Mikrocontroller ATmega328P

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- Register PORTB
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- Assembler: Quelle zum Opcode
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- Programm schreiben, Assembler-Code
- Assembler-Code-Listing
- Simulation SIM_02
- Scope SIM_02, SIM_05
- Cycles
- Informationen

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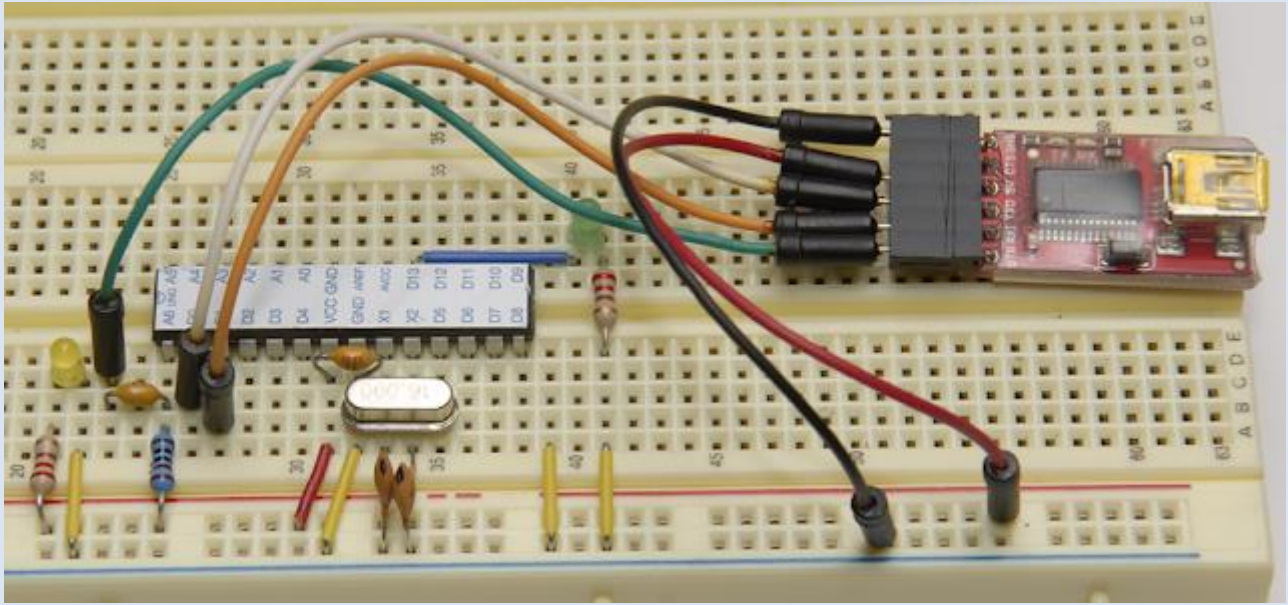
Thema

ATmega328p	Den ATmega328p Microcontroller (µC) in seinen Funktionen kennen lernen.
Idee	Gerd‘s AVR Simulator
Aufgabe	Maximale Frequenz einer Rechteckschwingung?
	• Experimentierbord mit ATmega328p Standalone.
	• Physikalische Pins des ATmega328p.
	• Erfahrungen mit Arduino.
	• Interner Aufbau des ATmega328.
	• Organisation der Speicher.
	• CPU und Register
	• Sprache Assembler
	• Gerd‘s AVR Simulator
	• Rechteckschwingung, Takte
Danksagung	Das Material von Gerhard Schmidt, DG4FAC, war sehr hilfreich bei der Erarbeitung des Themas. http://www.dg4fac.de/ http://www.avr-asm-tutorial.net/

Arduino Standalone



Quelle:
https://www.yuriystoys.com/2012/02/arduino-on-beadboard-uploading-your.html

FTDI (USB-USART-Interface)

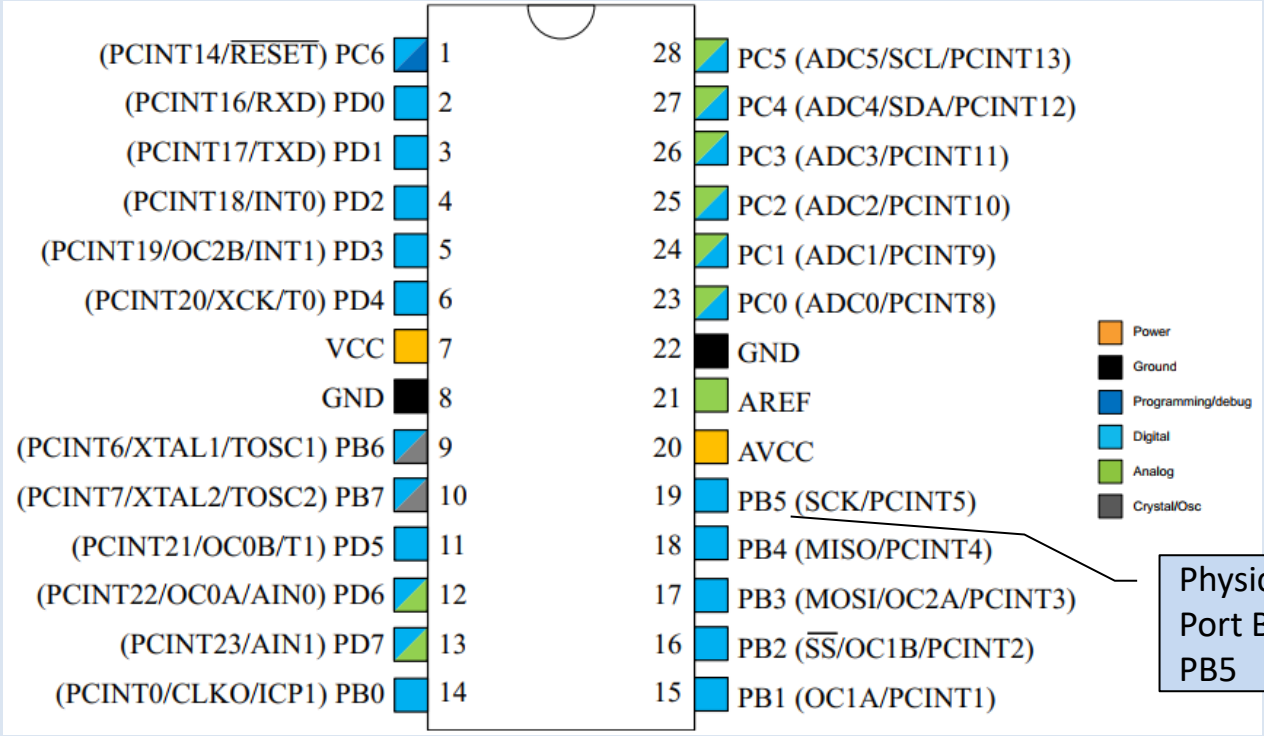
FTDI Tx an IC Pin #2 (Tx an Rx)
FTDI Rx an IC Pin #3 (Rx an Tx)
FTDI DTR an Kondensator
0 ,1 µF und weiter an IC Pin 1
FTDI Gnd an Steckbrett
FTDI 5V an Steckbrett

ATmega328P Daten

Hersteller	Microchip (vormals Atmel)
Familie	8-Bit-Mikrocontroller
Architektur	RISC
Anzahl Instruktionen	131
Register	32 x 8
Quarz	16 MHz
	16 MIPS at 16 MHz
Flash Programm Speicher	32 KiB kibibyte
EEPROM	1 KiB kibibyte
SRAM	2 KiB kibibyte
Peripherie	Timer/Counter; PWM; ADC; USART; SPI; I^2C
Betriebsspannung	2,7 V bis 5,5 V

