



# **Beginners Introduction to the Assembly Language of ATMEL-AVR-Microprocessors**

*by*

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# Why learning Assembler?

Assembler or other languages, that is the question. Why should I learn another language, if I already learned other programming languages? The best argument: while you live in France you are able to get through by speaking english, but you will never feel at home then, and life remains complicated. You can get through with this, but it is rather inappropriate. If things need a hurry, you should use the country's language.

## Short and easy

Assembler commands translate one by one to executed machine commands. The processor needs only to execute what you want it to do and what is necessary to perform the task. No extra loops and unnecessary features blow up the generated code. If your program storage is short and limited and you have to optimize your program to fit into memory, assembler is choice 1. Shorter programs are easier to debug, every step makes sense.

## Fast and quick

Because only necessary code steps are executed, assembly programs are as fast as possible. The duration of every step is known. Time critical applications, like time measurements without a hardware timer, that should perform excellent, must be written in assembler. If you have more time and don't mind if your chip remains 99% in a wait state type of operation, you can choose any language you want.

## Assembler is easy to learn

It is not true that assmby language is more complicated or not as easy to understand than other languages. Learning assembly language for whatever hardware type brings you to understand the basic concepts of any other assembly language dialect. Adding other dialects later is easy. The first assembly code does not look very attractive, with every 100 additional lines programmed it looks better. Perfect programs require some thousand lines of code of exercise, and optimization requires lots of work. As some features are hardware-dependant optimal code requires some familiarity with the hardware concept and the dialect. The first steps are hard in any language. After some weeks of programming you will laugh if you go through your first code. Some assembler commands need some monthes of experience.

## AT90Sxxxx are ideal for learning assembler

Assembler programs are a little bit silly: the chip executes anything you tell it to do, and does not ask you if you are sure overwriting this and that. All protections must be programmed by you, the chip does anything like it is told. No window warns you, unless you programmed it before.

Basic design errors are as complicated to debug like in any other computer language. But: testing programs on ATMEL chips is very easy. If it does not do what you expect it to do, you can easily add some diagnostic lines to the code, reprogram the chip and test it. Bye, bye to you EPROM programmers, to the UV lamps used to erase your test program, to you pins that don't fit into the socket after having them removed some douzend times.

Changes are now programmed fast, compiled in no time, and either simulated in the studio or checked in-circuit. No pin is removed, and no UV lamp gives up just in the moment when you had your excellent idea about that bug.

## Test it!

Be patient doing your first steps! If you are familiar with another (high-level) language: forget it for the first time. Behind every assembler language there is a certain hardware concept. Most of the special features of other computer languages don't make any sense in assembler.

The first five commands are not easy to learn, then your learning speed rises fast. After you had your first lines: grab the instruction set list and lay back in the bathtub, wondering what all the other commands are like.

Don't try to program a mega-machine to start with. This does not make sense in any computer language, and just produces frustration.

Comment your subroutines and store them in a special directory, if debugged: you will need them again in a short time.

Have success!

# Hardware for AVR-Assembler-Programming

Learning assembler requires some simple hardware equipment to test your programs, and see if it works in practice.

This section shows two easy schematics that enable you to homebrew the required hardware and gives you the necessary hints on the required background. This hardware really is easy to build. I know nothing easier than that to test your first software steps. If you like to make more experiments, leave some more space for future extensions on your experimental board.

If you don't like the smell of soldering, you can buy a ready-to-use board, too. The available boards are characterised in this section below.

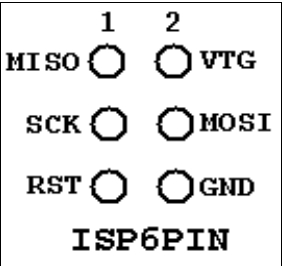
## The ISP-Interface of the AVR-processor family

Before going into practice, we have to learn a few essentials on the serial programming mode of the AVR family. No, you don't need three different voltages to program and read an AVR flash memory. No, you don't need another microprocessor to program the AVRs. No, you don't need 10 I/O lines to tell the chip what you like it to do. And you don't even have to remove the AVR from your experimental board, before programming it. It's even easier than that.

All this is done by a build-in interface in the AVR chip, that enables you to write and read the content of the program flash and the built-in-EEPROM. This interface works serially and needs three signal lines:

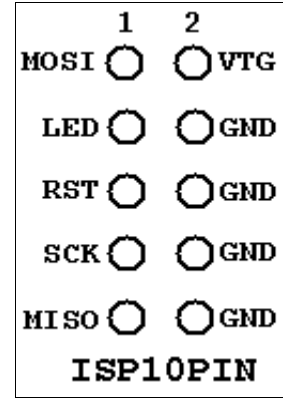
- SCK: A clock signal that shifts the bits to be written to the memory into an internal shift register, and that shifts out the bits to be read from another internal shift register,
- MOSI: The data signal that sends the bits to be written to the AVR,
- MISO: The data signal that receives the bits read from the AVR.

These three signal pins are internally connected to the programming machine only if you change the RESET (sometimes also called RST or restart) pin to zero. Otherwise, during normal operation of the AVR, these pins are programmable I/O lines like all the others.



If you like to use these pins for other purposes during normal operation, and for in-system-programming, you'll have to take care, that these two purposes do not conflict. Usually you then decouple these by resistors or by use of a multiplexer. What is necessary in your case, depends from your use of the pins in the normal operation mode. You're lucky, if you can use them for in- system-programming exclusively.

Not necessary, but recommendable for in-system-programming is, that you supply the programming hardware out of the supply voltage of your system. That makes it easy, and requires two additional lines between the programmer and the AVR board. GND is the common ground, VTG (target voltage) the supply voltage (usually 5.0 volts). This adds up to 6 lines between the programmer and the AVR board. The resulting ISP6 connection is, as defined by AMEL, is shown on the left.

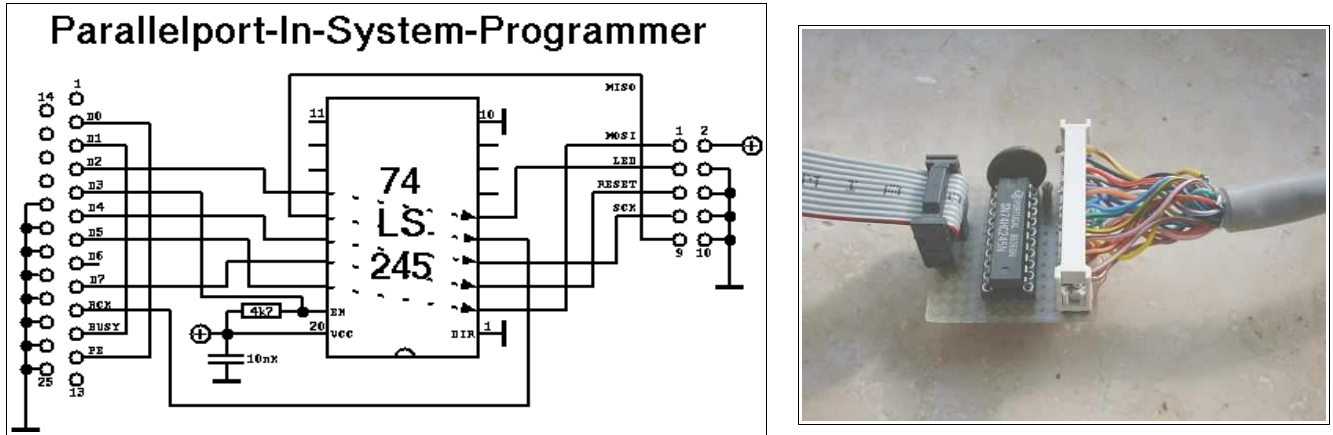


Standards always have alternative standards, that were used earlier. This is the technical basis that constitutes the adaptor industry. In our case the alternative standard was designed as ISP10 and was used on the STK200 board. It's still a very widespread standard, and even the STK500 is still equipped with it. ISP10 has an additional signal to drive a red LED. This LED signals that the programmer is doing his job. A good idea. Just connect the LED to a resistor and clamp it the positive supply voltage.

## Programmer for the PC-Parallel-Port

Now, heat up your soldering iron and build up your programmer. It is a quite easy schematic and works with standard parts from your well-sorted experiments box.

Yes, that's all you need to program an AVR. The 25-pin plug goes into the parallel port of your PC, the 10-pin-ISP goes to your AVR experimental board. If your box doesn't have a 74LS245, you can also use a 74HC245 or a 74LS244/74HC244 (by changing some pins and signals). If you use HC, don't forget to tie unused inputs either to GND or the supply voltage, otherwise the buffers might produce extra noise by capacitive switching.



The necessary program algorithm is done by the ISP software, that is available from ATMEL's software download page.

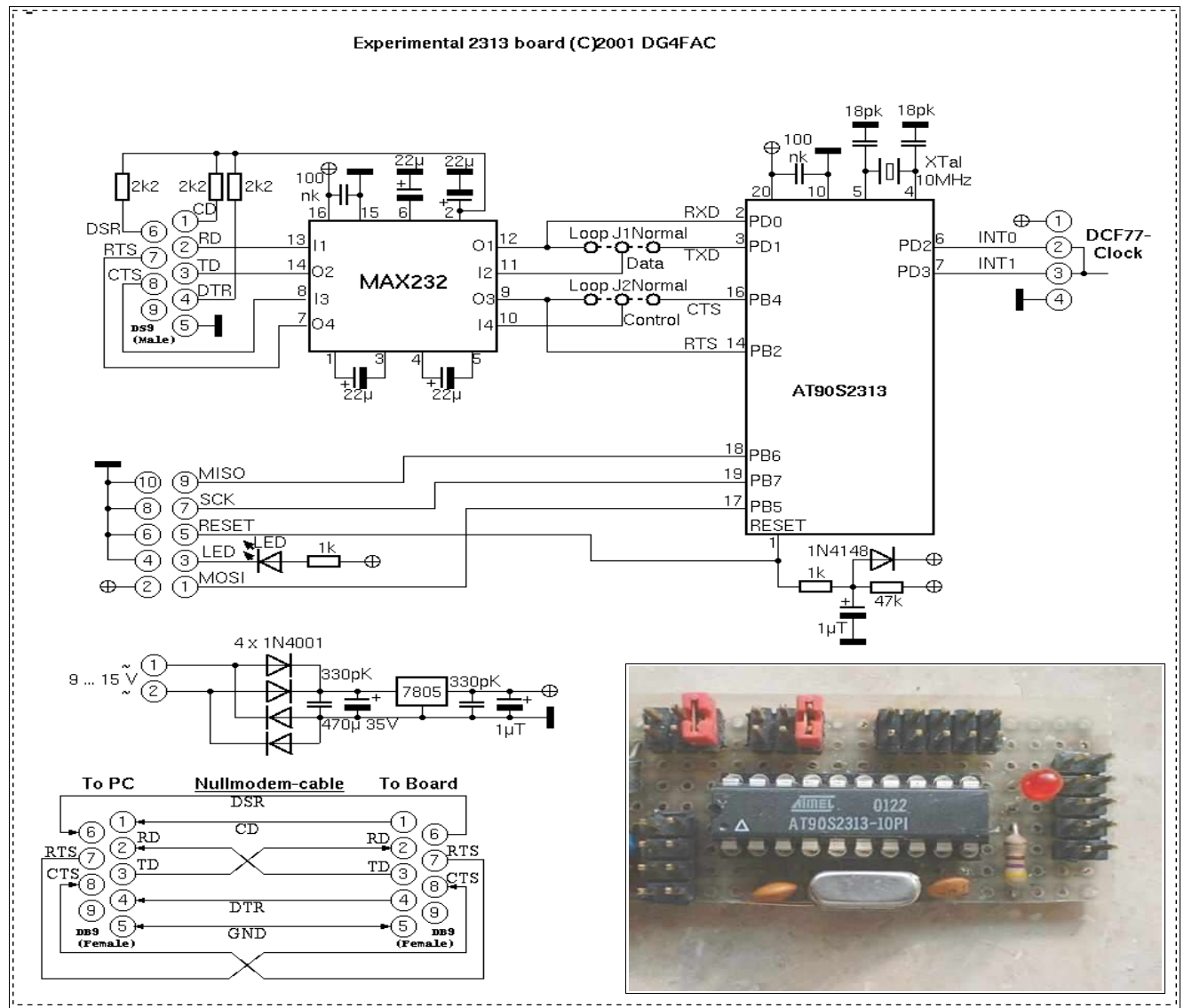
## Experimental board with a AT90S2313

For test purposes we use a AT90S2313 on an experimental board. The schematic shows

- a small voltage supply for connection to an AC transformer and a voltage regulator 5V/1A,
- a XTAL clock generator (here with a 10 Mcs/s, all other frequencies below the maximum for the 2313 will also work),
- the necessary parts for a safe reset during supply voltage switching,
- the ISP-Programming-Interface (here with a ISP10PIN-connector).

So that's what you need to start with. Connect other peripheral add-ons to the numerous free I/O pins of the 2313.

The easiest output device can be a LED, connected via a resistor to the positive supply voltage. With that, you can start writing your first assembler program switching the LED on and off.



## Ready-to-use commercial programming boards for the AVR-family

If you do not like homebrewed hardware, and if have some extra money left that you don't know what to do with, you can buy a commercial programming board. Easy to get is the STK500 (e.g. from ATMEL. It has the following hardware:

- Sockets for programming most of the AVR types,
- serial und parallel programming,
- ISP6PIN- and ISP10PIN-connector for external In-System-Programming,
- programmable oscillator frequency and supply voltages,
- plug-in switches and LEDs,
- a plugged RS232C-connector (UART),
- a serial Flash-EEPROM,
- access to all ports via a 10-pin connector.

Experiments can start with the also supplied AT90S8515. The board is connected to the PC using a serial port (COMx) and is controlled by later versions of AVR studio, available from ATMEL's webpage. This covers all hardware requirements that the beginner might have.



# Tools for AVR assembly programing

This section provides informations about the necessary tools that are used to program AVR's with the STK200 board. Programming with the STK500 is very different and shown in more detail in the Studio section. Note that the older software for the STK200 is not supported any more.

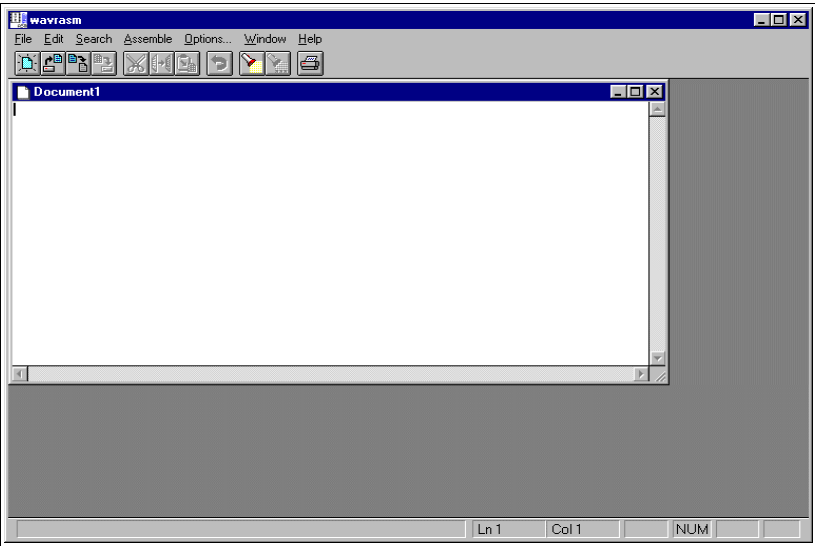
Four basic programs are necessary for assembly programming. These tools are:

- the editor,
- the assembler program,
- the chip programing interface, and
- the simulator.

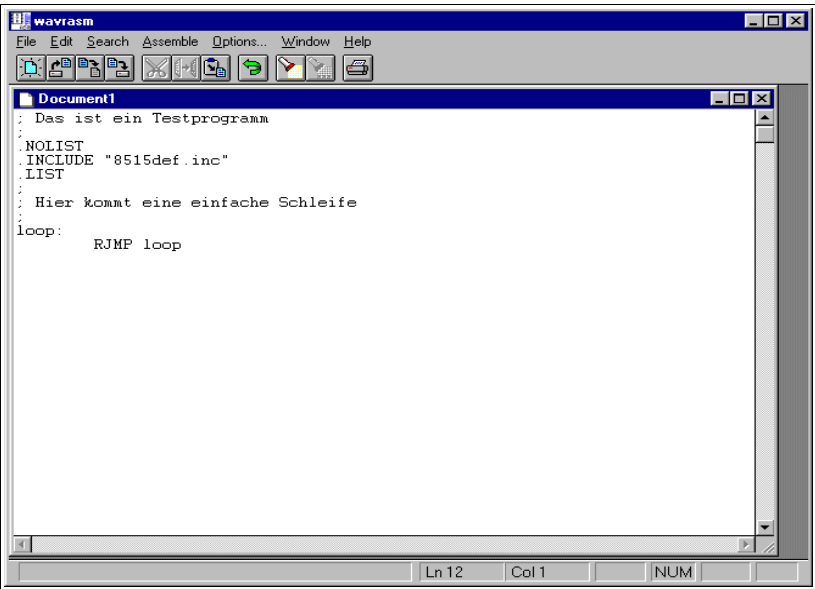
The necessary software tools are ©ATMEL and available on the webpage of ATMEL for download. The screenshots here are ©ATMEL. It should be mentioned that there are different versions of the software and some of the screenshots are subject to change with the used version. Some windows or menues look different in different versions. The basic functions are mainly unchanged. Refer to the programmer's handbook, this page just provides an overview for the beginner's first steps and is not written for the assembly programming expert.

