
- All AVR ports have:
  - bit-selectable pull-up resistors
  - bit-selectable tri-state outputs
  - schmitt trigger (i.e., comparator circuit) input buffers
  - are synchronized to the system clock to prevent metastability
  - have symmetrical DC drive capability

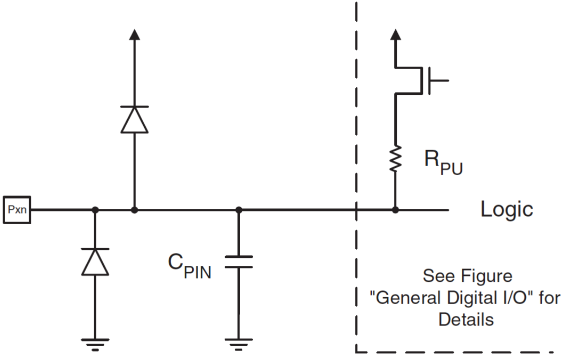


FIG 11. AVR I/O Pin Equivalent Schematic
The AVR I/O ports are the path to the outside world. The ports has protection diodes and programmable pull-up resistor

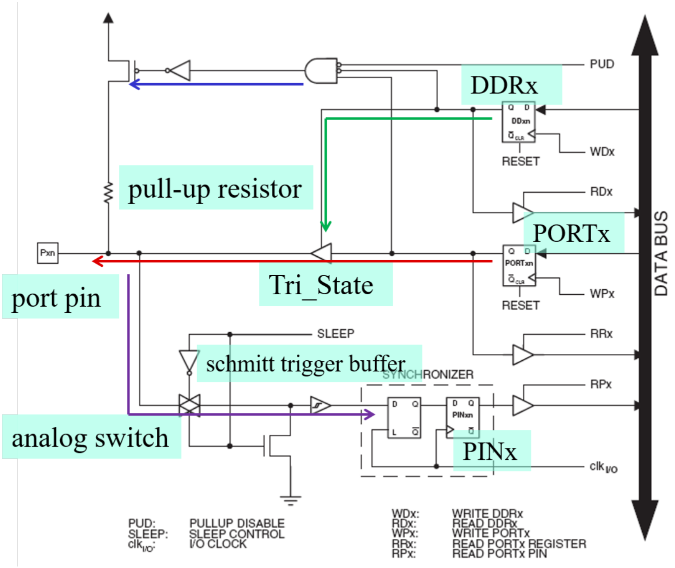


FIG 12. The ports are bi-directional I/O ports with optional internal pull-ups.

TAB 1. Absolute Maximum Ratings

Operating Temperature	-55°C to +125°C
Storage Temperature	-65°C to +150°C
Voltage on any Pin except $\overline{RESET}$ with respect to Ground	-0.5V to V_{CC}+0.5V
Voltage on $\overline{RESET}$ with respect to Ground	-0.5V to +13.0V
Maximum Operating Voltage	6.0V
DC Current per I/O Pin	40.0 mA
DC Current V_{CC} and GND Pins	200.0 - 400.0mA

TAB 2. AVR I/O port DC characteristics

T_A = -40°C to 85°C, V_{CC} = 2.7V to 5.5V (unless otherwise noted)