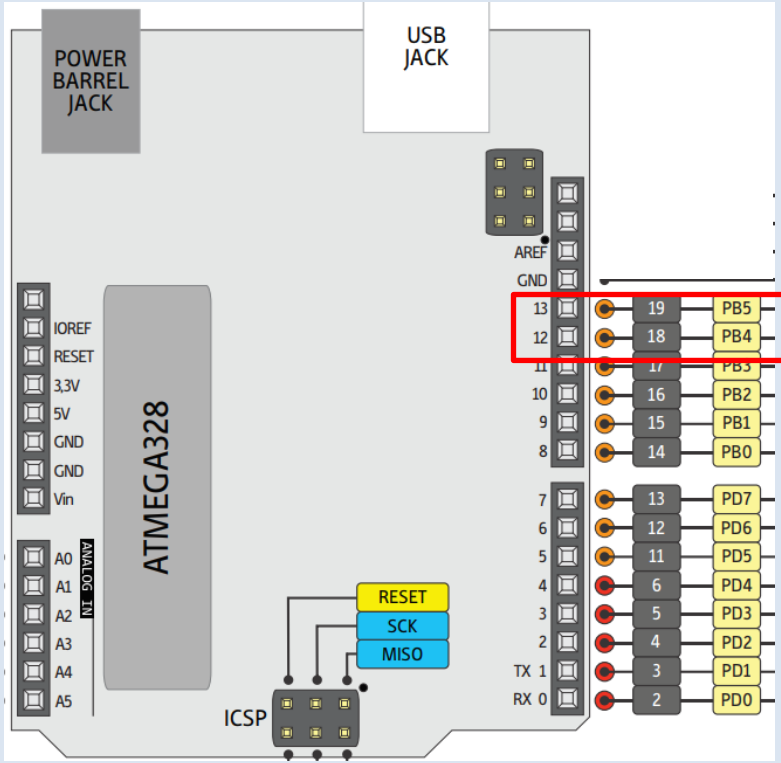
Quelle: Data Sheet Complete DS40002061A-page 1

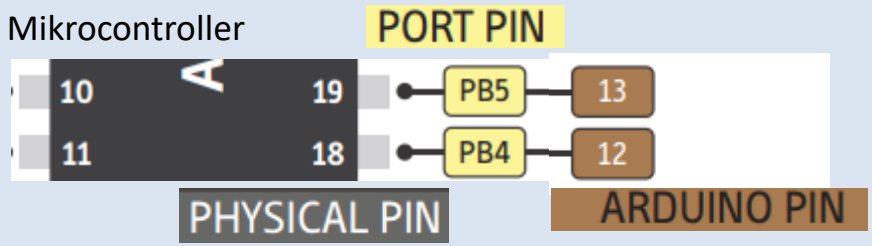
Externe Anschlüsse



Quelle: Atmel-42735A-ATmega328/P_Datasheet_Complete-06/2016

Arduino PINOUT Diagramm



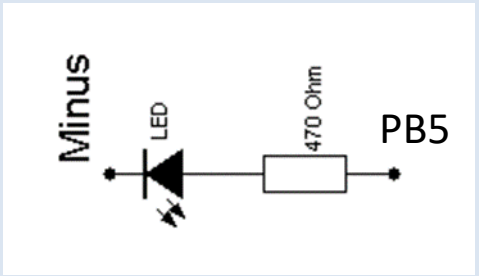


Crux der Bezeichnungen!	
Arduino:	ARDUINO PIN (13)
Mikroncontroller:	PHYSICAL PIN (19)
Pinout Diagramm (Datasheet):	PORT PIN (PB5)
	Adresse/Wert
Port B Data **Register**	PORTB (0x05)
Port B **Pin** Data	PORTB5 (5)
Port B Data Direction Register	DDRB (0x04)
Port B Pin Data Direction Register	DDB5 (5)
Port B Input (Pins) Register	PINB (0x03)

Quelle: The unofficial Arduino Uno Pinout Diagram

Arduino IDE Erfahrungen

Aufgabe:	Blinkende LED	
Arduino:	ARDUINO PIN:	Pin 13
Mikrokontroller:	PHYSICAL PIN	Pin 19
	Clock frequency	16 MHz



Arduino IDE Sketch

```
void setup() {
  pinMode(13, OUTPUT); // Arduino PIN 13
}

void loop() {
  digitalWrite(13, HIGH);
  delay(1000);
  digitalWrite(13, LOW);
  delay(1000);
}
```

Wie aus C++ Code ein maschineller Code wird, bleibt verborgen!

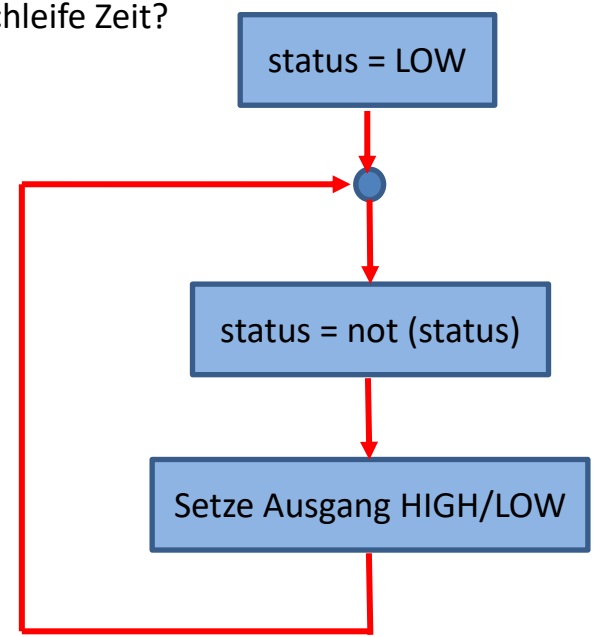
Flash	924 Bytes

Analyse

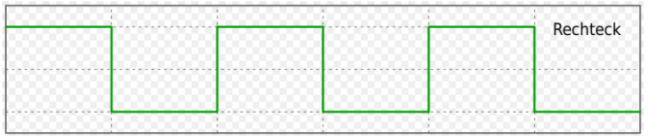
Ablaufplan

Jede Anweisung kostet Zeit (cyles)!

- Zuweisung Zeit?
- digitalWrite() Zeit?
- Schleife Zeit?



Frequenz = 1 / Periodendauer
f = 1 / T
16 MHz = 1 / 62,5 ns
1 cyle = 1 Takt = 62,5 ns

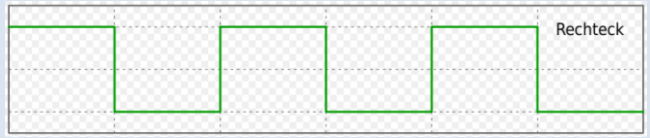


$$\frac{16\ MHz}{cyles} = \frac{1}{cyles * 62{,}5\ ns}$$

Wieviel Takte sind mindestens erforderlich, um eine 1 Periode zu erreichen?