## The editor

Assembler programs are written with a editor. The editor just has to be able to create and edit ASCII text files. So, basically, any simple editor does it. I recommend the use of a more advanced editor, either WAVRASM©ATMEL or the editor written by Tan Siliksaar (screenshot see below).



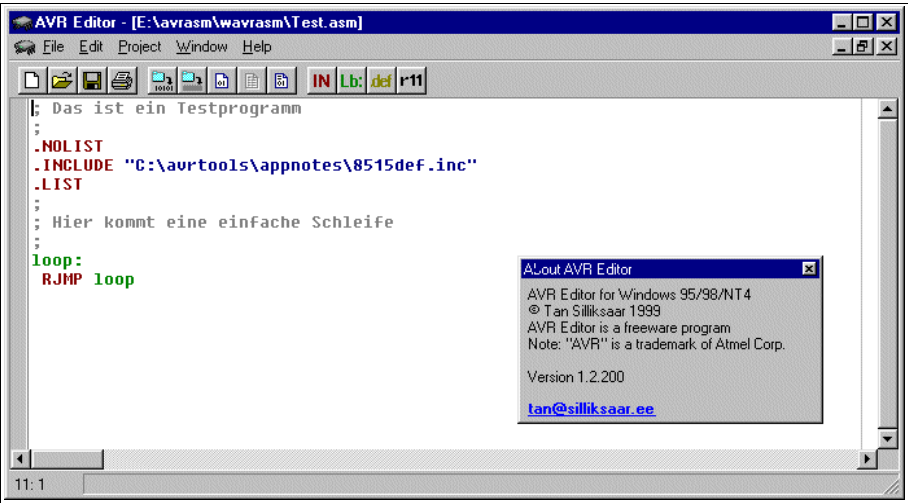
An assembly program written with WAVRASM© goes like this. Just install WAVRASM© and start the program:



Now we type in our directives and assembly commands in the WAVRASM editor window, together with some comments (starting with ;). That should look like this:

Now store the program text, named to something.asm into a dedicated directory, using the file menu. The assembly program is complete now.

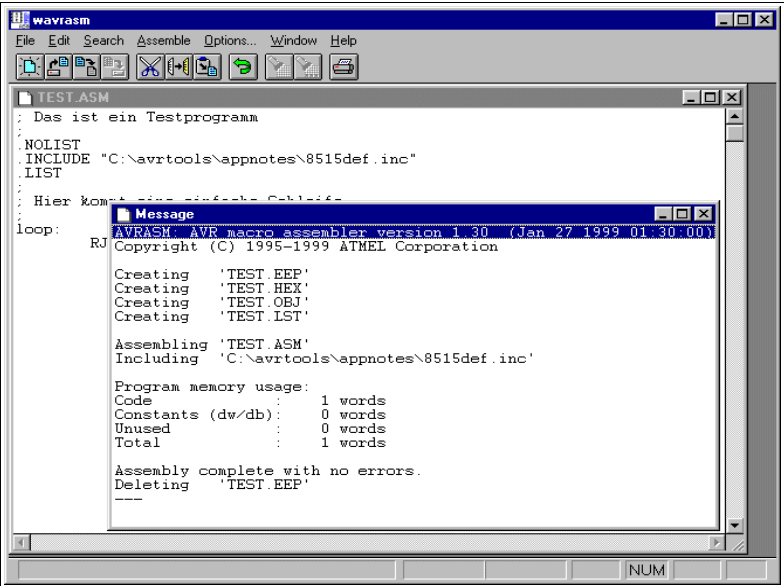
If you like editing a little more in a sophisticated manner you can use the excellent editor written by Tan Siliksaar. This editor tools is designed for AVR's and available for free from Tan's webpage. In this editor our program looks like this:



The editor recognizes commands automatically and uses different colors (syntax highlighting) to signal user constants and typing errors in those commands (in black). Storing the code in an .asm file provides nearly the same text file.

## The assembler

Now we have to translate this code to a machine-oriented form well understood by the AVR chip. Doing this is called assembling, which means collecting the right command words. If you use WAVRASM© just click assemble on the menu. The result is shown here:



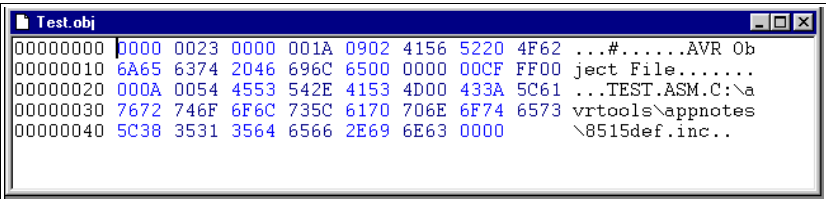
The assembler reports the complete translation with no errors. If errors occur these are notified. Assembling resulted in one word of code which resulted from the command we used. Assembling our single asm-text file now has produced four other files (not all apply here).

The first of these four new files, TEST.EEP, holds the content that should be written to the EEPROM of the AVR. This is not very interesting in our case, because we didn't program any content for the EEPROM. The assembler has therefore deleted this file when he completed the assembly run.

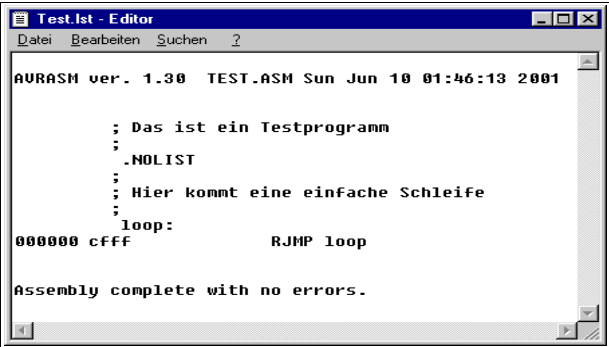


The second file, TEST.HEX, is more relevant because this file holds the commands later programmed into the AVR chip. This file looks like this.

The hex numbers are written in a special ASCII form, together with adress informations and a checksum for each line. This form is called Intel-hex-format, and it is very old. The form is well understood by the programing software.



The third file, TEST.OBJ, will be introduced later, this file is needed to simulate an AVR. Its format is hexadecimal and defined by ATMEL. Using a hex-editor its content looks like this. Attention: This file format is



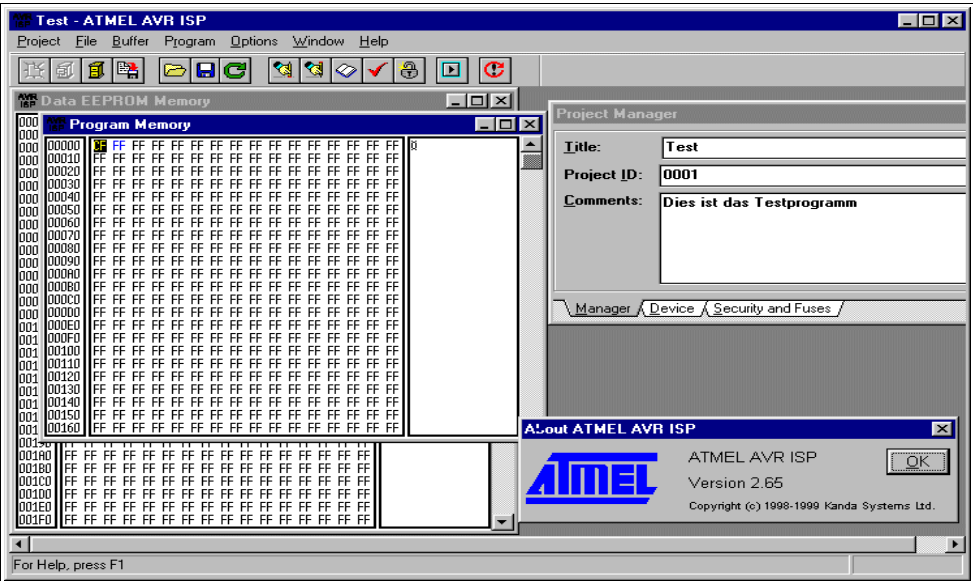
not compatible with the programer software, don't use this file to program the AVR (a very common error when starting).

The fourth file, TEST.LST, is a text file. Display its content with a simple editor. The following results.

The program with all its adresss, comands and error messages are displayed in a readable form. You will need that file in some cases to debug errors.

# Programming the chips

To program our hex code to the AVR ATMEL has written the ISP software package. (Not that this software is not supported and distributed any more.) We start the ISP software and load the hex file that we just generated (applying menue item LOAD PROGRAM). That looks like this:



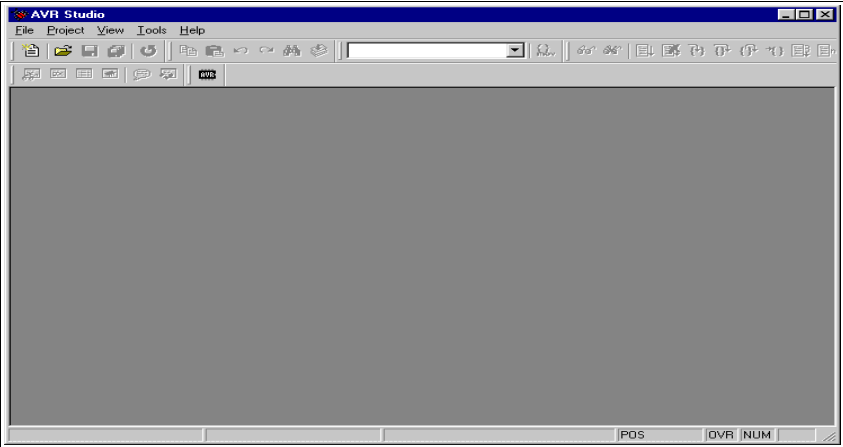
Applying menue item PROGRAM will burn our code in the chip's program store. There are a number of preconditions necessary for this step (the correct parallel port has to be selected, the programming adapter must be connected, the chip must be on board the adapter, the power supply must be on, etc.).

Besides the ATMEL-ISP and the programming boards other programming boards or adapters could be used, together with the

appropriate programming software. Some of these alternatives are available on the internet.

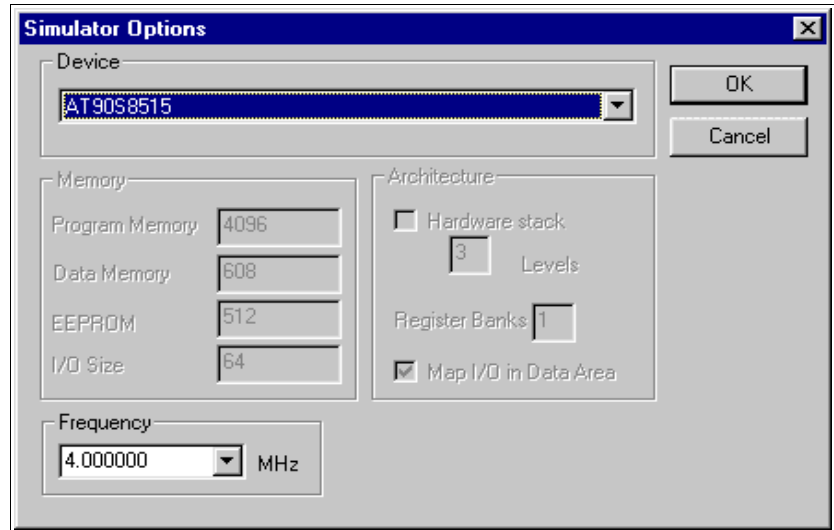
# Simulation in the studio

In some cases self-written assembly code, even assembled without errors, does not exactly do what it should do when burned into the chip. Testing the software on the chip could be complicated, esp. if you have a minimum hardware and no opportunity to display interim results or debugging signals. In these cases the studio from ATMEL provides ideal opportunities for debugging. Testing the software or parts of it is possible, the program could be tested step-by-step displaying results.



The studio is started and looks like this.

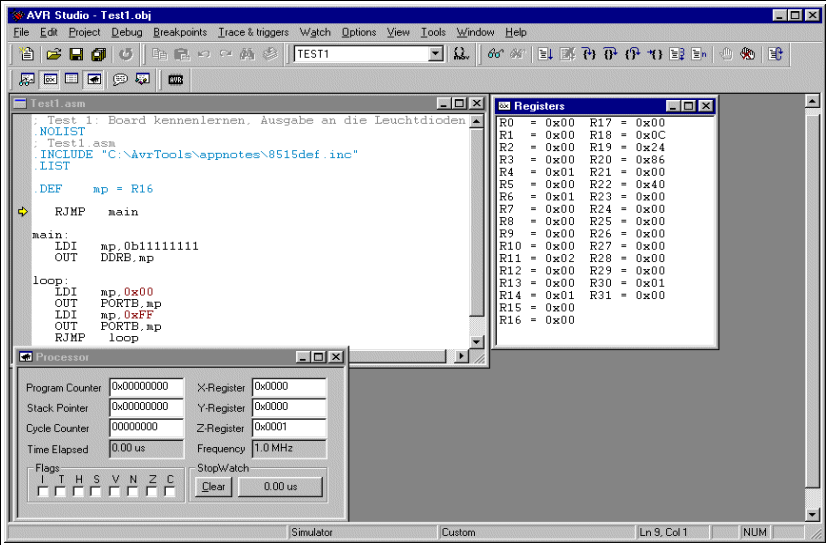
First we open a file (menue item FILE OPEN). We demonstrate this using the tutorial file test1.asm, because there are some more commands and action that in our single-command program above.



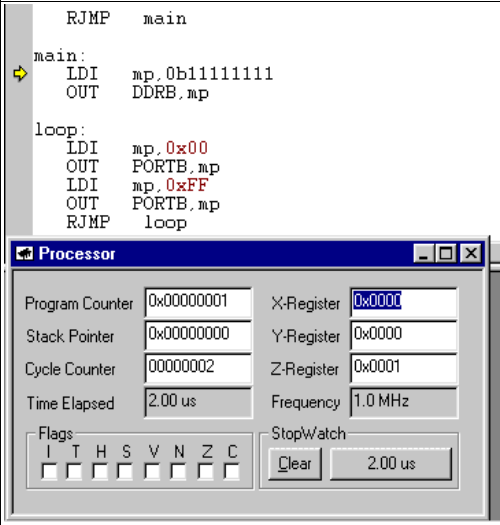
Open the file TEST1.OBJ that results by assembling TEST1.asm. You are asked which options you like to use (if not, you can change these using the menue item SIMULATOR OPTIONS). The following options will be selected:

In the device selection section we select the desired chip type. The correct frequency should be selected if you like to simulate correct timings.

In order to view the content of some registers and what the processor's status is we select VIEW PROCESSOR and REGISTERS. The display should now look like this.



The processor window displays all values like the command counter, the flags and the timing information (here: 1 MHz clock). The stop watch can be used to measure the necessary time for going through routines etc.



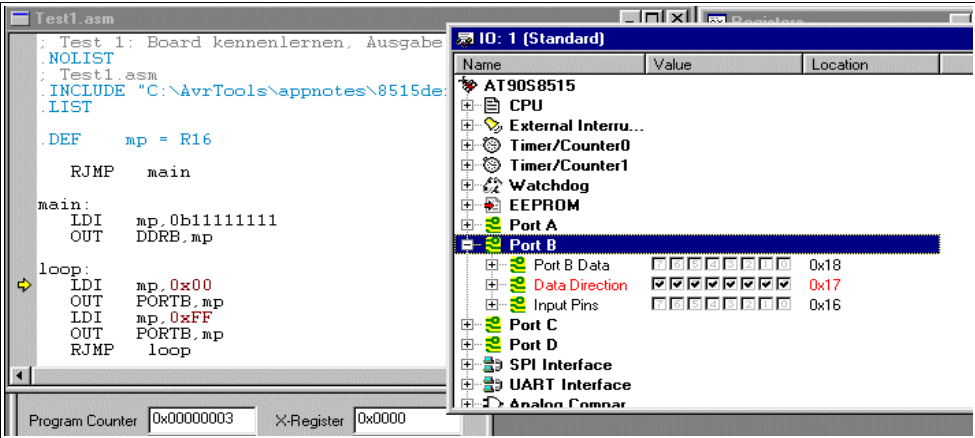
Now we start the program execution. We use the single step opportunity (TRACE INTO or F11). Using GO would result in continous exection and not much would be seen due to the high speed of simulation. After the first executed step the processor window should look like this.

The program counter is at step 1, the cycle counter at 2 (RJMP needed two cycles). At 1 MHz clock two microseconds have been wasted, the flags and pointer registers are not changed. The source text window displays a pointer on the next command that will be executed.

Pressing F11 again executes the next command, register mp (=R16) will be set to 0xFF. Now the register window should highlite this change.

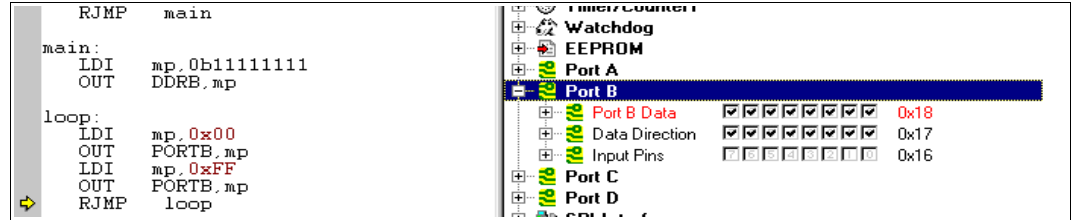


Register R16's new value is displayed in red letters. We can change the value of a register at any time to test what happens then.



Now step 3 is executed, output to the direction register of Port B. To display this we open a new I/O view window and select Port B. The display should look like this.

The Data Direction Register in the I/O-view window of Port B now shows the new value. The values could be changed manually, if desired, pin by pin.



The next two steps are simulated using F11. They are not displayed here. Setting the output ports to one with the command LDI

mp,0xFF and OUT PORTB,mp results in the following picture in the I/O view. Now the output port bits are all one, the I/O view shows this.