Symbol	Parameter	Condition	Min	Typ	Max	Units
V_{IL}	Input Low Voltage except XTAL1 and $\overline{\text{RESET}}$ pins	V_{CC} = 2.7V - 5.5V	-0.5		0.2 V_{CC}[1]	V
V_{IH}	Input High Voltage except XTAL1 and $\overline{\text{RESET}}$ pins	V_{CC} = 2.7V - 5.5V	0.6 V_{CC}[2]		V_{CC} + 0.5	V
V_{IL1}	Input Low Voltage XTAL1 pin	V_{CC} = 2.7V - 5.5V	-0.5		0.1 V_{CC}[1]	V
V_{IH1}	Input High Voltage XTAL1 pin	V_{CC} = 2.7V - 5.5V	0.7 V_{CC}[2]		V_{CC} + 0.5	V
V_{IL2}	Input Low Voltage $\overline{\text{RESET}}$ pin	V_{CC} = 2.7V - 5.5V	-0.5		0.2 V_{CC}[1]	V
V_{IH2}	Input High Voltage $\overline{\text{RESET}}$ pin	V_{CC} = 2.7V - 5.5V	0.85 V_{CC}[2]		V_{CC} + 0.5	V
V_{OL}	Output Low Voltage[3] (Ports A,B,C,D, E, F, G)	I_{OL} = 20mA, V_{CC} = 5V I_{OL} = 10mA, V_{CC} = 3V			0.7 0.5	V V
V_{OH}	Output High Voltage[4] (Ports A,B,C,D, E, F, G)	I_{OH} = -20mA, V_{CC} = 5V I_{OH} = -10mA, V_{CC} = 3V	4.2 2.2			V V
I_{IL}	Input Leakage Current I/O Pin	Vcc = 5.5V, pin low (absolute value)			1.0	µA
I_{IH}	Input Leakage Current I/O Pin	Vcc = 5.5V, pin high (absolute value)			1.0	µA
R_{RST}	Reset Pull-up Resistor		30		85	kΩ
R_{PEN}	PEN Pull-up Resistor		30		60	kΩ
R_{PU}	I/O Pin Pull-up Resistor		20		50	kΩ

TAB 3. AVR I/O port DC characteristics (continued)

T_A = -40°C to 85°C, V_{CC} = 2.7V to 5.5V (unless otherwise noted) (Continued)

Symbol	Parameter	Condition	Min	Typ	Max	Units
I_{CC}	Power Supply Current	Active 4MHz, V_{CC} = 3V (ATmega128L)		5	5.5	mA
		Active 8MHz, V_{CC} = 5V (ATmega128)		17	19	
		Idle 4MHz, V_{CC} = 3V (ATmega128L)		2	2.5	
		Idle 8MHz, V_{CC} = 5V (ATmega128)		8	11	
	Power-down mode	WDT enabled, V_{CC} = 3V		< 15	25	µA
		WDT disabled, V_{CC} = 3V		< 5	10	
V_{ACIO}	Analog Comparator Input Offset Voltage	V_{CC} = 5V $V_{in} = V_{CC}/2$			40	mV
I_{ACLK}	Analog Comparator Input Leakage Current	V_{CC} = 5V $V_{in} = V_{CC}/2$	-50		50	nA
t_{ACPD}	Analog Comparator Propagation Delay	V_{CC} = 2.7V V_{CC} = 5.0V		750 500		ns

Notes:
1. “Max” means the highest value where the pin is guaranteed to be read as low
2. “Min” means the lowest value where the pin is guaranteed to be read as high
3. Although each I/O port can sink more than the test conditions (20mA at V_{CC} = 5V, 10mA at V_{CC} = 3V) under steady state conditions (non-transient), the following must be observed:
   TQFP and QFN/MLF Package:
   1] The sum of all IOL, for all ports, should not exceed 400mA.
   2] The sum of all IOL, for ports A0 - A7, G2, C3 - C7 should not exceed 100mA.
   3] The sum of all IOL, for ports C0 - C2, G0 - G1, D0 - D7, XTAL2 should not exceed 100mA.
   4] The sum of all IOL, for ports B0 - B7, G3 - G4, E0 - E7 should not exceed 100mA.
   5] The sum of all IOL, for ports F0 - F7, should not exceed 100mA.
   If IOL exceeds the test condition, VOL may exceed the related specification. Pins are not guaranteed to sink current greater than the listed test condition.
4. Although each I/O port can source more than the test conditions (20mA at Vcc = 5V, 10mA at Vcc = 3V) under steady state conditions (non-transient), the following must be observed:
   TQFP and QFN/MLF Package:
   1] The sum of all IOH, for all ports, should not exceed 400mA.
   2] The sum of all IOH, for ports A0 - A7, G2, C3 - C7 should not exceed 100mA.
   3] The sum of all IOH, for ports C0 - C2, G0 - G1, D0 - D7, XTAL2 should not exceed 100mA.
   4] The sum of all IOH, for ports B0 - B7, G3 - G4, E0 - E7 should not exceed 100mA.
   5] The sum of all IOH, for ports F0 - F7, should not exceed 100mA.
   If IOH exceeds the test condition, VOH may exceed the related specification. Pins are not guaranteed to source current greater than the listed test condition.