Rechteckschwingung Arduino (*.ino)

Aufgabe:	Rechteckschwingung	Ziel maximale Frequenz?
Arduino:	ARDUINO PIN:	Pin 13
Mikrokontroller:	PHYSICAL PIN:	Pin 19
	Clock frequency	16 MHz



Arduino IDE Sketch

```
boolean status = 0;
void setup() {
  pinMode(13, OUTPUT);
}

void loop() {
  status = !status;
  digitalWrite(13, status);
}
```

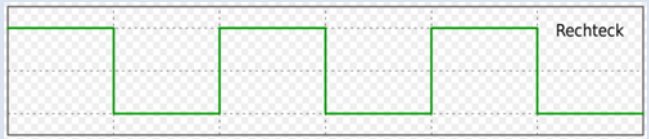
f ≈ 158 kHz
T ≈ 6,32 µs
≈ 1/100 vom Quarz

Flash

```
750 Bytes
```

Rechteckschwingung Arduino (*.cpp)

Aufgabe:	Rechteckschwingung	Ziel maximale Frequenz?
Arduino:	ARDUINO PIN:	Pin 13
Mikrokontroller:	PHYSICAL PIN:	Pin 19
	Port B Data **Register**	PORTB
	Port B **Pin** Data	PORTB5
	Port B Data Direction **Register**	DDRB
	Port B **Pin** Data Direction Register	DDB5
	Clock frequency	16 MHz



Arduino IDE Sketch

```
// Die *.ino-Datei bleibt bestehen, nur Inhalte löschen
// Zweiter Tab mit main.cpp

#include <avr/io.h>     // Defines names for AVR registers
                        // SFR special function registers
int main(void) {
    DDRB |= (1 << DDB5);          // make PORTB5 as output
    for(;;) {
        PORTB ^= (1 << PORTB5);   // toggle Pin PORTB5
    }
    return 0;           // the program executed successfully
}
```

f ≈ 1,6 MHz
T ≈ 624 ns
≈ 1/10 vom Quarz

Flash: 144 Bytes

AVR Architektur

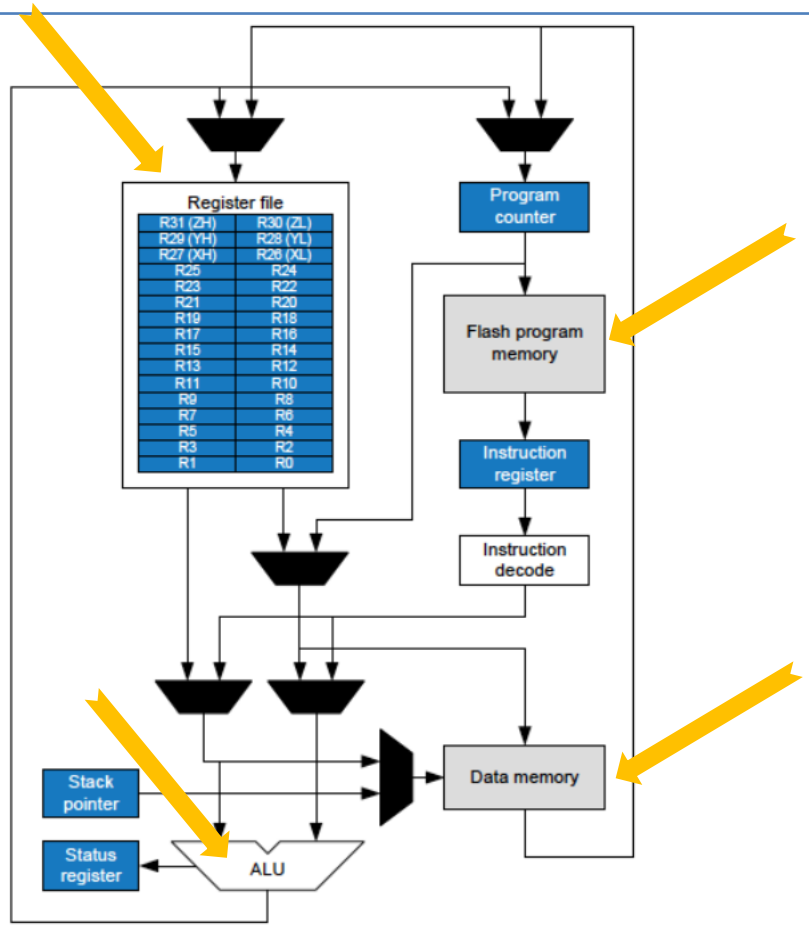
Harvard-Architektur
RISC

Program **Flash** Memory for Application …

Data Memory
- 32 x 8 General Purpose Working Registers
- I/O memory space wit 64 addresses, **Ports**
- Internal **SRAM**

ALU supports arithmetic and logic operations between registers or between a constant and a register