That is our short trip through the simulator software world. The simulator is capable to much more, so it should be applied extensively in cases of design errors. Visit the different menue items, there is much more than showed here.

# Register

## What is a register?

Registers are special storages with 8 bits capacity and they look like this:

Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0
-------	-------	-------	-------	-------	-------	-------	-------

Note the numeration of these bits: the least significant bit starts with zero ( $2^0 = 1$ ).

A register can either store numbers from 0 to 255 (positive number, no negative values), or numbers from -128 to +127 (whole number with a sign bit in bit 7), or a value representing an ASCII-coded character (e.g. 'A'), or just eight single bits that do not have something to do with each other (e.g. for eight single flags used to signal eight different yes/no decisions).

The special character of registers, compared to other storage sites, is that

- they can be used directly in assembler commands,
- operations with their content require only a single command word,
- they are connected directly to the central processing unit called the accumulator,
- they are source and target for calculations.

There are 32 registers in an AVR. They are originally named R0 to R31, but you can choose to name them to more meaningful names using an assembler directive. An example:

```
.DEF MyPreferredRegister = R16
```

Assembler directives always start with a dot in column 1 of the text. Instructions do NEVER start in column 1, they are always preceeded by a Tab- or blank character!

Note that assembler directives like this are only meaningful for the assembler but do not produce any code that is executable in the AVR target chip. Instead of using the register name R16 we can now use our own name MyPreferredRegister, if we want to use R16 within a command. So we write a little bit more text each time we use this register, but we have an association what might be the content of this register.

Using the command line

```
LDI    MyPreferredRegister, 150
```

which means: load the number 150 immediately to the register R16, LoaD Immediate. This loads a fixed value or a constant to that register. Following the assembly or translation of this code the program storage written to the AVR chip looks like this:

```
000000 E906
```

The load command code as well as the target register (R16) as well as the value of the constant (150) is part of the hex value E906, even if you don't see this directly. Don't be afraid: you don't have to remember this coding because the assembler knows how to translate all this to yield E906.

Within one command two different registers can play a role. The easiest command of this type is the copy command MOV. It copies the content of one register to another register. Like this:

```
.DEF MyPreferredRegister = R16
.DEF AnotherRegister = R15
LDI MyPreferredRegister, 150
MOV AnotherRegister, MyPreferredRegister
```

The first two lines of this monster program are directives that define the new names of the registers R16 and R15 for the assembler. Again, these lines do not produce any code for the AVR. The command lines with LDI and MOV produce code:

```
000000 E906
000001 2F01
```

The commands write 150 into register R16 and copy its content to the target register R15. IMPORTANT NOTE:

**The first register is always the target register where the result is written to!**

(This is unfortunately different from what one expects or from how we speak. It is a simple convention that was once defined that way to confuse the beginners learning assembler. That is why assembler is that complicated.)

## Different registers

The beginner might want to write the above commands like this:

```
.DEF AnotherRegister = R15
    LDI AnotherRegister, 150
```

And: you lost. Only the registers from R16 to R31 load a constant immediately with the LDI command, R0 to R15 don't do that. This restriction is not very fine, but could not be avoided during construction of the command set for the AVR's.

There is one exception from that rule: setting a register to Zero. This command

```
CLR MyPreferredRegister
```

is valid for all registers.

Besides the LDI command you will find this register class restriction with the following additional commands:

- ANDI Rx,K ; Bit-And of register Rx with a constant value K,
- CBR Rx,M ; Clear all bits in register Rx that are set to one within the constant mask value M,
- CPI Rx,K ; Compare the content of the register Rx with a constant value K,
- SBCI Rx,K ; Subtract the constant K and the current value of the carry flag from the content of register Rx and store the result in register Rx,
- SBR Rx,M ; Set all bits in register Rx to one, that are one in the constant mask M,
- SER Rx ; Set all bits in register Rx to one (equal to LDI Rx,255),
- SUBI Rx,K ; Subtract the constant K from the content of register Rx and store the result in register Rx.

In all these commands the register must be between R16 and R31! If you plan to use these commands you should select one of these registers for that operation. It is easier to program. This is an additional reason why you should use the directive to define a register's name, because you can easier change the registers location afterwards.

## Pointer-register

A very special extra role is defined for the register pairs R26:R27, R28:R29 and R30:R31. The role is so important that these pairs have extra names in AVR assembler: X, Y and Z. These pairs are 16-bit pointer registers, able to point to addresses with max. 16-bit into SRAM locations (X, Y or Z) or into locations in program memory (Z).

The lower byte of the 16-bit-address is located in the lower register, the higher byte in the upper register. Both parts have their own names, e.g. the higher byte of Z is named ZH (=R31), the lower Byte is ZL (=R30). These names are defined in the standard header file for the chips. Dividing these 16-bit-pointer-names into two different bytes is done like follows:

```
.EQU Adress = RAMEND ; RAMEND is the highest 16-bit adress in SRAM
    LDI YH,HIGH(Adress) ; Set the MSB
    LDI YL,LOW(Adress) ; Set the LSB
```

Accesses via pointers are programmed with specially designed commands. Read access is named LD (LoaD), write access named ST (STore), e.g. with the X-pointer:

Pointer	Sequence	Examples
X	Read/Write from adress X, don't change the pointer	LD R1,X or ST X,R1
X+	Read/Write from/to adress X and increment the pointer afterwards by one	LD R1,X+ or ST X+,R1
-X	Decrement the pointer by one and read/write from/to the new adress afterwards	LD R1,-X or ST -X,R1

Similiarly you can use Y and Z for that purpose.

There is only one command for the read access to the program storage. It is defined for the pointer pair Z and it is named LPM (Load from Program Memory). The command copies the byte at adress Z in the program memory to the register R0. As the program memory is organised word-wise (one command on one adress consists of 16 bits or two bytes or one word) the least significant bit selects the lower or higher byte (0=lower byte, 1= higher byte). Because of this the original adress must be multiplied by 2 and access is limited to 15-bit or 32 kB program memory. Like this:

```
LDI ZH,HIGH(2*Adress)
LDI ZL,LOW(2*Adress)
LPM
```

Following this command the address must be incremented to point to the next byte in program memory. As this is used very often a special pointer incrementation command has been defined to do this:

```
ADIW ZL,1
LPM
```

ADIW means ADd Immediate Word and a maximum of 63 can be added this way. Note that the assembler expects the lower of the pointer register pair ZL as first parameter. This is somewhat confusing as addition is done as 16-bit- operation.

The complement command, subtracting a constant value of between 0 and 63 from a 16-bit pointer register is named SBIW, Subtract Immediate Word. (SuBtract Immediate Word). ADIW and SBIW are possible for the pointer register pairs X, Y and Z and for the register pair R25:R24, that does not have an extra name and does not allow access to SRAM or program memory locations. R25:R24 is ideal for handling 16-bit values.

How to insert that table of values in the program memory? This is done with the assembler directives .DB and .DW. With that you can insert bitwise or wordwise lists of values. Bitwise organised lists look like this:

```
.DB 123,45,67,89 ; a list of four bytes
.DB "This is a text. " ; a list of byte characters
```

You should always place an even number of bytes on each single line. Otherwise the assembler will add a zero byte at the end, which might be unwanted.

The similiar list of words looks like this:

```
.DW 12345,6789 ; a list of two words
```

Instead of constants you can also place labels (jump targets) on that list, like that:

```
Label1:
[ ... here are some commands ... ]
Label2:
[ ... here are some more commands ... ]
Table:
.DW Label1,Label2 ; a wordwise list of labels
```

Labels ALWAYS start in column 1!. Note that reading the labels with LPM first yields the lower byte of the word.

A very special application for the pointer registers is the access to the registers themselves. The registers are located in the first 32 bytes of the chip's address space (at address 0x0000 to 0x001F). This access is only meaningful if you have to copy the register's content to SRAM or EEPROM or read these values from there back into the registers. More common for the use of pointers is the access to tables with fixed values in the program memory space. Here is, as an example, a table with 10 different 16-bit values, where the fifth table value is read to R25:R24:

```
MyTable:
.DW 0x1234,0x2345,0x3456,0x4568,0x5678 ; The table values, wordwise
.DW 0x6789,0x789A,0x89AB,0x9ABC,0xABCD ; organised
Read5: LDI ZH,HIGH(MyTable*2) ; Address of table to pointer Z
      LDI ZL,LOW(MyTable*2) ; multiplied by 2 for bitwise access
      ADIW ZL,10 ; Point to fifth value in table
      LPM ; Read least significant byte from program memory
      MOV R24,R0 ; Copy LSB to 16-bit register
      ADIW ZL,1 ; Point to MSB in program memory
      LPM ; Read MSB of table value
      MOV R25,R0 ; Copy MSB to 16-bit register
```

This is only an example. You can calculate the table adress in Z from some input value, leading to the respective table values. Tables can be organised byte- or character-wise, too.

## Recommendation for the use of registers

- Define names for registers with the .DEF directive, never use them with their direct name Rx.
- If you need pointer access reserve R26 to R31 for that purpose.
- 16-bit-counter are best located R25:R24.
- If you need to read from the program memory, e.g. fixed tables, reserve Z (R31:R30) and R0 for that purpose.
- If you plan to have access to single bits within certain registers (e.g. for testing flags), use R16 to R23 for that purpose.



# Ports

## What is a Port?

Ports in the AVR are gates from the central processing unit to internal and external hard- and software components. The CPU communicates with these components, reads from them or writes to them, e.g. to the timers or the parallel ports. The most used port is the flag register, where results of previous operations are written to and branch conditions are read from.

There are 64 different ports, which are not physically available in all different AVR types. Depending on the storage space and other internal hardware the different ports are either available and accessible or not. Which of these ports can be used is listed in the data sheets for the processor type.

Ports have a fixed address, over which the CPU communicates. The address is independent from the type of AVR. So e.g. the port address of port B is always 0x18 (0x stands for hexadecimal notation). You don't have to remember these port addresses, they have convenient aliases. These names are defined in the include files (header files) for the different AVR types, that are provided from the producer. The include files have a line defining port B's address as follows:

```
.EQU PORTB, 0x18
```

So we just have to remember the name of port B, not its location in the I/O space of the chip. The include file 8515def.inc is involved by the assembler directive

```
.INCLUDE "C:\Somewhere\8515def.inc"
```

and the registers of the 8515 are all defined then and easily accessible.

Ports usually are organised as 8-bit numbers, but can also hold up to 8 single bits that don't have much to do with each other. If these single bits have a meaning they have their own name associated in the include file, e.g. to enable manipulation of a single bit. Due to that name convention you don't have to remember these bit positions. These names are defined in the data sheets and are given in the include file, too. They are provided here in the port tables.

As an example the MCU General Control Register, called MCUCR, consists of a number of single control bits that control the general property of the chip (see the description in MCUCR in detail). It is a port, fully packed with 8 control bits with their own names (ISC00, ISC01, ...). Those who want to send their AVR to a deep sleep need to know from the data sheet how to set the respective bits. Like this:

```
.DEF MyPreferredRegister = R16  
LDI MyPreferredRegister, 0b00100000  
OUT MCUCR, MyPreferredRegister  
SLEEP
```

The Out command brings the content of my preferred register, a Sleep-Enable-Bit called SE, to the port MCUCR and sets the AVR immediately to sleep, if there is a SLEEP instruction executed. As all the other bits of MCUCR are also set by the above instructions and the Sleep Mode bit SM was set to zero, a mode called half-sleep will result: no further command execution will be performed but the chip still reacts to timer and other hardware interrupts. These external events interrupt the big sleep of the CPU if they feel they should notify the CPU.

Reading a port's content is in most cases possible using the IN command. The following sequence

```
.DEF MyPreferredRegister = R16  
IN MyPreferredRegister, MCUCR
```

reads the bits in port MCUCR to the register. As many ports have undefined and unused bits in certain ports, these bits always read back as zeros.

More often than reading all 8 bits of a port one must react to a certain status of a port. In that case we don't need to read the whole port and isolate the relevant bit. Certain commands provide an opportunity to execute commands depending on the level of a certain bit (see the JUMP section). Setting or clearing certain bits of a port is also possible without reading and writing the other bits in the port. The two commands are SBI (Set Bit I/o) and CBI (Clear Bit I/o). Execution is like this:

```
.EQU ActiveBit=0 ; The bit that is to be changed  
SBI PortB, ActiveBit ; The bit will be set to one  
CBI PortB, Activebit ; The bit will be cleared to zero
```

These two instructions have a limitation: only ports with an adress smaller than 0x20 can be handled, ports above cannot be accessed that way.

For the more exotic programmer: the ports can be accessed using SRAM access commands, e.g. ST and LD. Just add 0x20 to the port's adress (the first 32 addresses are the registers!) and access the port that way. Like demonstrated here:

```
.DEF MyPreferredRegister = R16  
LDI ZH,HIGH(PORTB+32)
```



```
LDI ZL,LOW(PORTB+32)
LD MyPreferredRegister,Z
```

That only makes sense in certain cases, but it is possible. It is the reason why the first address location of the SRAM is always 0x60.

## Details of relevant ports in the AVR

The following table holds the most used ports. Not all ports are listed here, some of the MEGA and AT90S4434/8535 types are skipped. If in doubt see the original reference.

<i>Component</i>	<i>Portname</i>	<i>Port-Register</i>
Accumulator	SREG	Status Register
Stack	SPL/SPH	Stackpointer
External SRAM/External Interrupt	MCUCR	MCU General Control Register
External Interrupt	GIMSK	Interrupt Mask Register
	GIFR	Interrupt Flag Register
Timer Interrupt	TIMSK	Timer Interrupt Mask Register
	TIFR	Timer Interrupt Flag Register
Timer 0	TCCR0	Timer/Counter 0 Control Register
	TCNT0	Timer/Counter 0
Timer 1	TCCR1A	Timer/Counter Control Register 1 A
	TCCR1B	Timer/Counter Control Register 1 B
	TCNT1	Timer/Counter 1
	OCR1A	Output Compare Register 1 A
	OCR1B	Output Compare Register 1 B
	ICR1L/H	Input Capture Register
Watchdog Timer	WDTCR	Watchdog Timer Control Register
EEPROM	EEAR	EEPROM Adress Register
	EEDR	EEPROM Data Register
	EECR	EEPROM Control Register
SPI	SPCR	Serial Peripheral Control Register
	SPSR	Serial Peripheral Status Register
	SPDR	Serial Peripheral Data Register
UART	UDR	UART Data Register
	USR	UART Status Register
	UCR	UART Control Register
	UBRR	UART Baud Rate Register
Analog Comparator	ACSR	Analog Comparator Control and Status Register
I/O-Ports	PORTx	Port Output Register
	DDRx	Port Direction Register
	PINx	Port Input Register

## The status register as the most used port

By far the most often used port is the status register with its 8 bits. Usually access to this port is only by automatic setting and clearing bits by the CPU or accumulator, some access is by reading or branching on certain bits in that port, in a few cases it is possible to manipulate these bits directly (using the assembler command SEx or CLx, where x is the bit abbreviation). Most of these bits are set or cleared by the accumulator through bit-test, compare- or calculation-operations. The following list has all assembler commands that set or clear status bits depending on the result of the execution.

<i>Bit</i>	<i>Calculation</i>	<i>Logic</i>	<i>Compare</i>	<i>Bits</i>	<i>Shift</i>	<i>Other</i>
Z	ADD, ADC, ADIW, DEC, INC, SUB, SUBI, SBC, SBCI, SBIW	AND, ANDI, OR, ORI, EOR, COM, NEG, SBR, CBR	CP, CPC, CPI	BCLR Z, BSET Z, CLZ, SEZ, TST	ASR, LSL, LSR, ROL, ROR	CLR
C	ADD, ADC, ADIW, SUB, SUBI, SBC, SBCI, SBIW	COM, NEG	CP, CPC, CPI	BCLR C, BSET C, CLC, SEC	ASR, LSL, LSR, ROL, ROR	-
N	ADD, ADC, ADIW, DEC, INC, SUB, SUBI, SBC, SBCI, SBIW	AND, ANDI, OR, ORI, EOR, COM, NEG, SBR, CBR	CP, CPC, CPI	BCLR N, BSET N, CLN, SEN, TST	ASR, LSL, LSR, ROL, ROR	CLR
V	ADD, ADC, ADIW, DEC, INC, SUB, SUBI, SBC, SBCI, SBIW	AND, ANDI, OR, ORI, EOR, COM, NEG, SBR, CBR	CP, CPC, CPI	BCLR V, BSET V, CLV, SEV, TST	ASR, LSL, LSR, ROL, ROR	CLR
S	SBIW	-	-	BCLR S, BSET S, CLS, SES	-	-
H	ADD, ADC, SUB, SUBI, SBC, SBCI	NEG	CP, CPC, CPI	BCLR H, BSET H, CLH, SEH	-	-
T	-	-	-	BCLR T, BSET T, BST, CLT, SET	-	-
I	-	-	-	BCLR I, BSET I, CLI, SEI	-	RETI

## Port details

Port details of the most common ports are shown in an extra table (see annex).