AVR MCU connection to a PCB

How to you connect the MCU to a circuit?

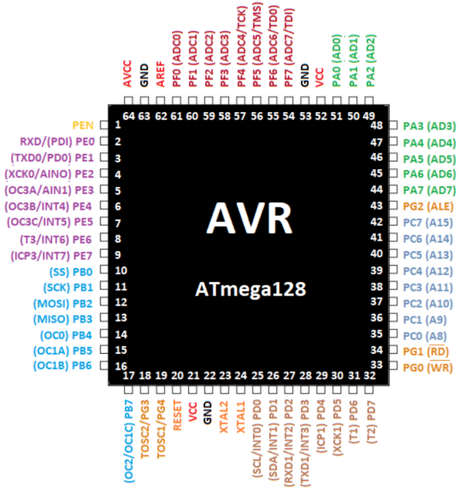


FIG 13. ATMEGA128 pin out

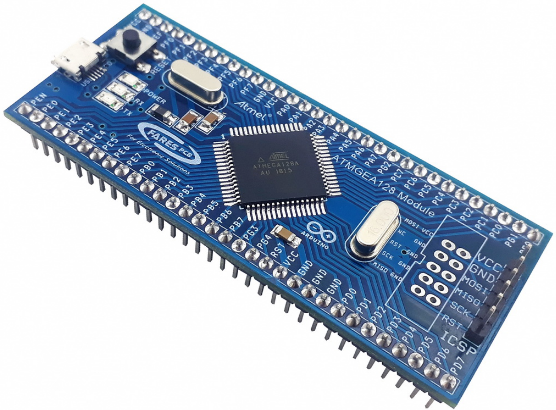
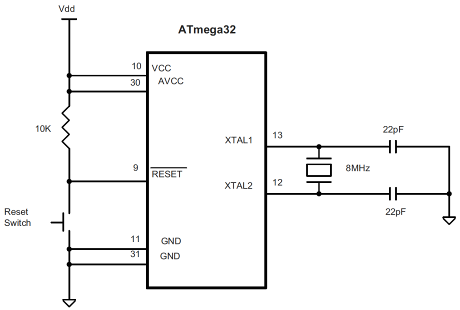


FIG 14. ATMEGA128 Module with Arduino bootloader

AVR pins connection

- **VCC**—this pin provides supply voltage to the chip. The typical voltage source is +5 V. Some AVR family members have lower voltage for VCC pins in order to reduce the noise and power dissipation of the AVR system.
- **AVCC** is the supply voltage pin for Port A and the A/D Converter. It should be externally connected to VCC, even if the ADC is not used.
- **AREF** is the analog reference pin for ADC.



Digital power supply

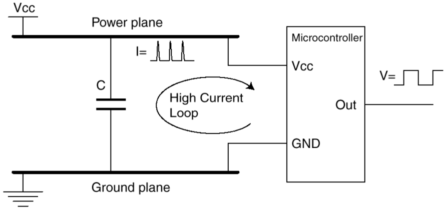


FIG 15. Insufficient power supply decoupling
The capacitor is placed too far away from the microcontroller, creating a large high current loop. As a result of this, noise is spread more easily to other devices on the board, and radiated emission from the board is increased even further. The whole ground plane will act as an antenna for the noise, instead of only the high current loop.

Digital power supply

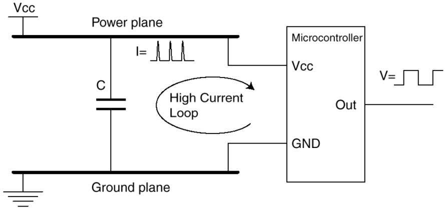


FIG 15. Insufficient power supply decoupling
The capacitor is placed too far away from the microcontroller, creating a large high current loop. As a result of this, noise is spread more easily to other devices on the board, and radiated emission from the board is increased even further. The whole ground plane will act as an antenna for the noise, instead of only the high current loop.