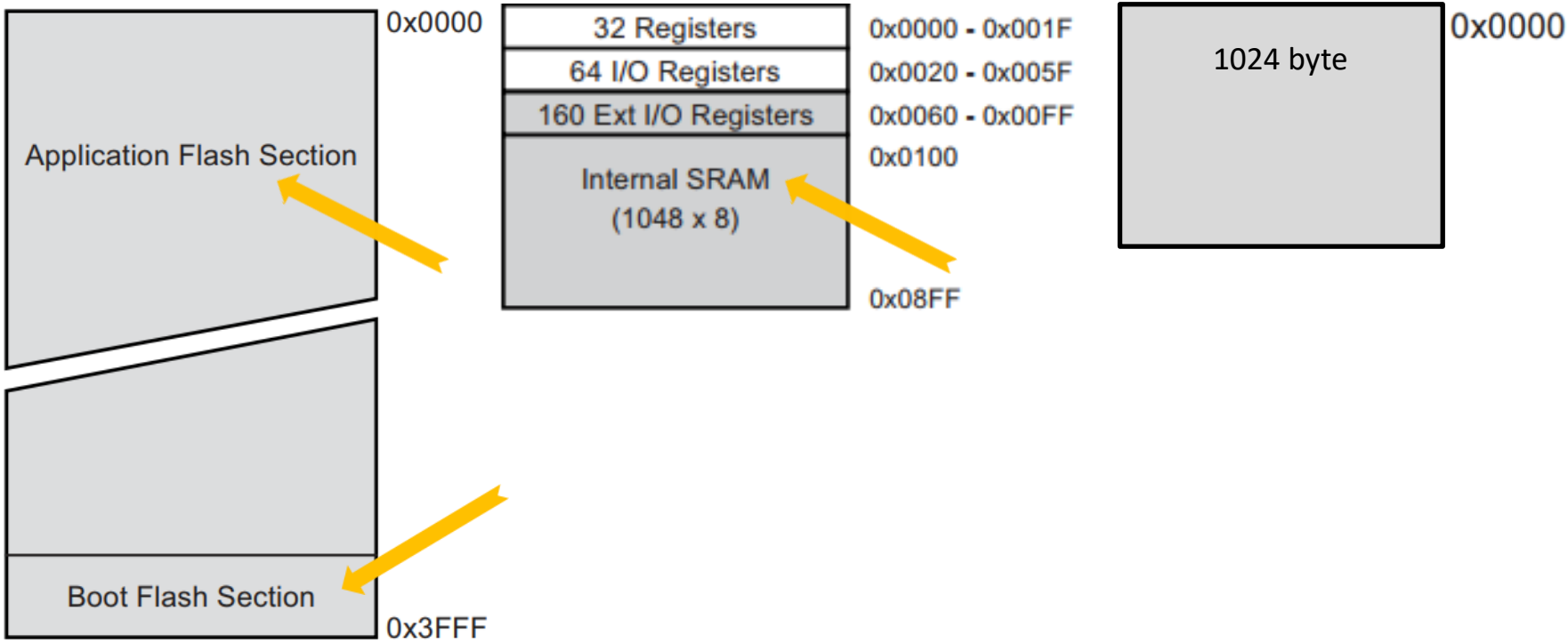
Digital Signalprocessing



Quelle: https://microchipdeveloper.com/8avr:avrcore

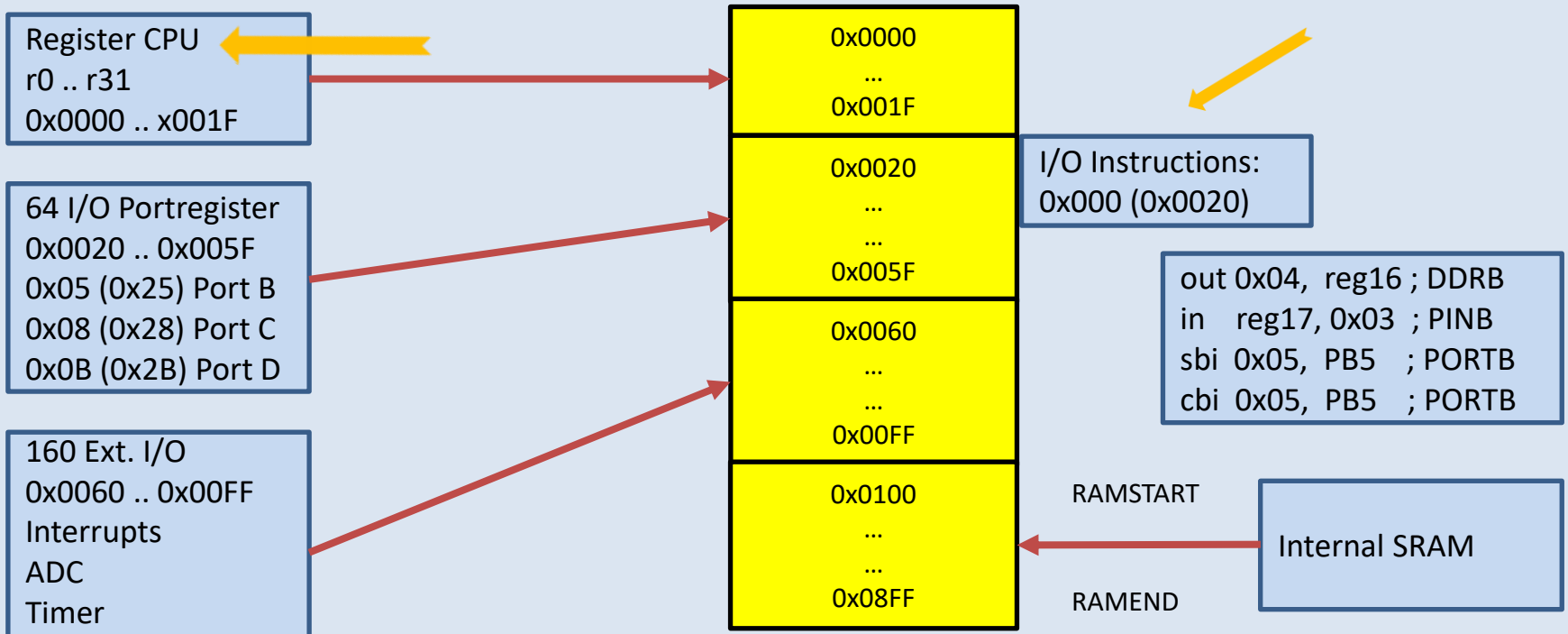
Memory

Program Memory (nicht flüchtig)	SRAM Data Memory (flüchtig)	EEPROM Data Memory

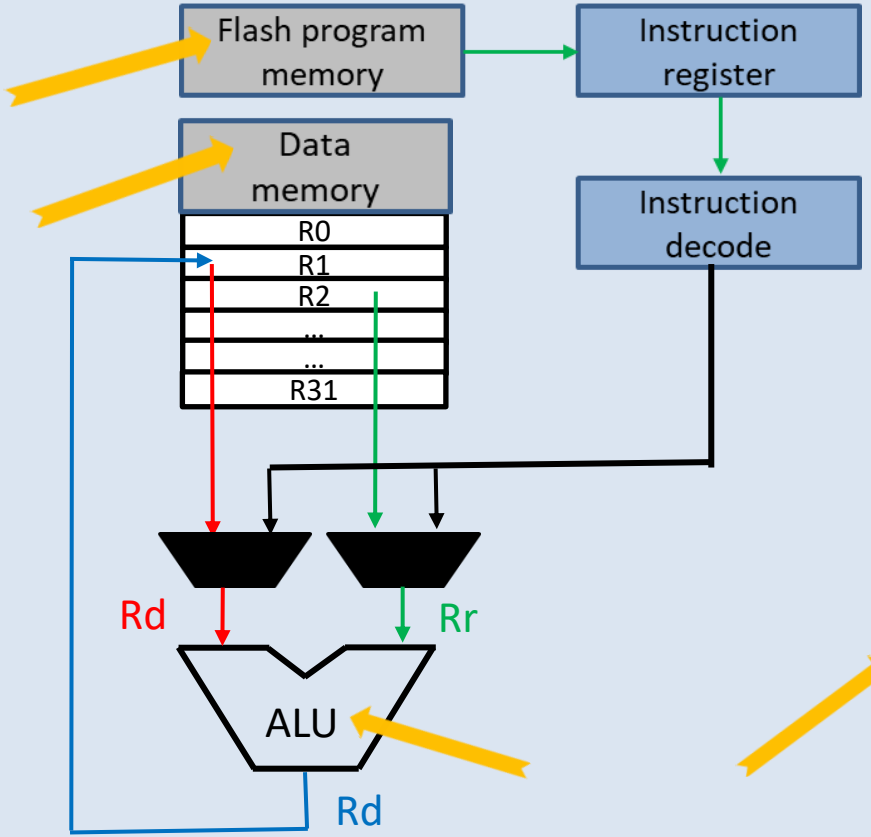


Quelle: © Atmel ATmega328P [DATASHEET] 7810D–AVR–01/15 page 17, 18

SRAM Data Memory



Arithmetic logic unit



Innerhalb eines Taktes werden arithmetische Operationen zwischen General Purpose Registern (oder einem Register und einer Konstanten) ausgeführt.
Die Operationen haben die Kategorien: Arithmetisch, logisch, bit-Operationen