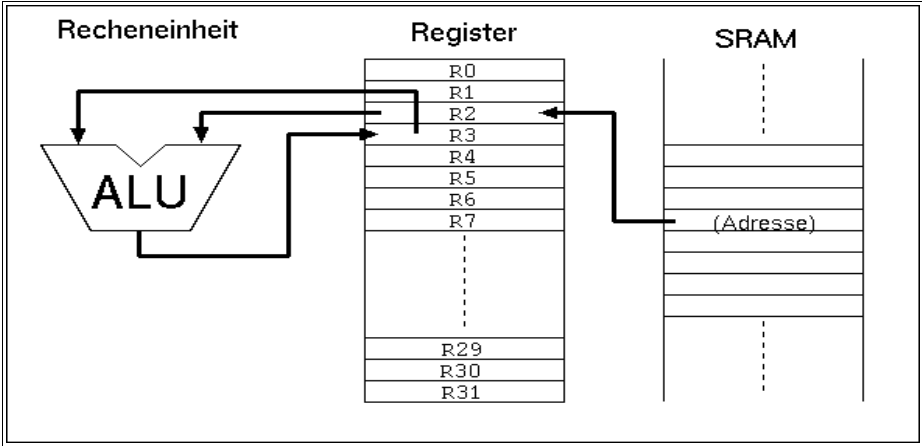
# SRAM

## Using SRAM in AVR assembler language

Nearly all AT90S-AVR-type MCUs have static RAM (SRAM) on board (some don't). Only very simple assembler programs can avoid using this memory space by putting all info into registers. If you run out of registers you should be able to program the SRAM to utilize more space.

## What is SRAM?

SRAM are memories that are not directly accessible to the central processing unit (Arithmetic and Logical Unit ALU, sometimes called accumulator) like the registers are.



If you access these memory locations you usually use a register as interim storage. In the following example a value in SRAM will be copied to the register R2 (1st command), a calculation with the value in R3 is made and the result is written to R3 (command 2). After that this value is written back to the SRAM location (command 3, not shown here).

So it is clear that operations with values stored in the SRAM are slower to perform than those using registers alone. On the other hand: the smallest AVR type has 128 bytes of SRAM available, much more than the 32 registers can hold.

The types from AT90S8515 upwards offer the additional opportunity to connect additional external RAM, expanding the internal 512 bytes. From the assembler point-of-view, external SRAM is accessed like internal SRAM. No extra commands must be used for that external SRAM.

## For what purposes can I use SRAM?

Besides simple storage of values, SRAM offers additional opportunities for its use. Not only access with fixed addresses is possible, but also the use of pointers, so that floating access to subsequent locations can be programmed. This way you can build up ring buffers for interim storage of values or calculated tables. This is not very often used with registers, because they are too few and prefer fixed access.

Even more relative is the access using an offset to a fixed starting address in one of the pointer registers. In that case a fixed address is stored in a pointer register, a constant value is added to this address and read/write access is made to that address with an offset. With that kind of access tables are better used.

The most relevant use for SRAM is the so-called stack. You can push values to that stack, be it the content of a register, a return address prior to calling a subroutine, or the return address prior to an hardware-triggered interrupt.

## How to use SRAM?

To copy a value to a memory location in SRAM you have to define the address. The SRAM addresses you can use reach from 0x0060 (hex notation) to the end of the physical SRAM on the chip (in the AT90S8515 the highest accessible internal SRAM location is 0x025F). With the command

```
STS 0x0060, R1
```

the content of register R1 is copied to the first SRAM location. With

```
LDS R1, 0x0060
```

the SRAM content at address 0x0060 is copied to the register. This is the direct access with an address that has to be defined by the programmer.

Symbolic names can be used to avoid handling fixed addresses, that require a lot of work, if you later want to change the structure of your data in the SRAM. These names are easier to handle than hex numbers, so give that address a name like:

```
.EQU MyPreferredStorageCell = 0x0060
```

*STS MyPreferredStorageCell, R1*

Yes, it isn't shorter, but easier to remember. Use whatever name that you find to be convenient.

Another kind of access to SRAM is the use of pointers. You need two registers for that purpose, that hold the 16-bit address of the location. As we learned in the Pointer-Register-Division pointer registers are the pairs X (XH:XL, R27:R26), Y (YH:YL, R29:R28) and Z (ZH:ZL, R31:R30). They allow access to the location they point to directly (e.g. with ST X, R1), after prior decrementing the address by one (e.g. ST -X, R1) or with subsequent incrementation of the address (e.g. ST X+, R1). A complete access to three cells in a row looks like this:

```
.EQU MyPreferredStorageCell = 0x0060
.DEF MyPreferredRegister = R1
.DEF AnotherRegister = R2
.DEF AndAnotherRegister = R3
    LDI XH, HIGH(MyPreferredStorageCell)
    LDI XL, LOW(MyPreferredStorageCell)
    LD MyPreferredRegister, X+
    LD AnotherRegister, X+
    LD AndAnotherRegister, X
```

Easy to operate, those pointers. And as easy as in other languages than assembler, that claim to be easier to learn.

The third construction is a little bit more exotic and only experienced programmers use this. Let's assume we very often in our program need to access three SRAM locations. Let's further assume that we have a spare pointer register pair, so we can afford to use it exclusively for our purpose. If we would use the ST/LD instructions we always have to change the pointer if we access another location. Not very convenient.

To avoid this, and to confuse the beginner, the access with offset was invented. During that access the register value isn't changed. The address is calculated by temporarily adding the fixed offset. In the above example the access to location 0x0062 would look like this. First, the pointer register is set to our central location 0x0060:

```
.EQU MyPreferredStorageCell = 0x0060
.DEF MyPreferredRegister = R1
    LDI YH, HIGH(MyPreferredStorageCell)
    LDI YL, LOW(MyPreferredStorageCell)
```

Somewhere later in the program I'd like to access cell 0x0062:

```
STD Y+2, MyPreferredRegister
```

Note that 2 is not really added to Y, just temporarily. To confuse you further, this can only be done with the Y- and Z-register-pair, not with the X-pointer!

The corresponding instruction for reading from SRAM with an offset

```
LDD MyPreferredRegister, Y+2
```

is also possible.

That's it with the SRAM, but wait: the most relevant use as stack is still to be learned.

## Use of SRAM as stack

The most common use of SRAM is its use as stack. The stack is a tower of wooden blocks. Each additional block goes onto the top of the tower, each recall of a value removes the upmost block from the tower. This structure is called Last-In-First-Out (LIFO) or easier: the last to go on top will be the first coming down.

### Defining SRAM as stack

To use SRAM as stack requires the setting of the stack pointer first. The stack pointer is a 16-bit-pointer, accessible like a port. The double register is named SPH:SPL. SPH holds the most significant address byte, SPL the least significant. This is only true, if the AVR type has more than 256 byte SRAM. If not, SPH is undefined and must not and cannot be used. We assume we have more than 256 bytes in the following examples.

To construct the stack the stack pointer is loaded with the highest available SRAM address. (In our case the tower grows downwards, towards lower addresses!).

```
.DEF MyPreferredRegister = R16
    LDI MyPreferredRegister, HIGH(RAMEND) ; Upper byte
    OUT SPH, MyPreferredRegister ; to stack pointer
    LDI MyPreferredRegister, LOW(RAMEND) ; Lower byte
    OUT SPL, MyPreferredRegister ; to stack pointer
```

The value RAMEND is, of course, specific for the processor type. It is defined in the INCLUDE file for the processor type. The file 8515def.inc has the line:

```
.equ RAMEND = $25F ; Last On-Chip SRAM Location
```

The file 8515def.inc is included with the assembler directive

```
.INCLUDE "C:\somewhere\8515def.inc"
```

at the beginning of our assembler source code.

So we defined the stack now, and we don't have to care about the stack pointer any more, because manipulations of that pointer are automatic.

## Use of the stack

Using the stack is easy. The content of registers are pushed onto the stack like this:

```
PUSH MyPreferredRegister ; Throw that value
```

Where that value goes to is totally uninteresting. That the stack pointer was decremented after that push, we don't have to care. If we need the content again, we just add the following instruction:

```
POP MyPreferredRegister ; Read back the value
```

With POP we just get the value that was last pushed on top of the stack. Pushing and popping registers makes sense, if

- the content is again needed some lines of code later,
- all registers are in use, and if
- no other opportunity exists to store that value somewhere else.

If these conditions are not given, the use of the stack for saving registers is useless and just wastes processor time.

More sense makes the use of the stack in subroutines, where you have to return to the program location that called the routine. In that case the calling program code pushes the return address (the current program counter value) onto the stack and jumps to the subroutine. After its execution the subroutine pops the return address from the stack and loads it back into the program counter. Program execution is continued exactly one instruction behind the call instruction:

```
RCALL Somewhat ; Jump to the label somewhat  
[...] here we continue with the program.
```

Here the jump to the label somewhat somewhere in the program code,

Somewhat: ; this is the jump address

```
[...] Here we do something  
[...] and we are finished and want to jump back to the calling location:  
RET
```

During execution of the RCALL instruction the already incremented program counter, a 16-bit-address, is pushed onto the stack, using two pushes. By reaching the RET instruction the content of the previous program counter is reloaded with two pops and execution continues there.

You don't need to care about the address of the stack, where the counter is loaded to. This address is automatically generated. Even if you call a subroutine within that subroutine the stack function is fine. This just packs two return addresses on top of the stack, the nested subroutine removes the first one, the calling subroutine the remaining one. As long as there is enough SRAM, everything is fine.

Servicing hardware interrupts isn't possible without the stack. Interrupts stop the normal execution of the program, wherever the program currently is. After execution of a specific service routine as a reaction to that interrupt program execution must return to the previous location, before the interrupt occurred. This would not be possible if the stack is not able to store the return address.

The enormous advances of having a stack for interrupts are the reason, why even the smallest AVR's without having SRAM have at least a very small hardware stack.

## Bugs with the stack operation

For the beginner there are a lot of possible bugs, if you first learn to use stack.

Very clever is the use of the stack without first setting the stack pointer. Because this pointer is set to zero at program start, the pointer points to register R0. Pushing a byte results in a write to that register, overwriting its previous content. An additional push to the stack writes to 0xFFFF, an undefined position (if you don't have external SRAM there). A RCALL and RET will return to a strange address in program memory. Be sure: there is no warning, like a window popping up saying something like „Illegal Access to Mem location xxxx“.

Another opportunity to construct bugs is to forget to pop a previously pushed value, or popping a value without pushing one first.

In a very few cases the stack overflows to below the first SRAM location. This happens in case of a never-ending recursive call. After reaching the lowest SRAM location the next pushes write to the ports (0x005F down to 0x0020), then to the registers (0x001F to 0x0000). Funny and unpredictable things happen with the chip hardware, if this goes on. Avoid this bug, it can even destroy your hardware!

# Jumping and Branching

Here we discuss all commands that control the sequential execution of a program. It starts with the starting sequence on power-up of the processor, jumps, interrupts, etc.

## Controlling sequential execution of the program

### What happens during a reset?

When the power supply of an AVR rises and the processor starts its work, the hardware triggers a reset sequence. The counter for the program steps will be set to zero. At this address the execution always starts. Here we have to have our first word of code. But not only during power-up this address is activated:

- During an external reset on the reset pin a restart is executed.
- If the Watchdog counter reaches its maximum count, a reset is initiated. A watchdog timer is an internal clock that must be resetted from time to time by the program, otherwise it restarts the processor.
- You can call reset by a direct jump to that address (see the jump section below).

The third case is not a real reset, because the automatic resetting of register- and port-values to a well-defined default value is not executed. So, forget that for now.

The second option, the watchdog reset, must first be enabled by the program. It is disabled by default. Enabling requires write commands to the watchdog's port. Setting the watchdog counter back to zero requires the execution of the command

*WDR*

to avoid a reset.

After execution of a reset, with setting registers and ports to default values, the code at address 0000 is wordwise read to the execution part of the processor and is executed. During that execution the program counter is already incremented by one and the next word of code is already read to the code fetch buffer (Fetch during Execution). If the executed command does not require a jump to another location in the program the next command is executed immediately. That is why the AVR's execute extremely fast, each clock cycle executes one command (if no jumps occur).

The first command of an executable is always located at address 0000. To tell the compiler (assembler program) that our source code starts now and here, a special directive can be placed at the beginning, before the first code in the source is written:

```
.CSEG  
.ORG 0000
```

The first directive lets the compiler switch to the code section. All following is translated as code and is written to the program memory section of the processor. Another target segment would be the EEPROM section of the chip, where you also can write bytes or words to.

```
.ESEG
```

The third segment is the SRAM section of the chip.

```
.DSEG
```

Other than with EEPROM content, that really goes to the EEPROM during programming of the chip, the DSEG segment content is not programmed to the chip. It is only used for correct label calculation during the assembly process.

The ORG directive above stands for origin and manipulates the address within the code segment, where assembled words go to. As our program always starts at 0x0000 the CSEG/ORG directives are trivial, you can skip these without getting into an error. We could start at 0x0100, but that makes no real sense as the processor starts execution at 0000. If you want to place a table exactly to a certain location of the code segment, you can use ORG. If you want to set a clear sign within your code, after first defining a lot of other things with .DEF- and .EQU-directives, use the CSEG/ORG sequence, even though it might not be necessary to do that.

As the first code word is always at address zero, this location is also called the reset vector. Following the reset vector the next positions in the program space, addresses 0x0001, 0x0002 etc., are interrupt vectors. These are the positions where the execution jumps to if an external or internal interrupt has been enabled and occurs. These positions called vectors are specific for each processor type and depend on the internal hardware available (see below). The commands to react to such an interrupt have to be placed to the proper vector location. If you use interrupts, the first code, at the reset vector, must be a jump command, to jump over the other vectors. Each interrupt vector must hold a jump command to the respective interrupt service routine. The typical program sequence at the beginning is like follows:

```
.CSEG
.ORG 0000
    RJMP Start
    RJMP IntServRout1
```

*[...] here we place the other interrupt vector commands*

*[...] and here is a good place for the interrupt service routines themselves*

*Start: ; This here is the program start*  
*[...] Here we place our main program*

The command RJMP results in a jump to the label Start:, located some lines below. Remember, labels always start in column 1 of the source code and end with a :. Labels, that don't fulfil these conditions are not taken for serious by many compiler. Missing labels result in an error message ("Undefined label"), and compilation is interrupted.

## Linear program execution and branches

Program execution is always linear, if nothing changes the sequential execution. These changes are the execution of an interrupt or of branching instructions.

Branching is very often depending on some condition, conditioned branching. As an example we assume we want to construct a 32-bit-counter using registers R1 to R4. The least significant byte in R1 is incremented by one. If the register overflows during that operation ( $255 + 1 = 0$ ), we have to increment R2 similarly. If R2 overflows, we have to increment R3, and so on.

Incrementation by one is done with the instruction INC. If an overflow occurs during that execution of INC R1 the zero bit in the status register is set to one (the result of the operation is zero). The carry bit in the status register, usually set by overflows, is not changed during an INC. This is not to confuse the beginner, but carry is used for other purposes instead. The Zero-Bit or Zero-flag in this case is enough to detect an overflow. If no overflow occurs we can just leave the counting sequence.

If the Zero-bit is set, we must execute additional incrementation of the other registers. To confuse the beginner the branching command, that we have to use, is not named BRNZ but BRNE (BRanch if Not Equal). A matter of taste ...

The whole count sequence of the 32-bit-counter should then look like this:

```
    INC R1
    BRNE GoOn32
    INC R2
    BRNE GoOn32
    INC R3
    BRNE GoOn32
    INC R4
GoOn32:
```

So that's about it. An easy thing. The opposite condition to BRNE is BREQ or BRanch EQual.

Which of the status bits, also called processor flags, are changed during execution of a command is listed in instruction code tables, see the List of Instructions. Similarly to the Zero-bit you can use the other status bits like that:

```
BRCC label/BRCS label; Carry-flag 0 oder 1
BRSH label; Equal or greater
BRLO label; Smaller
BRMI label; Minus
BRPL label; Plus
BRGE label; Greater or equal (with sign bit)
BRLT label; Smaller (with sign bit)
BRHC label/BRHS label; Half overflow flag 0 or 1
BRTC label/BRTS label; T-Bit 0 or 1
BRVC label/BRVS label; Two's complement flag 0 or 1
BRIE label/BRID label; Interrupt enabled or disabled
```

to react to the different conditions. Branching always occurs if the condition is met. Don't be afraid, most of these commands are rarely used. For the beginner only Zero and Carry are relevant.

## Timing during program execution

Like mentioned above the required time to execute one instruction is equal to the processor's clock cycle. If the processor runs on a 4 MHz clock frequency then one instruction requires  $1/4 \mu\text{s}$  or 250 ns, at 10 MHz clock only 100 ns. The required time is as exact as the xtal clock. If you need exact timing an AVR is the optimal solution for your problem. Note that there are a few commands that require two or more cycles, e.g. the branching instructions (if branching occurs) or the SRAM read/write sequence. See the instruction table for details.

To define exact timing there must be an opportunity that does nothing else than delay program execution.



You might use other instructions that do nothing, but more clever is the use of the NO Operation command NOP. This is the most useless instruction:

```
NOP
```

This instruction does nothing but wasting processor time. At 4 MHz clock we need just four of these instructions to waste 1  $\mu$ s. No other hidden meanings here on the NOP instruction. For a signal generator with 1 kHz we don't need to add 4000 such instructions to our source code, but we use a software counter and some branching instructions. With these we construct a loop that executes for a certain number of times and are exactly delayed. A counter could be a 8-bit-register that is decremented with the DEC instruction, e.g. like this:

```
CLR R1
Count:
    DEC R1
    BRNE Count
```

16-bit counting can also be used to delay exactly, like this

```
LDI ZH,HIGH(65535)
LDI ZL,LOW(65535)
Count:
    SBIW ZL,1
    BRNE Count
```

If you use more registers to construct nested counters you can reach any delay. And the delay is absolutely exact, even without a hardware timer.

## Macros and program execution

Very often you have to write identical or similiar code sequences on different occasions in your source code. If you don't want to write it once and jump to it via a subroutine call you can use a macro to avoid getting tired writing the same sequence several times. Macros are code sequences, designed and tested once, and inserted into the code by its macro name. As an example we assume we need to delay program execution several times by 1  $\mu$ s at 4 MHz clock. Then we define a macro somewhere in the source:

```
.MACRO Delay1
    NOP
    NOP
    NOP
    NOP
.ENDMACRO
```

This definition of the macro does not yet produce any code, it is silent. Code is produced if you call that macro by its name:

```
[...] somewhere in the source code
    Delay1
[... code goes on here
```

This results in four NOP incstructions inserted to the code at that location. An additional Delay1 inserts additional four NOP instructions.