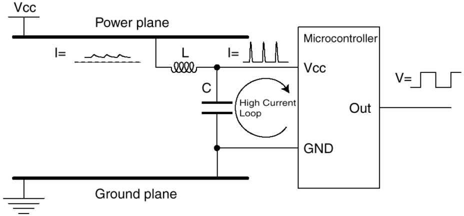


FIG 16. Better placement of the capacitor
The lines that are part of the high current loop are not part of the power or ground planes. This prevents the power and ground planes to spread a lot of noise. Furthermore, a series inductor is inserted to reduce the switching noise on the power plane.

Analog power supply

- The ADC has a separate analog supply voltage pin called AVCC.
- AVCC make sure that the analog circuits less prone to the digital noise originating from the switching of the digital circuits.
- The ADC supply voltage must be decoupled separately
- The analog ground should be separated from the digital ground.

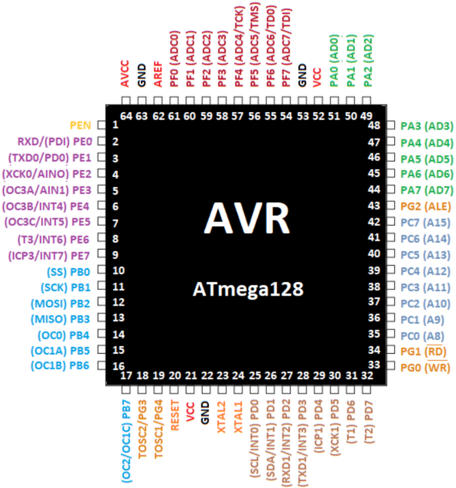


FIG 17. ATMEGA128 pin out

Reset hardware

- The RESET pin on the AVR is active LOW, and setting the pin LOW externally will thus result in a reset of the AVR.
- The recommended pull-up resistor is 4.7kOhm or larger
- The capacitor protect the RESET line further from noise
- The components should be located physically close to the RESET pin of the AVR.

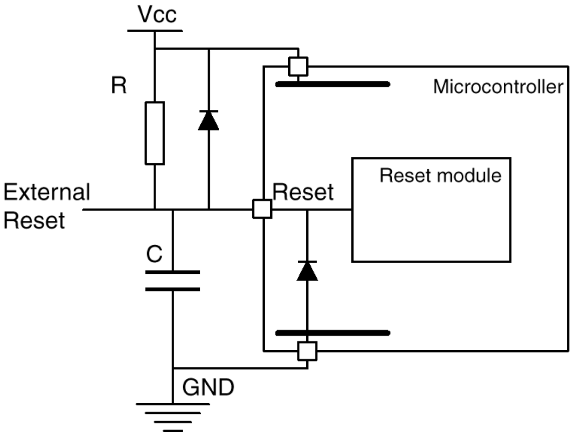
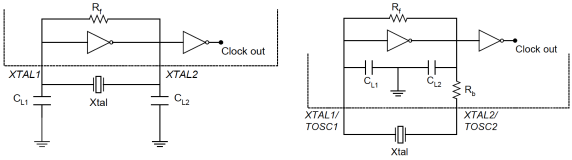


FIG 18. Recommended Reset Pin connection.

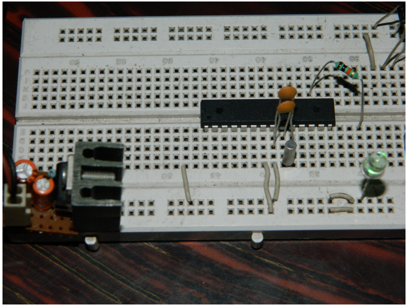
Oscillator Hardware

- The oscillator circuit is the "heartbeat" of the system and is crucial to correct operation.
- As a general rule, the speed at which an embedded system runs is directly determined by the oscillator frequency: in most cases, if you double the oscillator frequency, the application will run twice as fast.
- Although most MCU have internal oscillator, it is often necessarily to use an external oscillator for an accurate and stable frequency



(A) (B)

Notes: (A) Oscillator circuit for crystals and ceramic resonators faster than 400kHz
(B) Circuit for low frequency crystals (32.768kHz) (not on all AVRs)



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