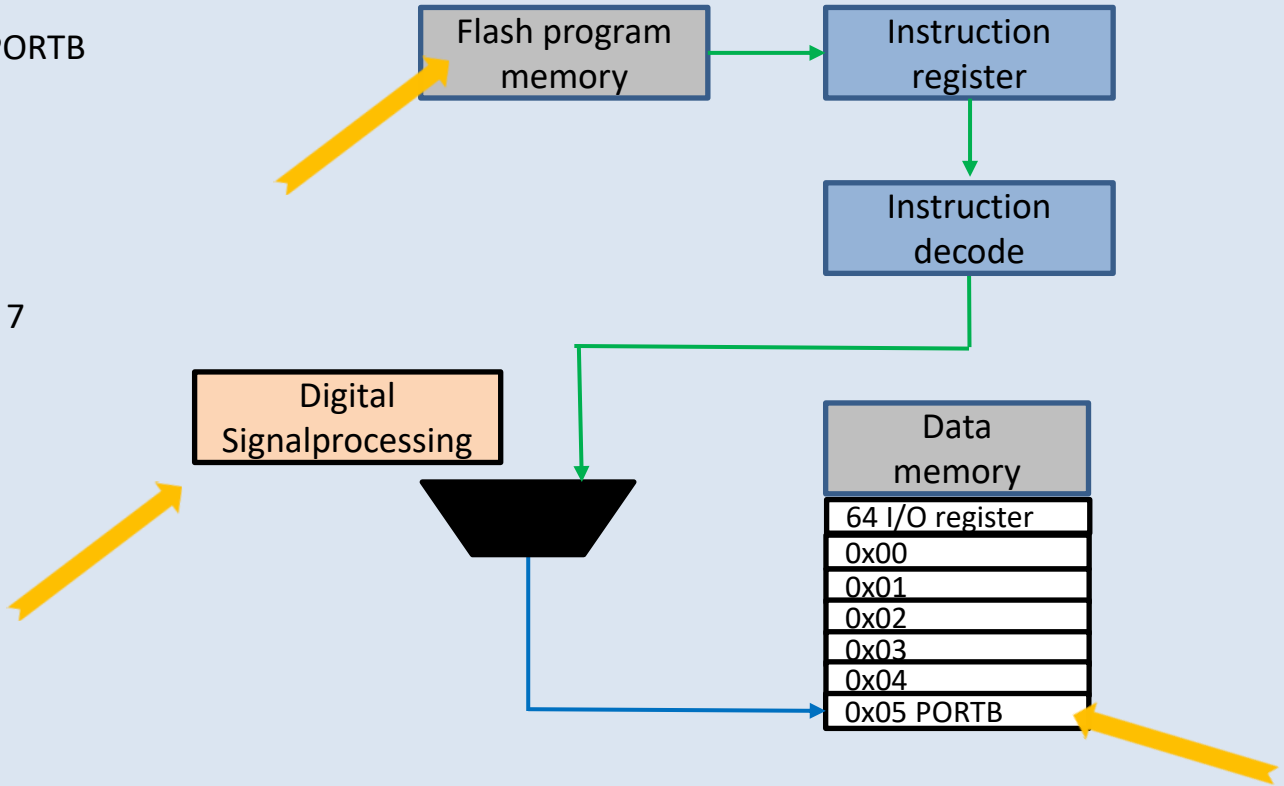
Beispiel:
add r1,r2 ; Add r2 to r1 (r1=r1+r2)

ADD Rd,Rr
Rd ← Rd + Rr
$0 \le d \le 31, 0 \le r \le 31$

Signalprocessing

Beispiel:
Setze High Bit in PORTB
sbi 0x05, 0x01

Syntax:
SBI A,b
I/O(A,b) ← 1
0 ≤ A ≤ 31, 0 ≤ b ≤ 7



Register PORTB

PORTB – The Port B Data Register

Bit	7	6	5	4	3	2	1	0	
0x05 (0x25)	PORTB7	PORTB6	PORTB5	PORTB4	PORTB3	PORTB2	PORTB1	PORTB0	PORTB
Read/Write	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	
Initial Value	0	0	0	0	0	0	0	0	

DDRB – The Port B Data Direction Register

Bit	7	6	5	4	3	2	1	0	
0x04 (0x24)	DDB7	DDB6	DDB5	DDB4	DDB3	DDB2	DDB1	DDB0	DDRB
Read/Write	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	
Initial Value	0	0	0	0	0	0	0	0	

PINB – The Port B Input Pins Address

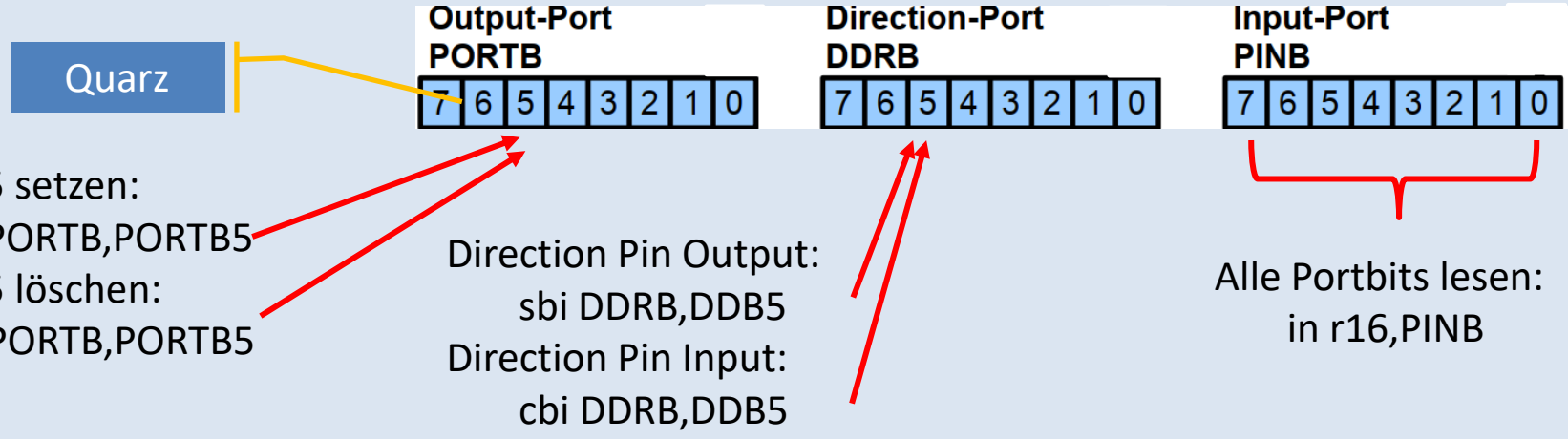
Bit	7	6	5	4	3	2	1	0	
0x03 (0x23)	PINB7	PINB6	PINB5	PINB4	PINB3	PINB2	PINB1	PINB0	PINB
Read/Write	R	R	R	R	R	R	R	R	
Initial Value	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	

Quelle: © 2018 Microchip Technology Inc. Data Sheet Complete DS40002061A-page 100

I/O-Port programmieren

ATmega328P Ports und Pins:
PORTB: PORTB0 bis PORTB5
PORTC: PORTC0 bis PORTC5
PORTD: PORTD0 bis PORTD7

I/O-Pin
Arduino Pin 13
Mikrokontroller Pin 19
Port Pin PORTB5



Mnemonic SBI

Description

Sets a specified bit in an I/O Register. This instruction operates on the lower 32 I/O Registers – addresses 0-31.

Operation:

(i) I/O(A,b) ← 1

Syntax:	Operands:	Program Counter:
(i) SBI A,b	0 ≤ A ≤ 31, 0 ≤ b ≤ 7	PC ← PC + 1

16-bit Opcode:

1001	1010	AAAA	Abbb

Example:

```
sbi 0x1C,0 ; Set read bit in EECR
```

Words: 1 (2 bytes)

Cycles: 2

Quelle: © 2020 Microchip Technology Inc. Manual DS40002198A-page 116

Mnemonic OUT

Description

Stores data from register Rr in the Register File to I/O space.