By calling a macro by its name you can add some parameters to manipulate the produced code. But this is more than a beginner has to know about macros.

If your macro has longer code sequences, or if you are short in code storage space, you should avoid the use of macros and use subroutines instead.

## Subroutines

In contrary to macros a subroutine does save program storage space. The respective sequence is only once stored in the code and is called from whatever part of the code. To ensure continued execution of the sequence following the subroutine call you need to return to the caller. For a delay of 10 cycles you need to write this subroutine:

```
Delay10:
    NOP
    NOP
    NOP
    RET
```

Subroutines always start with a label, otherwise you would not be able to jump to it, here Delay10:. Three NOPs follow and a RET instruction. If you count the necessary cycles you just find 7 cycles (3 for the NOPs, 4 for the RET). The missing 3 are for calling that routine:

```
[...] somewhere in the source code:
    RCALL Delay10
[... further on with the source code
```

RCALL is a relative call. The call is coded as relative jump, the relative distance from the calling routine to the subroutine is calculated by the compiler. The RET instruction jumps back to the calling routine. Note that before you use subroutine calls you must set the stackpointer (see Stack), because the return address must be packed on the stack by the RCALL instruction.

If you want to jump directly to somewhere else in the code you have to use the jump instruction:

```
[...] somewhere in the source code
    RJMP Delay10
Return:
[...] further on with source code
```

The routine that you jumped to can not use the RET command in that case. To return back to the calling location in the source requires to add another label and the called routine to jump back to this label. Jumping like this is not like calling a subroutine because you can't call this routine from different locations in the code.

RCALL and RJMP are unconditioned branches. To jump to another location, depending on some condition, you have to combine these with branching instructions. Conditioned calling of a subroutine can best be done with the following commands. If you want to call a subroutine depending on a certain bit in a register use the following sequence:

```
SBRC R1,7 ; Skip the next instruction if bit 7 is 0
RCALL UpLabel ; Call that subroutine
```

SBRC reads „Skip next instruction if Bit 7 in Register R1 is Clear(Zero)“. The RCALL instruction to UpLabel: is only executed if bit 7 in register R1 is 1, because the next instruction is skipped if it would be 0. If you like to call the subroutine in case this bit is 0 then you use the corresponding instruction SBRS. The instruction following SBRS/SBRC can be a single word or double word instruction, the processor knows how far he has to jump over it. Note that execution times are different then. To jump over more than one following instruction these commands cannot be used.

If you have to skip an instruction if two registers have the same value you can use the following exotic instruction

```
CPSE R1,R2 ; Compare R1 and R2, skip if equal
RCALL SomeSubroutine ; Call SomeSubroutine
```

A rarely used command, forget it for the beginning. If you like to skip the following instruction depending on a certain bit in a port use the following instructions SBIC und SBIS. That reads Skip if the Bit in I/o space is Clear (or Set), like this:

```
SBIC PINB,0 ; Skip if Bit 0 on port B is 0
RJMP ATarget ; Jump to the label ATarget
```

The RJMP-instruction is only executed if bit 0 in port B is high. This is something confusing for the beginner. The access to the port bits is limited to the lower half of ports, the upper 32 ports are not usable here.

Now, another exotic application for the expert. Skip this if you are a beginner. Assume we have a bit switch with 4 switches connected to port B. Depending on the state of these 4 bits we would like to jump to 16 different locations in the code. Now we can read the port and use several branching instructions to find out, where we have to jump to today. As alternative you can write a table holding the 16 addresses, like this:

```
MyTab:
    RJMP Routine1
    RJMP Routine2
    [...]
    RJMP Routine16
```

In our code we copy that adress of the table to the Z pointer register:

```
LDI ZH,HIGH(MyTab)
LDI ZL,LOW(MyTab)
```

and add the current state of the port B (in R16) to this address.

```
ADD ZL,R16
BRCC NoOverflow
INC ZH
NoOverflow:
```

Now we can jump to this location in the table, either for calling a subroutine:

```
ICALL
```

or as a jump with no way back:

```
IJMP
```

The processor loads the content of the Z register pair into its program counter and continues operation there. More clever than branching over and over?

# Interrupts and program execution

Very often we have to react on hardware conditions or other events. An example is a change on an input pin. You can program such a reaction by writing a loop, asking whether a change on the pin has occurred. This method is called polling, its like a bee running around in circles searching for new flowers. If there are no other things to do and reaction time does not matter, you can do this with the processor. If you have to detect short pulses of less than a  $\mu$ s duration this method is useless. In that case you need to program an interrupt.

An interrupt is triggered by some hardware conditions. The condition has to be enabled first, all hardware interrupts are disabled at reset time by default. The respective port bits enabling the component's interrupt ability are set first. The processor has a bit in its status register enabling him to respond to the interrupt of all components, the Interrupt Enable Flag. Enabling the general response to interrupts requires the following command:

```
SEI ; Set Int Enable Bit
```

If the interrupting condition occurs, e.g. a change on the port bit, the processor pushes the actual program counter to the stack (which must be enabled first! See initiation of the stackpointer in the Stack section of the SRAM description). Without that the processor wouldn't be able to return back to the location, where the interrupt occurred (which could be any time and anywhere within program execution). After that, processing jumps to the predefined location, the interrupt vector, and executes the instructions there. Usually the instruction there is a JUMP instruction to the interrupt service routine, located somewhere in the code. The interrupt vector is a processor-specific location and depending from the hardware component and the condition that leads to the interrupt. The more hardware components and the more conditions, the more vectors. The different vectors for some of the AVR types are listed in the following table. (The first vector isn't an interrupt but the reset vector, performing no stack operation!)

Name	Interrupt Vector Adress			Triggered by
	2313	2323	8515	
RESET	0000	0000	0000	Hardware Reset, Power-On-Reset, Watchdog Reset
INT0	0001	0001	0001	Level change on the external INT0 pin
INT1	0002	-	0002	Level change on the external INT1 pin
TIMER1CAPT	0003	-	0003	Capture event on Timer/Counter 1
TIMER1COMPA	-	-	0004	Timer/Counter 1 = Compare value A
TIMER1 COMPB	-	-	0005	Timer/Counter 1 = Compare value B
TIMER1 COMP1	0004	-	-	Timer/Counter 1 = Compare value 1
TIMER1 OVF	0005	-	0006	Timer/Counter 1 Overflow
TIMER0 OVF	0006	0002	0007	Timer/Counter 0 Overflow
SPI STC	-	-	0008	Serial Transmit Complete
UART TX	0007	-	0009	UART char in receive buffer available
UART UDRE	0008	-	000A	UART transmitter ran empty
UART TX	0009	-	000B	UART All Sent
ANA_COMP	-	-	000C	Analog Comparator

Note that the capability to react to events is very different for the different types. The addresses are sequential, but not identical for different types. Consult the data sheet for each AVR type.

The higher a vector in the list the higher is its priority. If two or more components have an interrupt condition pending at the same time, the upmost vector with the lower vector address wins. The lower int has to wait until the upper int was served. To disable lower ints from interrupting during the execution of its service routine the first executed int disables the processor's I-flag. The service routine must re-enable this flag after it is done with its job.

For re-setting the I status bit there are two ways. The service routine can end with the command:

```
RETI
```

This return from the int routine restores the I-bit after the return address has been loaded to the program counter.

The second way is to enable the I-bit by the instruction

```
SEI ; Set Interrupt Enabled
RET ; Return
```

This is not the same as the RETI, because subsequent interrupts are already enabled before the program

counter is re-loaded with the return address. If another int is pending, its execution is already starting before the return address is popped from the stack. Two or more nested addresses remain on the stack. No bug is to be expected, but it is an unnecessary risk doing that. So just use the RETI instruction to avoid this unnecessary flow to the stack.

An Int-vector can only hold a relative jump instruction to the service routine. If a certain interrupt is not used or undefined we can just put a RETI instruction there, in case a false int happens. In a few cases it is absolutely necessary to react to these false ints. That is the case if the execution of the respective service routine does not automatically reset the interrupt condition flag of the peripheral. In that case a simple RETI would reset in never-ending interrupts. This is the case with some of the UART interrupts.

As, after an interrupt is under service, further execution of lower-priority ints is blocked, all int service routines should be as short as possible. If you need to have a longer routine to serve the int, use one of the two following methods. The first is to allow ints by SEI within the service routine, whenever you're done with the most urgent tasks. Not very clever. More convenient is to perform the urgent tasks, setting a flag somewhere in a register for the slower reactions and return from the int immediately.

A very serious rule for int service routines is: First instruction is always to save the status register on the stack, before you use instructions that might change flags in the status register. The interrupted main program might just be in a state using the flag for a branch decision, and the int would just change that flag to another state. Funny things would happen from time to time. The last instruction before the RETI therefore is to pop the status register content from the stack and restore its original content.

For the same reason all used registers in a service routine should either be exclusively reserved for that purpose or saved on stack and restored at the end of the service routine. Never change the content of a register within an int service routine that is used somewhere else in the normal program without restoring it.

Because of these basic requirements a more sophisticated example for an interrupt service routine here.

```
.CSEG ; Code-Segment starts here
.ORG 0000 ; Address is zero
    RJMP Start ; The reset-vector on Address 0000
    RJMP IService ; 0001: first Int-Vektor, INT0 service routine
[...] here other vectors

Start: ; Here the main program starts
[...] here is enough space for defining the stack and other things

IService: ; Here we start with the Interrupt-Service-Routine
    PUSH R16 ; save a register to stack
    IN R16,SREG ; read status register
    PUSH R16 ; and put on stack
[...] Here the Int-Service-Routine does something and uses R16
    POP R16 ; get previous flag register from stack
    OUT SREG,R16 ; restore old status
    POP R16 ; get previous content of R16 from the stack
    RETI ; and return from int
```

Looks a little bit complicated, but is a prerequisite for using ints without producing serious bugs. Skip PUSH R16 and POP R16 if you can afford reserving the register for exclusive use in the service routine. As an interrupt service routine cannot be interrupted (unless you allow interrupts within the routine), all different int service routines can use the same register.

That's it for the beginner. There are some other things with ints, but this is enough to start with, and not to confuse you.

# Calculations

Here we discuss all necessary commands for calculating in AVR assembler language. This includes number systems, setting and clearing bits, shift and rotate, and adding/subtracting/comparing and the format conversion of numbers.

## Number systems in assembler

The following formats of numbers are common in assembler:

- Positive whole numbers (Bytes, Words, etc.),
- Signed whole numbers (Integers),
- Binary Coded Digits, BCD,
- Packed BCDs,
- ASCII-formatted numbers.

### Positive whole numbers (bytes, words, etc.)

The smallest whole number to be handled in assembler is a byte with eight bits. This codes numbers between 0 and 255. Such bytes fit exactly into one register of the MCU. All bigger numbers must be based on this basic format, using more than one register. Two bytes yield a word (range from 0 .. 65,535), three bytes form a longer word (range from 0 .. 16,777,215) and four bytes form a double word (range from 0 .. 4,294,967,295).

The single bytes of a word or a double word can be stored in whatever register you prefer. Operations with these single bytes are programmed byte by byte, so you don't have to put them in a row. In order to form a row for a double word we could store it like this:

```
.DEF r16 = dw0  
.DEF r17 = dw1  
.DEF r18 = dw2  
.DEF r19 = dw3
```

dw0 to dw3 are in a row in the registers. If we need to initiate this double word at the beginning of an application (e.g. to 4,000,000), this should look like this:

```
.EQU dwi = 4000000 ; define the constant  
    LDI dw0,LOW(dwi) ; The lowest 8 bits to R16  
    LDI dw1,BYTE2(dwi) ; bits 8 .. 15 to R17  
    LDI dw2,BYTE3(dwi) ; bits 16 .. 23 to R18  
    LDI dw3,BYTE4(dwi) ; bits 24 .. 31 to R19
```

So we have splitted this decimal number, called dwi, to its binary portions and packed them into the four byte packages. Now you can calculate with this double word.

### Signed numbers (integers)

Sometimes, but in rare cases, you need negative numbers to calculate with. A negative number is defined by interpreting the most significant bit of a byte as sign bit. If it is 0 the number is positive. If it is 1 the number is negative. If the number is negative we usually do not store the rest of the number as is, but we use its inverted value. Inverted means that -1 as an byte integer is not written as 1000.0001 but as 1111.1111 instead. That means: subtract 1 from 0 and forget the overflow. The first bit is the sign bit, signalling that this is a negative number. Why this different format (subtracting the negative number from 0) is used is easy to understand: adding -1 (1111.1111) and +1 (0000.0001) yields exactly zero, if you forget the overflow that occurs during that operation (the ninth bit).

In one byte the biggest integer number to be handled is +127 (binary 0,1111111), the smallest one is -128 (binary 1,0000000). In other computer languages this number format is called short integer. If you need a bigger range of values you can add another byte to form a normal integer value, ranging from +32,767 .. -32,768, four bytes provide a range from +2,147,483,647 .. -2,147,483,648, usually called a LongInt or DoubleInt.

### Binary Coded Digits, BCD

Positive or signed whole numbers in the formats discussed above use the available space most effectively. Another, less dense number format, but easier to handle is to store decimal numbers in a byte for one digit each. The decimal digit is stored in its binary form in a byte. Each digit from 0 .. 9 needs four bits (0000 .. 1001), the upper four bits of the byte are zeros, blowing a lot of air into the byte. For to handle the value 250 we would need at least three bytes, e.g.:

<i>Bit value</i>	<i>128</i>	<i>64</i>	<i>32</i>	<i>16</i>	<i>8</i>	<i>4</i>	<i>2</i>	<i>1</i>
R16, Digit 1 =2	0	0	0	0	0	0	1	0
R17, Digit 2 = 5	0	0	0	0	0	1	0	1
R18, Digit 3 = 0	0	0	0	0	0	0	0	0

```
;Instructions to use:  
LDI R16,2  
LDI R17,5  
LDI R18,0
```

You can calculate with these numbers, but this is a bit more complicated in assembler than calculating with binary values. The advantage of this format is that you can handle as long numbers as you like, as long as you have enough storage space. The calculations are as precise as you like (if you program AVR's for banking applications), and you can convert them very easily to character strings.

Packed BCDs

If you pack two decimal digits into one byte you don't loose that much storage space. This method is called packed binary coded digits. The two parts of a byte are called upper and lower nibble. The upper nibble usually holds the more significant digit, which has advantages in calculations (special instructions in AVR assembler language). The decimal number 250 would look like this when formatted as a packed BCD:

<i>Byte</i>	<i>Digits</i>	<i>Value</i>	<i>8</i>	<i>4</i>	<i>2</i>	<i>1</i>	<i>8</i>	<i>4</i>	<i>2</i>	<i>1</i>
2	4 & 3	02	0	0	0	0	0	0	1	0
1	2 & 1	50	0	1	0	1	0	0	0	0

```
; Instructions for setting:  
LDI R17,0x02 ; Upper byte  
LDI R16,0x50 ; Lower byte
```

To set this correct you can use the binary notation (0b...) or the hexadecimal notation (0x...) to set the proper bits to their correct nibble position.

Calculating with packed BCDs is a little more complicated compared to the binary form. Format changes to character strings are as easy as with BCDs. Length of numbers and precision of calculations is only limited by the storage space.

Numbers in ASCII-format

Very similiar to the unpacked BCD format is to store numbers in ASCII format. The digits 0 to 9 are stored using their ASCII (ASCII = American Standard Code for Information Interchange) representation. ASCII is a very old format, develloped and optimized for teletype writers, unnecessarily very complicated for computer use (do you know what a char named End Of Transmission EOT meant when it was invented?), very limited in range for other than US languages (only 7 bits per character), still used in communications today due to the limited efforts of some operating system programmers to switch to more effective character systems. This ancient system is only topped by the european 5-bit long teletype character set called Baudot set or the still used Morse code.

Within the ASCII code system the decimal digit 0 is represented by the number 48 (hex 0x30, binary 0b0011.0000), digit 9 is 57 decimal (hex 0x39, binary 0b0011.1001). ASCII wasn't designed to have these numbers on the beginning of the code set as there are already command chars like the above mentioned EOT for the teletype. So we still have to add 48 to a BCD (or set bit 4 and 5 to 1) to convert a BCD to ASCII. ASCII formatted numbers need the same storage space like BCDs. Loading 250 to a register set representing that number would look like this:

```
LDI R18,'2'  
LDI R17,'5'  
LDI R16,'0'
```

The ASCII representation of these characters are written to the registers.

Bit manipulations

To convert a BCD coded digit to its ASCII representation we need to set bit 4 and 5 to a one. In other words we need to OR the BCD with a constant value of hex 0x30. In assembler this is done like this:

```
ORI R16,0x30
```

If we have a register that is already set to hex 0x30 we can use the OR with this register to convert the BCD:

*OR R1,R2*

Back from an ASCII character to a BCD is as easy. The instruction

*ANDI R1,0x0F*

isolates the lower four bits (= the lower nibble). Note that ORI and ANDI are only possible with registers above R15. If you need to do this, use one of the registers R16 to R31!