Operation:

(i) I/O(A) ← Rr

Syntax:	Operands:	Program Counter:
(i) OUT A,Rr	0 ≤ r ≤ 31, 0 ≤ A ≤ 63	PC ← PC + 1

16-bit Opcode:

1011	1AAr	rrrr	AAAA

Example:

```
clr r16 ; Clear r16
ser r17 ; Set r17
out 0x18,r16 ; Write zeros to Port B
nop ; Wait (do nothing)
```

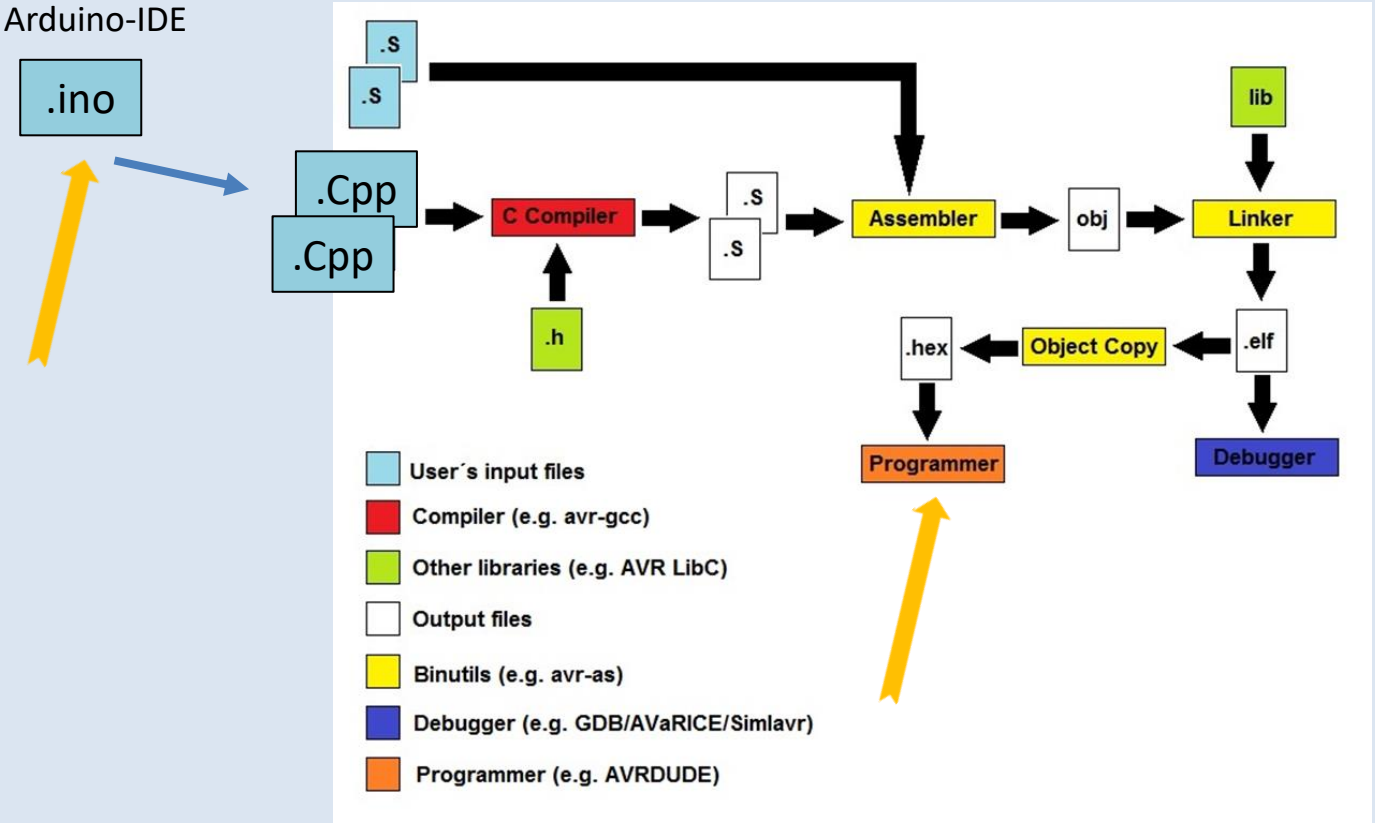
Words: 1 (2 bytes)

Cycles: 1

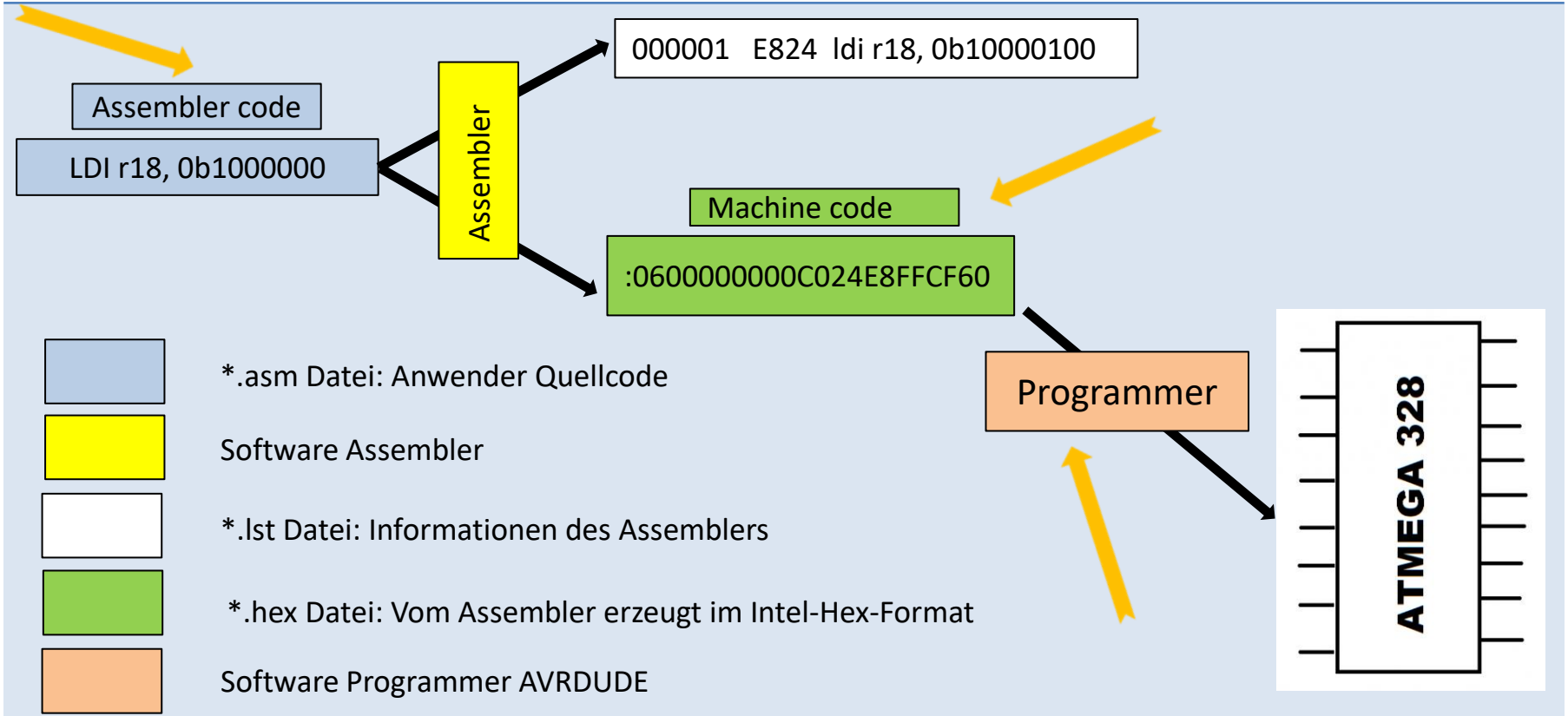
Quelle: © 2020 Microchip Technology Inc. Manual DS40002198A-page 105

GNU AVR-GCC

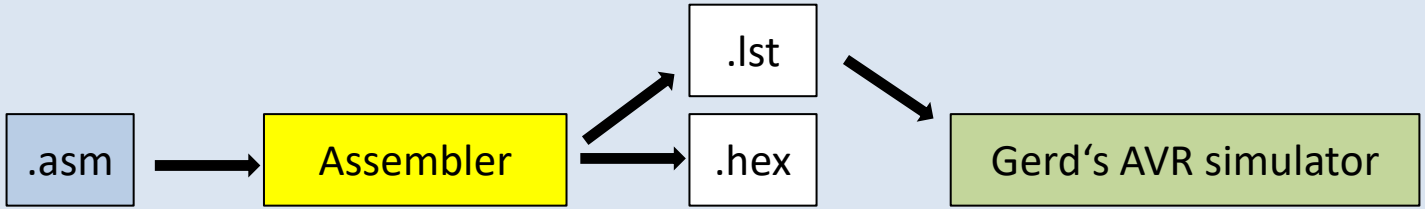
Arduino-IDE



Assembler: Quelle zum Opcode



Gerd‘s AVR Simulator



Anwender Eingabe Datei

gavrasm Assembler

Ausgabe Datei Intel-Hex-Format

Gerd‘s AVR Simulator

Programm schreiben

Gerd‘s AVR Simulator	Starten (Zur detaillierte Anwendung siehe u. g. Handbuch.)
	Projekt anlegen
	Assembler-Programm in Editor eingeben
	Quellcode assemblieren
	Simulation
Quelle:	http://www.avr-asm-tutorial.net/avr_sim/index_en.html http://www.avr-asm-tutorial.net/avr_sim/23/avr_sim_Handbuch_v23.pdf

Assembler-Code

SIM_02.asm

```
1  ; Blink LED 2 MHz
2
3  .nolist
4  .include "m328pdef.inc" ; get definitions of ATmega328P
5  .list
6
7       sbi DDRB, PB5      ; set bit PB5 in Direction-Port B
8
9  loop:                   ; jump target label "loop"
10      sbi PORTB, PB5     ; set bit PB5 in Output-Port B
11      nop                ; do nothing
12      nop                ; do nothing
13      cbi PORTB, PB5     ; clear bit PB5 in Output-Port B
14      rjmp loop          ; relative jump to label "loop"
15
16 ; End of source code
```

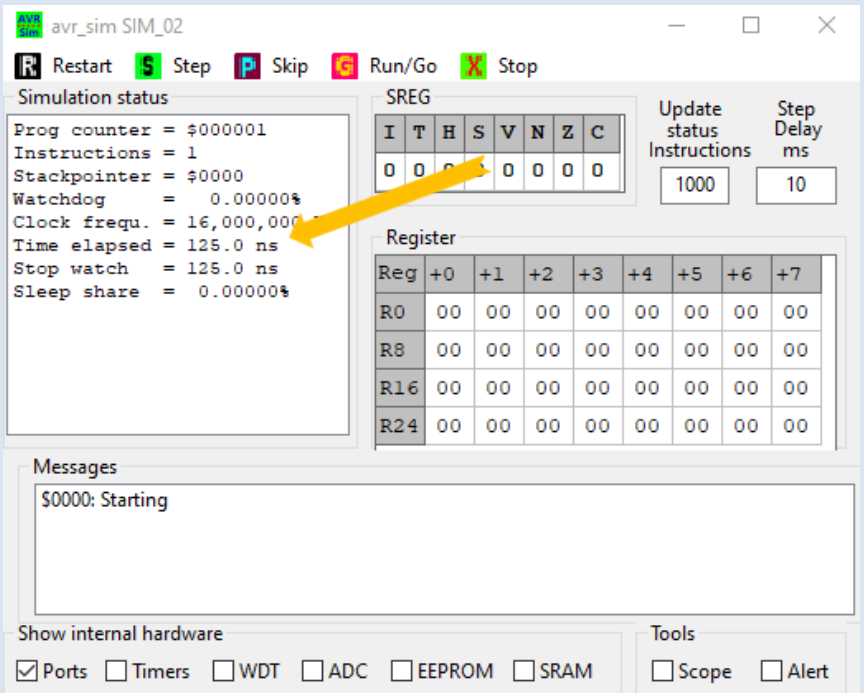
Assembler-Code-Listing

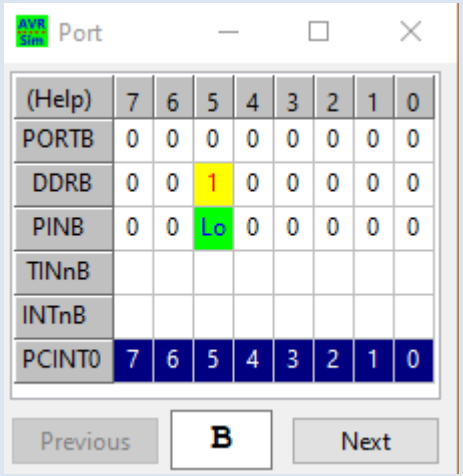
SIM_02.lst

```
 1 gavrasm Gerd's AVR assembler version 4.8 (C)2020 by DG4FAC
 2 ------------------------------------------------------------
 3
 4 Path:         C:\Users\enno_\Desktop\Assembler-EBW\GerdsSimulator\SIM_02\
 5 Source file:  SIM_02.asm
 6 Hex file:     SIM_02.hex
 7 Eeprom file:  SIM_02.eep
 8 Compiled:     09.05.2021, 12:38:34
 9 Pass:         2
10
11      1: ; Blink LED 2 MHz
12      2:
13      3: .nolist
14      6:
15      7: 000000   9A25  sbi DDRB, PB5      ; set bit PB5 in Direction-Port B
16      8:
17      9: loop:                    ; jump target label "loop"
18     10: 000001   9A2D  sbi PORTB, PB5     ; set bit PB5 in Output-Port B
19     11: 000002   0000  nop                ; do nothing
20     12: 000003   0000  nop                ; do nothing
21     13: 000004   982D  cbi PORTB, PB5     ; clear bit PB5 in Output-Port B
22     14: 000005   CFFB  rjmp loop          ; relative jump to label "loop"
23     15:
24     16: ; End of source code
```

Simulation SIM_02

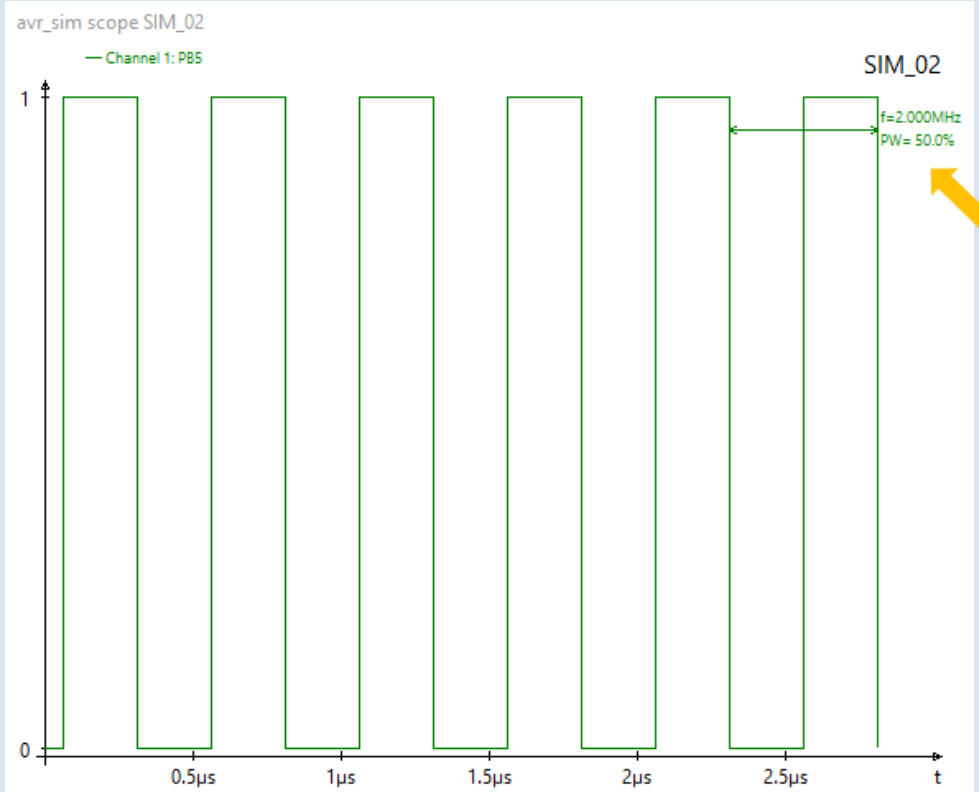
```
    15      7: 000000   9A25   sbi DDRB, PB5       ; set bit PB5 in Direction-Port B
    16      8
    17      9: loop:                               ; jump target label "loop"
    18     10: 000001   9A2D   sbi PORTB, PB5      ; set bit PB5 in Output-Port B
```