If the hex value 0x0F is already in register R2, you can AND the ASCII character with this register:

*AND R1,R2*

The other instructions for manipulating bits in a register are also limited for registers above R15. They would be formulated like this:

*SBR R16,0b00110000 ; Set bits 4 und 5 to one*  
*CBR R16,0b00110000 ; Clear bits 4 and 5 to zero*

If one or more bits of a byte have to be inverted you can use the following instruction (which is not possible for use with a constant):

*LDI R16,0b10101010 ; Invert all even bits*  
*EOR R1,R16 ; in register R1 and store result in R1*

To invert all bits of a byte is called the One's complement:

*COM R1*

inverts the content in register R1 and replaces zeros by one and vice versa. Different from that is the Two's complement, which converts a positive signed number to its negative complement (subtracting from zero). This is done with the instruction

*NEG R1*

So +1 (decimal: 1) yields -1 (binary 1.1111111), +2 yields -2 (binary 1.1111110), and so on.

Besides the manipulation of the bits in a register, copying a single bit is possible using the so-called T-bit of the status register. With

*BLD R1,0*

the T-bit is loaded with a copy of bit 0 in register R1. The T-bit can be set or cleared, and its content can be copied to any bit in any register:

*CLT ; clear T-bit, or*  
*SET ; set T-bit, or*  
*BST R2,2 ; copy T-bit to register R2, bit 2*

## Shift and rotate

Shifting and rotating of binary numbers means multiplying and dividing them by 2. Shifting has several sub-instructions.

Multiplication with 2 is easily done by shifting all bits of a byte one binary digit left and writing a zero to the least significant bit. This is called logical shift left. The former bit 7 of the byte will be shifted out to the carry bit in the status register.

*LSL R1*

The inverse division by 2 is the instruction called logical shift right.

*LSR R1*

The former bit 7, now shifted to bit 6, is filled with a 0, while the former bit 0 is shifted into the carry bit of the status register. This carry bit could be used to round up and down (if set, add one to the result). Example, division by four with rounding:

*LSR R1 ; division by 2*  
*BRCC Div2 ; Jump if no round up*  
*INC R1 ; round up*

*Div2:*

*LSR R1 ; Once again division by 2*  
*BRCC DivE ; Jump if no round up*  
*INC R1 ; Round Up*

*DivE:*

So, dividing is easy with binaries as long as you divide by multiples of 2.

If signed integers are used the logical shift right would overwrite the sign-bit in bit 7. The instruction „arithmetic shift right“ ASR leaves bit 7 untouched and shifts the 7 lower bits, inserting a zero into bit location 6.

### ASR R1

Like with logical shifting the former bit 0 goes to the carry bit in the status register.

What about multiplying a 16-bit word by 2? The most significant bit of the lower byte has to be shifted to yield the lowest bit of the upper byte. In that step a shift would set the lowest bit to zero, but we need to shift the carry bit from the previous shift of the lower byte into bit 0. This is called a rotate. During rotation the carry bit in the status register is shifted to bit 0, the former bit 7 is shifted to the carry during rotation.

*LSL R1 ; Logical Shift Left of the lower byte*  
*ROL R2 ; ROTate Left of the upper byte*

The logical shift left in the first instruction shifts bit 7 to carry, the ROL instruction rolls it to bit 0 of the upper byte. Following the second instruction the carry bit has the former bit 7. The carry bit can be used to either indicate an overflow (if 16-bit-calculation is performed) or to roll it into upper bytes (if more than 16 bit calculation is done).

Rolling to the right is also possible, dividing by 2 and shifting carry to bit 7 of the result:

*LSR R2 ; Logical Shift Right, bit 0 to carry*  
*ROR R1 ; ROTate Right and shift carry in bit 7*

It's easy dividing with big numbers. You see that learning assembler is not THAT complicated.

The last instruction that shifts four bits in one step is very often used with packed BCDs. This instruction shifts a whole nibble from the upper to the lower position and vice versa. In our example we need to shift the upper nibble to the lower nibble position. Instead of using

*ROR R1*  
*ROR R1*  
*ROR R1*  
*ROR R1*

we can perform that with a single

*SWAP R1*

This instruction exchanges the upper and lower nibble. Note that the upper nibble's content will be different after applying these two methods.

## Adding, subtracting and comparing

The following calculation operations are too complicated for the beginners and demonstrate that assembler is only for extreme experts, hi. Read on your own risk!

To start complicated we add two 16-bit-numbers in R1:R2 and R3:R4. (In this notation, we mean that the first register is the most significant byte, the second the least significant).

*ADD R2,R4 ; first add the two low-bytes*  
*ADC R1,R3 ; then the two high-bytes*

Instead of a second ADD we use ADC in the second instruction. That means add with carry, which is set or cleared during the first instruction, depending from the result. Already scared enough by that complicated math? If not: take this!

We subtract R3:R4 from R1:R2.

*SUB R2,R4 ; first the low-byte*  
*SBC R1,R3 ; then the high-byte*

Again the same trick: during the second instruction we subtract another 1 from the result if the result of the first instruction had an overflow. Still breathing? If yes, handle the following!

Now we compare a 16-bit-word in R1:R2 with the one in R3:R4 to evaluate whether it is bigger than the second one. Instead of SUB we use the compare instruction CP, instead of SBC we use CPC:

*CP R2,R4 ; compare lower bytes*  
*CPC R1,R3 ; compare upper bytes*

If the carry flag is set now, R1:R2 is bigger than R3:R4.

Now we add some more complicated stuff. We compare the content of R16 with a constant: 0b10101010.

*CPI R16,0xAA*

If the Zero-bit in the status register is set after that, we know that R16 is 0xAA. If the carry-bit is set, we know, it is smaller. If Carry is not set and the Zero-bit is not set either, we know it is bigger.

And now the most complicated test. We evaluate whether R1 is zero or negative:

*TST R1*

If the Z-bit is set, the register R1 is zero and we can follow with the instructions BREQ, BRNE, BRMI,



BRPL, BRLO, BRSH, BRGE, BRLT, BRVC or BRVS to branch around a bit.

Still with us? If yes, here is some packed BCD calculations. Adding two packed BCDs can result in two different overflows. The usual carry shows an overflow, if the higher of the two nibbles overflows to more than 15 decimal. Another overflow, from the lower to the upper nibble occurs, if the two lower nibbles add to more than 15 decimal.

To take an example we add the packed BCDs 49 (=hex 49) and 99 (=hex 99) to yield 148 (=hex 0x0148). Adding these in binary math, results in a byte holding hex 0xE2, no byte overflow occurs. The lower of the two nibbles should have an overflow, because  $9+9=18$  (more than 9) and the lower nibble can only handle numbers up to 15. The overflow was added to bit 4, the lowest significant bit of the upper nibble. Which is correct! But the lower nibble should be 8 and is only 2 ( $18 = 0b0001.0010$ ). We should add 6 to that nibble to yield a correct result. Which is quite logic, because whenever the lower nibble reaches more than 9 we have to add 6 to correct that nibble.

The upper nibble is totally incorrect, because it is 0xE and should be 3 (with a 1 overflowing to the next upper digit of the packed BCD). If we add 6 to this 0xE we get to 0x4 and the carry is set (=0x14). So the trick is to first add these two numbers and then add 0x66 to correct the 2 digits of the packed BCD. But halt: what if adding the first and the second number would not result in an overflow to the next nibble? And not result in a digit above 9 in the lower nibble? Adding 0x66 would then result in a totally incorrect result. The lower 6 should only be added if the lower nibble either overflows to the upper nibble or results in a digit greater than 9. The same with the upper nibble.

How do we know, if an overflow from the lower to the upper nibble has occurred? The MCU sets the H-bit in the status register, the half-carry bit. The following shows the algorithm for the different cases that are possible after adding two nibbles and adding hex 0x6 after that.

1. Add the nibbles. If overflow occurs (C for the upper nibbles, or H for the lower nibbles), add 6 to correct, if not, do step 2.
2. Add 6 to the nibble. If overflow occurs (C resp. H), you're done. If not, subtract 6.

To program an example we assume that the two packed BCDs are in R2 and R3, R1 will hold the overflow, and R16 and R17 are available for calculations. R16 is the adding register for adding 0x66 (the register R2 cannot add a constant value), R17 is used to correct the result depending from the different flags. Adding R2 and R3 goes like that:

```

LDI R16,0x66 ; for adding 0x66 to the result
LDI R17,0x66 ; for later subtracting from the result
ADD R2,R3 ; add the two two-digit-BCDs
BRCC NoCy1 ; jump if no byte overflow occurs
INC R1 ; increment the next higher byte
ANDI R17,0x0F ; don't subtract 6 from the higher nibble
NoCy1:
BRHC NoHc1 ; jump if no half-carry occurred
ANDI R17,0xF0 ; don't subtract 6 from lower nibble
NoHc1:
ADD R2,R16 ; add 0x66 to result
BRCC NoCy2 ; jump if no carry occurred
INC R1 ; increment the next higher byte
ANDI R17,0x0F ; don't subtract 6 from higher nibble
NoCy2:
BRHC NoHc2 ; jump if no half-carry occurred
ANDI R17,0xF0 ; don't subtract 6 from lower nibble
NoHc2:
SUB R2,R17 ; subtract correction

```

A little bit shorter than that:

```

LDI R16,0x66
ADD R2,R16
ADD R2,R3
BRCC NoCy
INC R1
ANDI R16,0x0F
NoCy:
BRHC NoHc
ANDI R16,0xF0
NoHc:
SUB R2,R16

```

Question to think about: Why is that equally correct, half as long and complicated and where is the trick?

## Format conversion for numbers

All number formats can be converted to any other format. The conversion from BCD to ASCII and vice versa was already shown above (Bit manipulations).

Conversion of packed BCDs is not very complicated either. First we have to copy the number to another register. With the copied value we change nibbles using the SWAP instruction to exchange the upper and

the lower one. The upper part is cleared, e.g. by ANDing with 0x0F. Now we have the BCD of the upper nibble and we can either use as is (BCD) or set bit 4 and 5 to convert it to an ASCII character. After that we copy the byte again and treat the lower nibble without first SWAPping and get the lower BCD.

A little bit more complicated is the conversion of BCD digits to a binary. Depending on the numbers to be handled we first clear the necessary bytes that will hold the result of the conversion. We then start with the highest BCD digit. Before adding this to the result we multiply the result with 10. (Note that in the first step this is not necessary, because the result is zero either).

In order to do the multiplication by 10, we copy the result to somewhere else. Then we multiply the result by four (two left shifts resp. rolls). Adding the previously copied number to this yields a multiplication with 5. Now a mulitiplication with 2 (left shift/roll) yields the 10-fold of the result. Finally we add the BCD and repeat that algorithm until all decimal digits are converted. If, during one of these operations, there occurs a carry of the result, the BCD is too big to be converted. This algorithm handles numbers of any length, as long as the result registers are prepared.

The conversion of a binary to BCDs is more complicated than that. If we convert a 16-bit-binary we can subtract 10,000 (0x2710), until an overflow occurs, yielding the first digit. Then we repeat that with 1,000 (0x03E8) to yield the second digit. And so on with 100 (0x0064) and 10 (0x000A), then the remainder is the last digit. The constants 10,000, 1,000, 100 and 10 can be placed to the program memory storage in a wordwise organised table, like this:

```
DezTab:
.DW 10000, 1000, 100, 10
```

and can be read wordwise with the LPM instruction from the table.

An alternative is a table that holds the decimal value of each bit in the 16-bit-binary, e.g.

```
.DB 0,3,2,7,6,8
.DB 0,1,6,3,8,4
.DB 0,0,8,1,9,2
.DB 0,0,4,0,9,6
.DB 0,0,2,0,4,8 ; and so on until
.DB 0,0,0,0,0,1
```

Then you shift the single bits of the binary left out of the registers to the carry. If it is a one, you add the number in the table to the result by reading the numbers from the table using LPM. This is more complicated to program and a little bit slower than the above method.

A third method is to calculate the table value, starting with 000001, by adding this BCD with itself, each time after you have shifted a bit from the binary to the right and added the BCD.

Many methods, much to optimize here.

## Multiplication

Multiplication of binary numbers is explained here.

### Decimal multiplication

In order to multiply two 8-bit-binaries we remind ourselves, how this is done with decimal numbers:

```
1234 * 567 = ?
-----
1234 * 7 = 8638
+ 1234 * 60 = 74040
+ 1234 * 500 = 617000
-----
1234 * 567 = 699678
=====
```

In single steps decimal:

- We multiply the first number by the lowest significant digit of the second number and add this to the result.
- We multiply the first number by 10 and then by the next higher digit of the second number and add to the result.
- We multiply the first number by 100, then with the third-highest digit, and add this to the result.

### Binary multiplication

Now in binary. Multiplication with the single digits is not necessary, because there are only the digits 1

(add the number) and 0 (don't add the number). Multiplication by 10 in decimal goes to multiplication by 2 in binary mode. Multiplication by 2 is done easily, either by adding the number with itself, or by shifting all bits one position left and writing a 0 to the void position on the right. You see that binary math is very much easier than decimal. Why didn't mankind use this from the beginning?

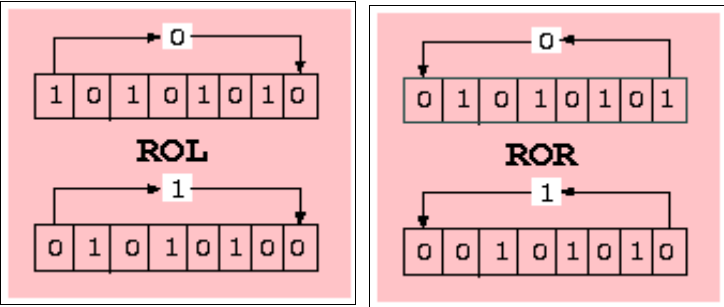
## AVR-Assembler program

The following source code demonstrates realisation of multiplication in assembler.

```
; Mult8.asm multiplies two 8-bit-numbers to yield a 16-bit-result
;
;
.NOLIST
INCLUDE "C:\avrtools\appnotes\8515def.inc"
.LIST
;
; Flow of multiplication
;
; 1.The binary to be multiplied with, is shifted bitwise into the carry bit. If it is a one, the binary number is added to the
; result, if it is not a one that was shifted out, the number is not added
; 2.The binary number is multiplied by 2 by rotating it one position left, shifting a 0 into the void position.
; 3.If the binary to be multiplied with, is not zero, the multiplication loop is repeated. If it is zero, the multiplication is done.
;
; Used registers
;
.DEF rm1 = R0 ; Binary number to be multiplied (8 Bit)
.DEF rmh = R1 ; Interim storage
.DEF rm2 = R2 ; Binary number to be multiplied with (8 Bit)
.DEF rel = R3 ; Result, LSB (16 Bit)
.DEF reh = R4 ; Result, MSB
.DEF rmp = R16 ; Multi purpose register for loading
;
.CSEG
.ORG 0000
;
    rjmp START
;
START:
    ldi rmp,0xAA ; example binary 1010.1010
    mov rm1,rmp ; to the first binary register
    ldi rmp,0x55 ; example binary 0101.0101
    mov rm2,rmp ; to the second binary register
;
; Here we start with the multiplication of the two binaries in rm1 und rm2, the result will go to reh:rel (16 Bit)
;
MULT8:
;
; Clear start values
    clr rmh ; clear interim storage
    clr rel ; clear result registers
    clr reh
;
; Here we start with the multiplication loop
;
MULT8a:
;
; Step 1: Rotate lowest bit of binary number 2 to the carry flag (divide by 2, rotate a zero into bit 7)
;
    clc ; clear carry bit
    ror rm2 ; bit 0 to carry, bit 1 to 7 one position to the right, carry bit to bit 7
;
; Step 2: Branch depending if a 0 or 1 has been rotated to the carry bit
;
    brcc MULT8b ; jump over adding, if carry has a 0
;
; Step 3: Add 16 bits in rmh:rml to the result, with overflow from LSB to MSB
;
    add rel,rm1 ; add LSB of rm1 to the result
    adc reh,rmh ; add carry and MSB of rm1
;
MULT8b:
;
; Step 4: Multiply rmh:rm1 by 2 (16 bits, shift left)
;
    clc ; clear carry bit
    rol rm1 ; rotate LSB left (multiply by 2)
    rol rmh ; rotate carry into MSB and MSB one left
;
; Step 5: Check if there are still one's in binary 2, if yes, go on multiplying
;
    tst rm2 ; all bits zero?
    brne MULT8a ; if not, go on in the loop
;
;
```

```
; End of the multiplication, result in reh:rel
;
; Endless loop
;
LOOP:
    rjmp loop
```