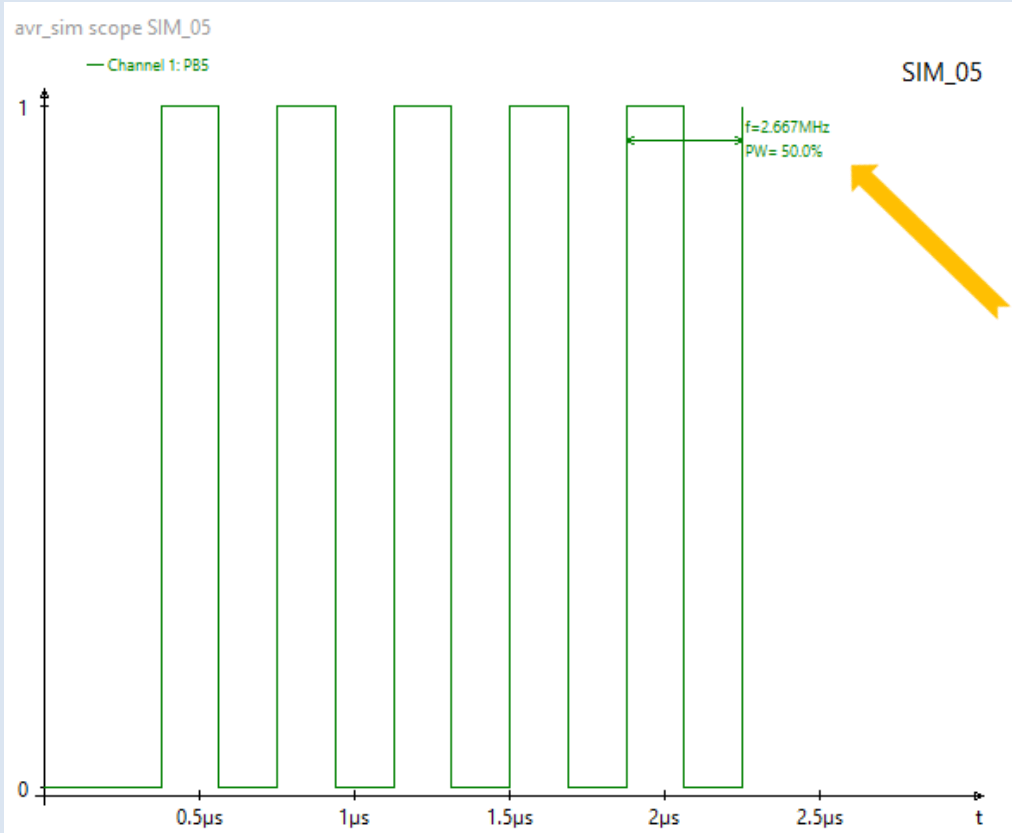
Scope SIM_02

Ergebnis
f = 2 MHz
T = 500 ns
2 MHz / 16 MHz
1 / 8
8 Takte (cyles)



Scope SIM_05

Ergebnis
f = 2,667 MHz
T = 375 ns
2,667 MHz / 16 MHz
1 / 6
6 Takte (cyles)



Cycles

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
1																
2					f	16.000.000	1/s									
3					T=1/f	0,0000000625	s									
4						0,0000625000	ms		0,0625	us		62,5	ns			
5	time at start of loop					0,0001250000	ms		0,125	us		125	ns			
6																
7															0	ns
8		SBI DDRB	2		cycle	0,0001250000	ms		0,125	us		125	ns		125	ns
9																
10		SBI PORTB	2		cycle	0,0001250000	ms		0,125	us		125	ns		250	ns
11		NOP	1		cyle	0,0000625000	ms		0,0625	us		62,5	ns		312,5	ns
12		NOP	1	4	cyle	0,0000625000	ms		0,0625	us		62,5	ns		375	ns
13		CBI PORTB	2		cyle	0,0001250000	ms		0,125	us		125	ns		500	ns
14		RJMP	2	4	cyle	0,0001250000	ms		0,125	us		125	ns		625	ns
15																
16		loop										500	ns			
17					f=1/T							2.000.000,00	Hz			
18												2.000,00	kHz			
19												2,00	MHz			
20																

Hardware

Arduino UNO	Arduino UNO Board mit ATmega328p.
Standalone	ATmega328p auf Steckbrett
USB zu TTL Adapter	“FTDI232 USB to TTL Serial Adapter Module” zur Programmierung über die serielle Schnittstelle
ISP	ISP (In-System-Programmer)

Arduino auf Breadboard

Idee	Standalone ATmega328p
Arduino Standalone	https://www.arduino.cc/en/Main/Standalone https://www.arduino.cc/en/Tutorial/ArduinoToBreadboard https://www.mikrocontroller.net/articles/AVR-Tutorial:_Equipment
FTDI Adapter	https://www.yuriystoys.com/2012/02/arduino-on-beadboard-uploading-your.html
Arduino ISP	https://www.arduino.cc/en/Main.ArduinoISP https://www.arduino.cc/en/uploads/Main/ArduinoISP_WindowsDrivers.zip

Assembler Compiler

Simulator	Gerd‘s AVR assembler http://www.avr-asm-tutorial.net/avr_sim/index_en.html http://www.avr-asm-tutorial.net/avr_sim/23/avr_sim_23_win64_debug.zip
Programmiersoftware: AVRDUDE GUI	https://blog.zakkemble.net/avrdudess-a-gui-for-avrdude/
Programmiersoftware: AVRDUDE 6.3	Vorhanden in: …\arduino-1.8.12\hardware\tools\avr\bin\avrdude.exe
	Konfigurationsdatei in: …\arduino-1.8.12\hardware\tools\avr\etc\avrdude.conf

Tutorials

AVR-GCC-Tutorial	https://www.mikrocontroller.net/articles/AVR-GCC-Tutorial
WinAVR	https://www.mikrocontroller.net/articles/WinAVR
ArduinoISP	https://www.arduino.cc/en/Guide/ArduinoISP
AVR-Assembler lernen	http://www.avr-asm-tutorial.net/avr_de/absolute_beginner/starten/starten.html
Unterrichtsmaterial	https://www.rahner-edu.de/grundlagen/avr-assembler-teil-0/
AVR Assembler Einführung	https://rn-wissen.de/wiki/index.php?title=AVR_Assembler_Einf%C3%BChrung
Anfängerkurs G. Schmidt	http://www.avr-asm-download.de/beginner_de.pdf
AVR beginners	http://avrbeginners.net/
MICROCHIP	https://onlinedocs.microchip.com/pr/GUID-E06F3258-483F-4A7B-B1F8-69933E029363-en-US-2/index.html
MICROCHIP Defeloper	https://microchipdeveloper.com/8avr:start
Block Diagram	https://www.avrfreaks.net/forum/atmega328p-alu-and-multiplier-question?page=all