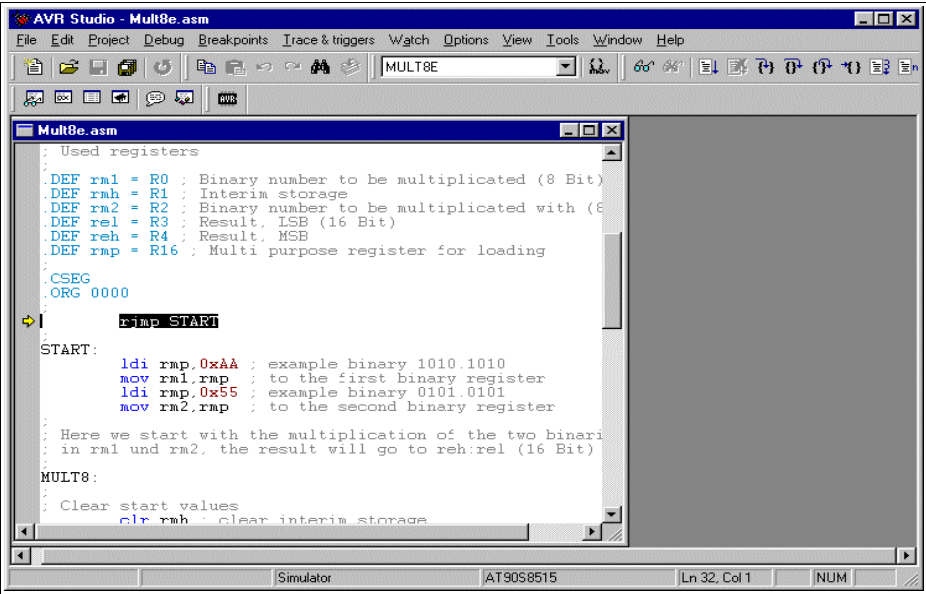
Binary rotation



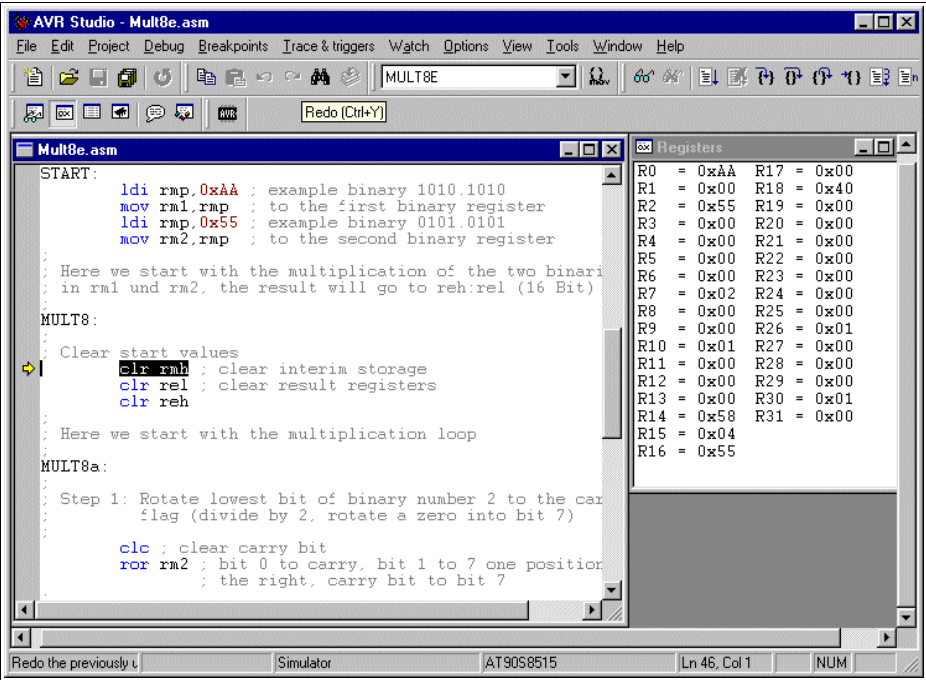
For understanding the multiplication operation, it is necessary to understand the binary rotation commands ROL and ROR. These instructions shift all bits of a register one position left (ROL) resp. right (ROR). The void position in the register is filled with the content of the carry bit of the status register, the bit that rolls out of the register is shifted to the carry bit. This operation is demonstrated using 0xAA as an example for ROL and 0x55 as an example for ROR.

Multiplication in the studio

The following screenshots show the multiplication program in the simulator.



The object-code has been opened, the cursor is placed on the first executable instruction. F11 does single steps.



The registers R0 and R2 are set to 0xAA and 0x55, our test binaries, to be multiplied.

The screenshot shows the AVR Studio 4.10.0 interface. The main window displays the assembly code for 'MULT8e.asm'. The code includes comments in Chinese and assembly instructions for clearing registers, setting up a loop, and performing a right-rotate operation. The 'Registers' window on the right shows the current state of the AVR registers, with R0 through R31 listed and their values in hexadecimal.

**AVR Studio - Mult8e.asm**

File Edit Project Debug Breakpoints Trace & triggers Watch Options View Tools Window Help

MULT8E

**Mult8e.asm**

```

Here we start with the multiplication of the two binary
in rm1 und rm2, the result will go to reh:rel (16 Bit)

MULT8:
    Clear start values
    clr rmh ; clear interim storage
    clr rel ; clear result registers
    clr reh

    Here we start with the multiplication loop

MULT8a:
    Step 1: Rotate lowest bit of binary number 2 to the carry
            flag (divide by 2, rotate a zero into bit 7)

    ror rm2 ; bit 0 to carry, bit 1 to 7 one position
            ; the right, carry bit to bit 7

    Step 2: Branch depending if a 0 or 1 has been rotated to
            the carry bit

    brcc MULT8b ; jump over adding, if carry has a 0

```

**Registers**

R0	= 0xAA	R17	= 0x00
R1	= 0x00	R18	= 0x40
R2	= 0x55	R19	= 0x00
R3	= 0x00	R20	= 0x00
R4	= 0x00	R21	= 0x00
R5	= 0x00	R22	= 0x00
R6	= 0x00	R23	= 0x00
R7	= 0x02	R24	= 0x00
R8	= 0x00	R25	= 0x00
R9	= 0x00	R26	= 0x01
R10	= 0x01	R27	= 0x00
R11	= 0x00	R28	= 0x00
R12	= 0x00	R29	= 0x00
R13	= 0x00	R30	= 0x01
R14	= 0x58	R31	= 0x00
R15	= 0x04		
R16	= 0x55		

Simulator AT90S8515 Ln 57, Col 1 NUM

R2 is rotated to the right, to roll the least significant bit into the carry bit. 0x55 (0101.0101) yielded 0x2A (0010.1010).

The screenshot shows the AVR Studio interface with the file 'Mult8e.asm' open. The assembly code is as follows:

```

; Here we start with the multiplication of the two binary
; in rm1 und rm2, the result will go to reh:rel (16 Bit)
MULT8:
; Clear start values
clr rmh ; clear interim storage
clr rel ; clear result registers
clr reh

; Here we start with the multiplication loop
MULT8a:
; Step 1: Rotate lowest bit of binary number 2 to the carry
; flag (divide by 2, rotate a zero into bit 7)

clc ; clear carry bit
ror rm2 ; bit 0 to carry, bit 1 to 7 one position
; the right, carry bit to bit 7

; Step 2: Branch depending if a 0 or 1 has been rotated to
; the carry bit

brc MULT8a ; jump over adding, if carry has a 0

```

The Registers window on the right shows the following values:

Register	Value
R0	0xAA
R1	0x00
R2	0x2A
R3	0x00
R4	0x00
R5	0x00
R6	0x00
R7	0x02
R8	0x00
R9	0x00
R10	0x01
R11	0x00
R12	0x00
R13	0x00
R14	0x58
R15	0x04
R16	0x55
R17	0x00
R18	0x40
R19	0x00
R20	0x00
R21	0x00
R22	0x00
R23	0x00
R24	0x00
R25	0x00
R26	0x01
R27	0x00
R28	0x00
R29	0x00
R30	0x01
R31	0x00

The status bar at the bottom indicates the simulator is running on an AT90S8515 chip, with the cursor at line 64, column 1.

Because the carry bit had a one the content of the registers R1:R0 is added to the (empty) register pair R4:R3, resulting in 0x00AA there.

The screenshot displays the AVR Studio interface with the file "Mult8e.asm" open. The main editor shows assembly code for multiplying two 8-bit numbers. The code includes comments explaining each step, such as clearing carry bits, rotating registers, and checking for zero. A Registers window on the right shows the state of the registers.

```

; AVR Studio - Mult8e.asm
File Edit Project Debug Breakpoints Trace & triggers Watch Options View Tools Window Help

[Icons] [MULT8E] [Icons]

[Icons] [AVR]

Mult8e.asm
clc ; clear carry bit
ror rm2 ; bit 0 to carry, bit 1 to 7 one position
; the right, carry bit to bit 7

Step 2: Branch depending if a 0 or 1 has been rotated to
the carry bit

brcc MULT8b ; jump over adding, if carry has a 0

Step 3: Add 16 bits in rnh:rml to the result, with overflow
from LSB to MSB

add re1,rml ; add LSB of rml to the result
adc reh,rmh ; add carry and MSB of rml

MULT8b:

Step 4: Multiply rnh:rml by 2 (16 bits, shift left)

< clc ; clear carry bit
rol rml ; rotate LSB left (multiply by 2)
rol rmh ; rotate carry into MSB and MSB one left

Step 5: Check if there are still one's in binary 2, if
yes, go on multiplying

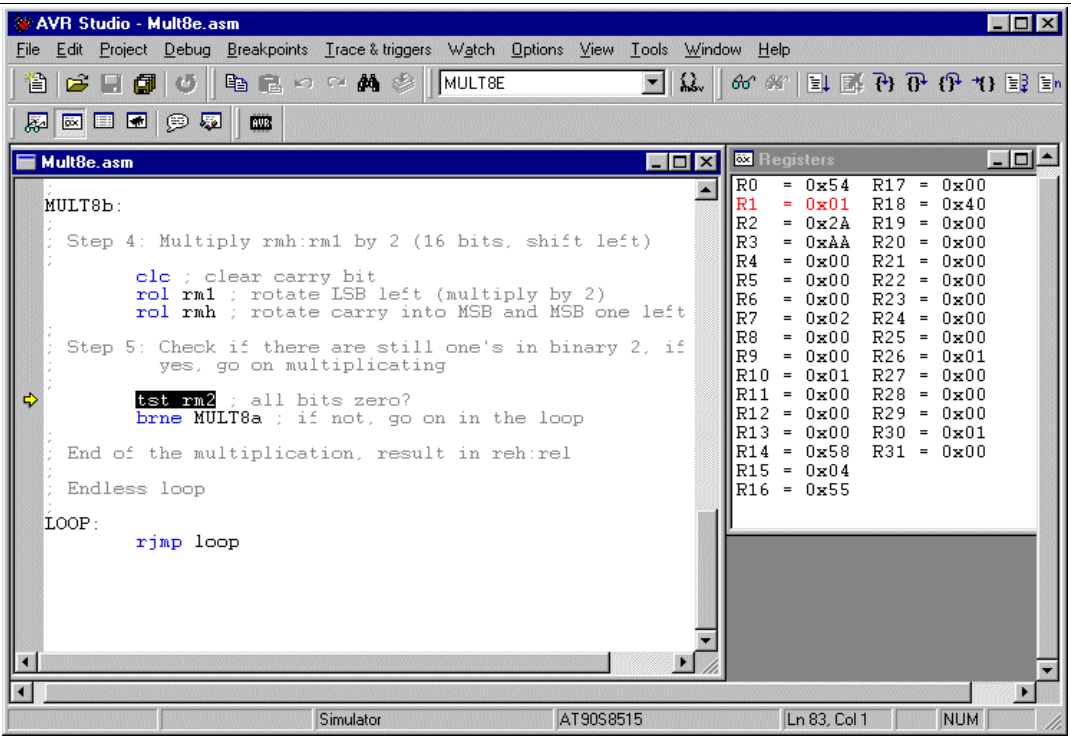
tst.rm2 ; all bits zero?

Registers
R0 = 0xAA R17 = 0x00
R1 = 0x00 R18 = 0x40
R2 = 0xA R19 = 0x00
R3 = 0xAA R20 = 0x00
R4 = 0x00 R21 = 0x00
R5 = 0x00 R22 = 0x00
R6 = 0x00 R23 = 0x00
R7 = 0x02 R24 = 0x00
R8 = 0x00 R25 = 0x00
R9 = 0x00 R26 = 0x01
R10 = 0x01 R27 = 0x00
R11 = 0x00 R28 = 0x00
R12 = 0x00 R29 = 0x00
R13 = 0x00 R30 = 0x01
R14 = 0x58 R31 = 0x00
R15 = 0x04
R16 = 0x55

Simulator AT90S8515 Ln 76, Col 1 NUM
```

Now the register pair R1:R0 is rotated one position left to multiply this binary by 2. From 0x00AA, multiplication by 2 yields 0x0154.

The whole multiplication loop is repeated as long there is at least one binary 1 in register R2. These following loops are not shown here.



Using key F5 of the studio we multi-stepped over these loops to a break-point at the end of the multiplication routine. The result register pair R4:R3 has the result of the multiplication of 0xAA by 0x55: 0x3872.

This wasn't that complicated, just remind yourself on the similiar decimal operations. Binary multiplication is much easier than decimal.

Division

Decimal division

Again we start with the decimal division, to better understand the binary division. We assume a division of 5678 by 12. This is done like this:

```

          5678 : 12 = ?
-----
- 4 * 1200 = 4800
          ----
          878
- 7 * 120 = 840
          ---
           38
- 3 * 12 = 36
          --
            2
Result: 5678 : 12 = 473 Remainder 2
=====
```

Binary division

In binary the multiplication of the second number (4 \* 1200, etc.) is not necessary, due to the fact that we have only 0 and 1 as digits. Unfortunately binary numbers have much more single digits than their decimal equivalent, so transferring the decimal division to its binary equivalent is a little bit inconvenient. So the program works a bit different than that.

The division of a 16-bit binary number by a 8-bit binary in AVR assembler is listed in the following section.

```

; Div8 divides a 16-bit-number by a 8-bit-number (Test: 16-bit-number: 0xAAAA, 8-bit-number: 0x55)
.NOLIST
.INCLUDE "C:\avrtools\appnotes\8515def.inc"
.LIST
; Registers
.DEF rd1l = R0 ; LSB 16-bit-number to be divided
.DEF rd1h = R1 ; MSB 16-bit-number to be divided
.DEF rd1u = R2 ; interim register
.DEF rd2 = R3 ; 8-bit-number to divide with
.DEF rel = R4 ; LSB result
.DEF reh = R5 ; MSB result
.DEF rmp = R16; multipurpose register for loading
;
.CSEG
.ORG 0
    rjmp start
```



```
start:
; Load the test numbers to the appropriate registers
ldi rmp,0xAA ; 0xAAAA to be divided
mov rd1h,rmp
mov rd1l,rmp
ldi rmp,0x55 ; 0x55 to be divided with
mov rd2,rmp
; Divide rd1h:rd1l by rd2
div8:
clr rd1u ; clear interim register
clr reh ; clear result (the result registers
clr rel ; are also used to count to 16 for the
inc rel ; division steps, is set to 1 at start)
; Here the division loop starts
div8a:
clc ; clear carry-bit
rol rd1l ; rotate the next-upper bit of the number
rol rd1h ; to the interim register (multiply by 2)
rol rd1u
brcs div8b ; a one has rolled left, so subtract
cp rd1u,rd2 ; Division result 1 or 0?
brcs div8c ; jump over subtraction, if smaller
div8b:
sub rd1u,rd2 ; subtract number to divide with
sec ; set carry-bit, result is a 1
rjmp div8d ; jump to shift of the result bit
div8c:
clc ; clear carry-bit, resulting bit is a 0
div8d:
rol rel ; rotate carry-bit into result registers
rol reh
brcc div8a ; as long as zero rotate out of the result registers: go on with the division loop
; End of the division reached
stop:
rjmp stop ; endless loop
```

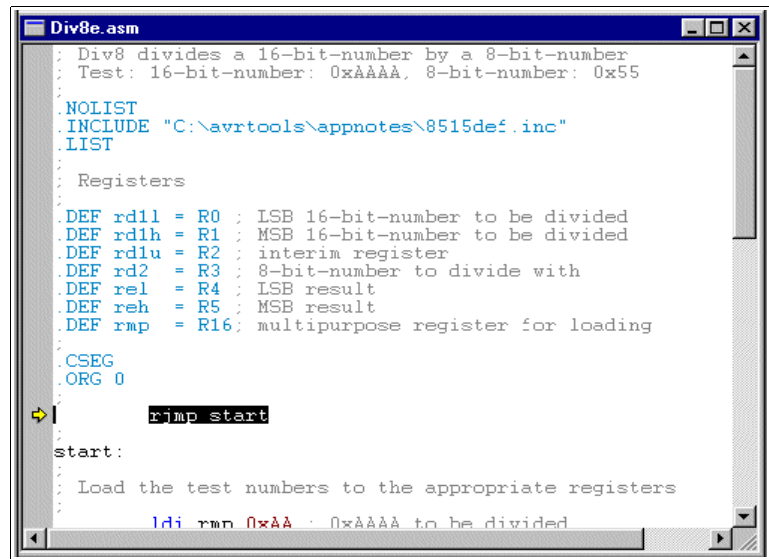
Program steps during division

During execution of the program the following steps are ran:

- Definition and preset of the registers with the test binaries,
- presetting the interim register and the result register pair (the result registers are presetted to 0x0001! After 16 rotations the rolling out of the one stops further division steps.),
- the 16-bit-binary in rd1h:rd1l is rotated bitwise to the interim register rd1u (multiplication by 2), if a 1 is rotated out of rd1u, the program branches to the subtraction step in step 4 immediately,
- the content of the interim register is compared with the 8-bit binary in rd2, if rd2 is smaller it is subtracted from the interim register and the carry-bit is set to one, if rd2 is greater the subtraction is skipped and a zero is set to the carry flag,
- the content of the carry flag is rotated into the result register reh:rel from the right,
- if a zero rotated out of the result register, we have to repeat the division loop, if it was a one the division is completed.

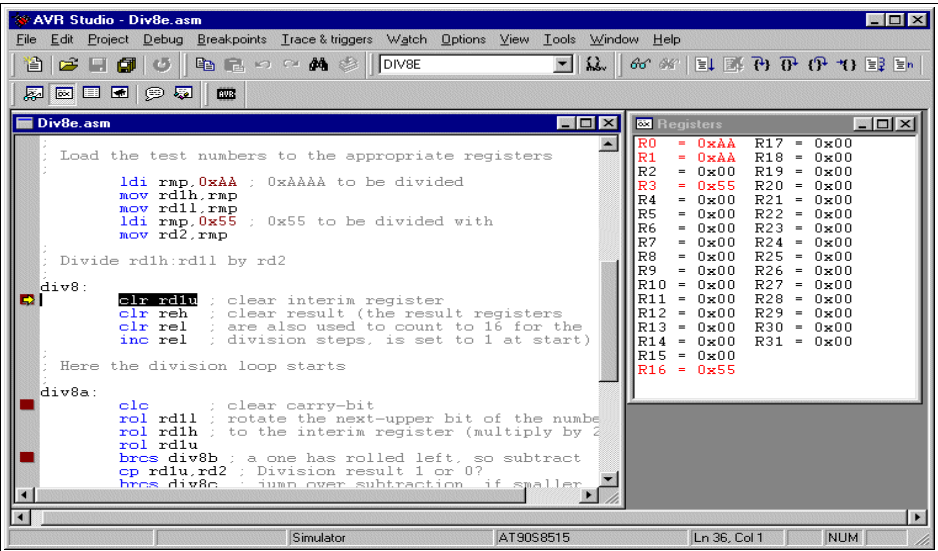
If you don't understand rotation yet you'll find this operation discussed in the multiplication section.

Division in the simulator

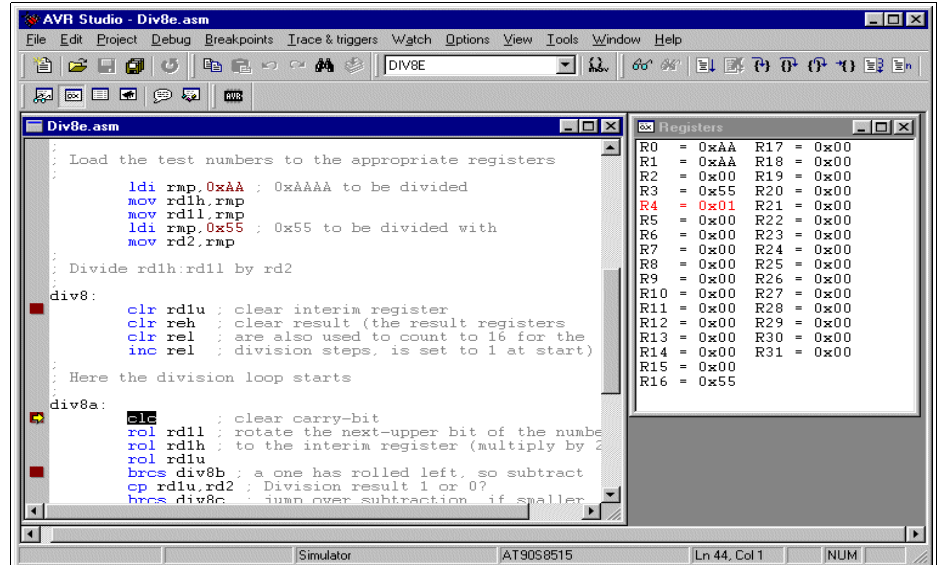


The following screen shots demonstrate the program steps in the studio. To do this, you have to assemble the source code and open the resulting object file in the studio.

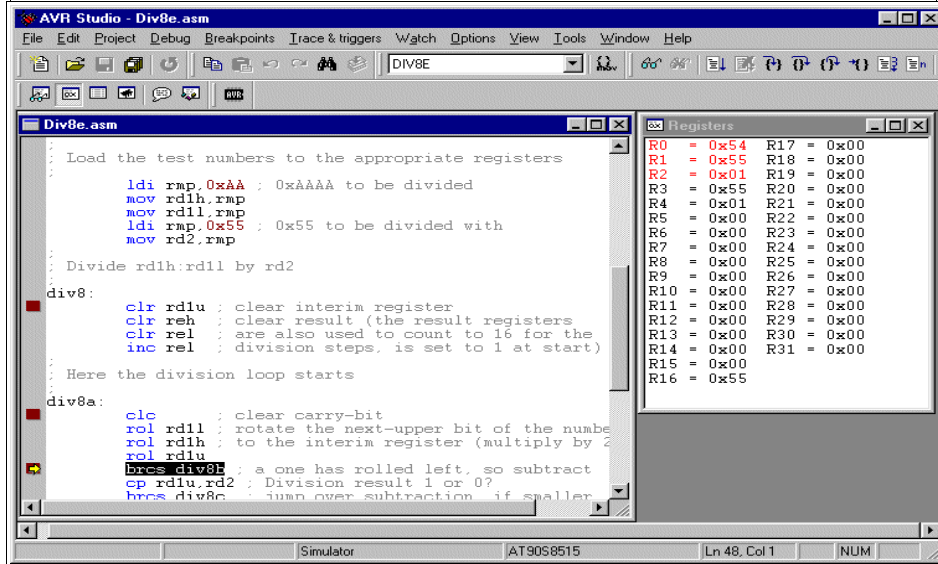
The object code has been started, the cursor is on the first executable instruction. The key F11 performs single steps.



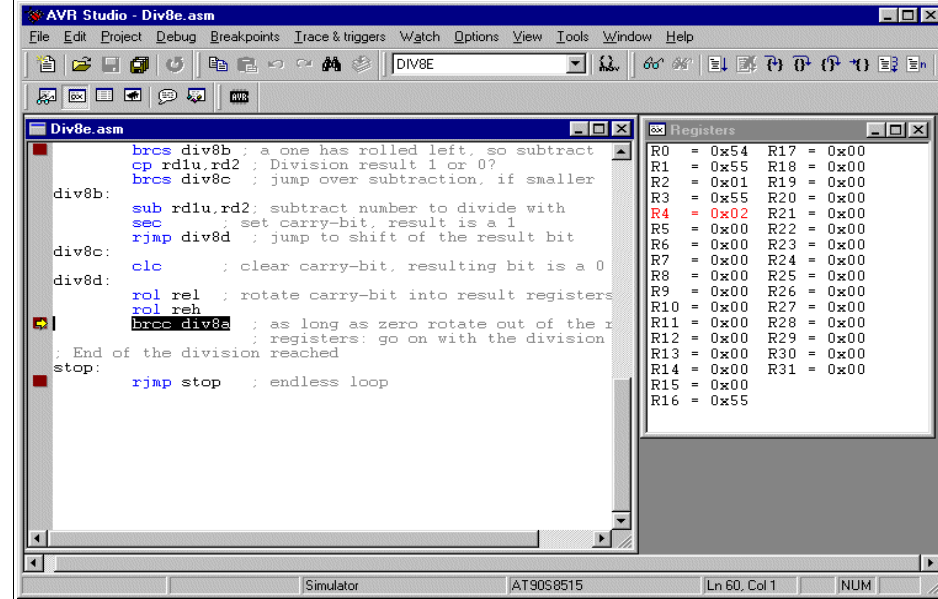
The test binaries 0xAAAA and 0x55, to be divided, are written to the registers R1:R0 and R3.



The interim register R2 and the result register pair are set to their predefined values.

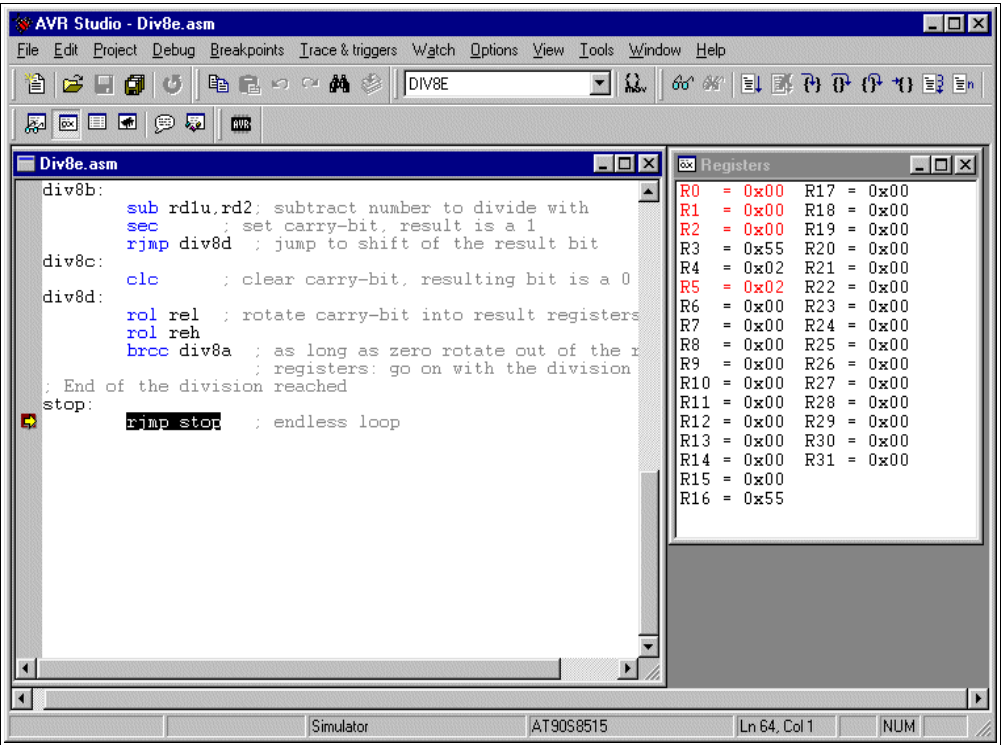


R1:R0 was rotated left to R2, from 0xAAAA the doubled value of 0x015554 was yielded.

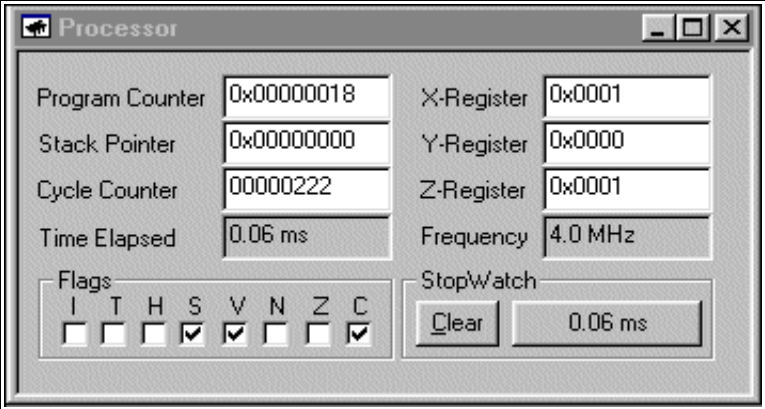


No overflow from rotation into carry has occurred and 0x01 in R2 was smaller than 0x55 in R3, so subtraction was skipped. A zero in the carry is rotated into the result register R5:R4. The former content of the result register, a single 1-bit in position 0 has rotated to position 1 (content now: 0x0002). As a zero was rotated out of the result register pair, the next step to be executed is a branch to the beginning of the division loop start and the loop is repeated.





After executing the loop 16 times we have reached the breakpoint set at the end of the division routine. The result register in R5:R4 holds 0x0202, the result of the division. The registers R2:R1:R0 are empty, so we do not have a remainder left. If a remainder would have been resulted we can use it to decide whether an incrementation of the result should take place, rounding of the result up. This step is not coded here.



The whole division needs 60 micro-seconds processor time (open a processor view in the studio menuue). A rather long time for a division.

## Number conversion

Number conversion routines are not included here. Please refer to the website, if you need the source code or a better understanding.

## Decimal Fractions

First: Do not use any floating points, unless you really need them. Floating points are resource killers in an AVR, lame ducks und need extreme execution times. Run into this dilemma, if you think assembler is too complicated, and you prefer Basic or other languages like C and Pascal.

Not so, if you use assembler. You'll be shown here, how you can perform the multiplication of a fixed point real number in less than 60 micro-seconds, in special cases even within 18 micro-seconds, at 4 Mcs/s clock frequency. Without any floating point processor extensions and other expensive tricks for people too lazy to use their brain.

How to do that? Back to the roots of math! Most tasks with floating point reals can be done using integer numbers. Integers are easy to program in assembler and perform fast. The decimal point is only in the brain of the programmer, and is added somewhere in the decimal digit stream. No one realizes, that this is a trick.

### Linear conversions

As an example the following task: an 8-Bit-AD-Converter measures an input signal in the range from 0.00 to 2.55 Volt, and returns as the result a binary in the range from \$00 and \$FF. The result, a voltage, is to be displayed on a LCD display. Silly example, as it is so easy: The binary is converted to a decimal ASCII string between 000 and 255, and just behind the first digit the decimal point has to be inserted. Done!

The electronics world sometimes is more complicated. E.g., the AD-Converter returns an 8-Bit-Hex for input voltages between 0.00 and 5.00 Volt. Now we're tricked and do not know how to proceed. To display the correct result on the LCD we would have to multiply the binary by 500/255, which is 1.9608. This is a silly number, as it is almost 2, but only almost. And we don't want that kind of inaccuracy of 2%, while we have an AD-converter with around 0.25% accuracy.

To cope with this, we multiply the input by 500/255\*256 or 501.96 and divide the result by 256. Why first

multiply by 256 and then divide by 256? It's just for enhanced accuracy. If we multiply the input by 502 instead of 501.96, the error is just in the order of 0.008%. That is good enough for our AD-converter, we can live with that. And dividing by 256 is an easy task, because it is a well-known power of 2. By dividing with numbers that are a power of 2, the AVR feels very comfortable and performs very fast. By dividing with 256, the AVR is even faster, because we just have to skip the last byte of the binary number. Not even shift and rotate!

The multiplication of an 8-bit-binary with the 9-bit-binary 502 (hex 1F6) can have a result greater than 16 bits. So we have to reserve 24 bits or 3 registers for the result. During multiplication, the constant 502 has to be shifted left (multiplication by 2) to add these numbers to the result each time a one rolls out of the input number. As this might need eight shifts left, we need futher three bytes for this constant. So we chose the following combination of registers for the multiplication:

<i>Number</i>	<i>Value (example)</i>	<i>Register</i>
Input value	255	R1
Multiplicator	502	R4 : R3 : R2
Result	128,010	R7 : R6 : R5

After filling the value 502 (00.01.F6) to R4 : R3 : R2 and clearing the result registers R7 : R6 : R5 the multiplication goes like this:

- 1.Test, if the input number is already zero. If yes, we're done.
- 2.If no, one bit of the input number is shifted out of the register to the right, into the carry, while a zero is stuffed into bit 7. This instruction is named Logical-Shight-Right or LSR.
- 3.If the bit in carry is a one, we add the multiplicator (during step 1 the value 502, in step 2 it's 1004, a.s.o.) to the result. During adding, we care for any carry (adding R2 to R5 by ADD, adding R3 to R6 and R4 to R7 with the ADC instruction!). If the bit in the carry was a zero, we just don't add the multiplicator to the result and jump to the next step.
- 4.Now the multiplicator is multiplied by 2, because the next bit shifted out of the input number is worth double as much. So we shift R2 to the left (by inserting a zero in bit 0) using LSL. Bit 7 is shifted to the carry. Then we rotate this carry into R3, rotating its content left one bit, and bit 7 to the carry. The same with R4.
- 5.Now we're done with one digit of the input number, and we proceed with step 1 again.

The result of the multiplication by 502 now is in the result registers R7 : R6 : R5. If we just ignore register R5 (division by 256), we have our desired result. To enhance occuracy, we can use bit 7 in R5 to round the result. Now we just have to convert the result from its binary form to decimal ASCII (see Conversion bin to decimal-ASCII on the website). If we just add a decimal point in the right place in the ASCII string, our voltage string is ready for the display.

The whole program, from the input number to the resulting ASCII string, requires between 79 and 228 clock cycles, depending from the input number. Those who want to beat this with the floating point routine of a more sophisticated language than assembler, feel free to mail me your conversion time (and program flash and memory usage).

Example 1: 8-bit-AD-converter with fixed decimal output

```
; Demonstrates floating point conversion in Assembler, (C)2003 www.avr-asm-tutorial.net
;
; The task: You read in an 8-bit result of an analogue-digital-converter, number is in the range from hex 00 to FF.
; You need to convert this into a floating point number in the range from 0.00 to 5.00 Volt
; The program scheme:
; 1. Multiplication by 502 (hex 01F6).That step multiplies by 500, 256 and divides by 255 in one step!
; 2. Round the result and cut the last byte of the result. This step divides by 256 by ignoring the last byte of the result.
; Before doing that, bit 7 is used to round the result.
; 3. Convert the resulting word to ASCII and set the correct decimal sign. The resulting word in the range from 0 to 500
; is displayed in ASCII-characters as 0.00 to 5.00.
; The registers used:
; The routines use the registers R8..R1 without saving these before. Also required is a multipurpose register called rmp,
; located in the upper half of the registers. Please take care that these registers don't conflict with the register use in the
; rest of your program.
; When entering the routine the 8-bit number is expected in the register R1. The multiplication uses R4:R3:R2 to hold
; the multiplicator 502 (is shifted left max. eight times during multiplication). The result of the multiplication is calculated
; in the registers R7:R6:R5. The result of the so called division by 256 by just ignoring R5 in the result, is in R7:R6. R7:R6
; is rounded, depending on the highest bit of R5, and the result is copied to R2:R1.
; Conversion to an ASCII-string uses the input in R2:R1, the register pair R4:R3 as a divisor for conversion, and places the
; ASCII result string to R5:R6:R7:R8 (R6 is the decimal char).
; Other conventions:
; The conversion uses subroutines and the stack.The stack must work fine for the use of three levels (six bytes SRAM).
```

```

; Conversion times:
; The whole routine requires 228 clock cycles maximum (converting $FF), and 79 clock cycles minimum (converting $00).
; At 4 MHz the times are 56.75 microseconds resp. 17.75 microseconds.
; Definitions:
; Registers
.DEF rmp = R16 ; used as multi-purpose register
; AVR type: Tested for type AT90S8515, only required for stack setting, routines work fine with other AT90S-types also
.NOLIST
.INCLUDE "8515def.inc"
.LIST
; Start of test program
; Just writes a number to R1 and starts the conversion routine, for test purposes only
.CSEG
.ORG $0000
    rjmp main
main:
    ldi rmp,HIGH(RAMEND) ; Set the stack
    out SPH,rmp
    ldi rmp,LOW(RAMEND)
    out SPL,rmp
    ldi rmp,$FF ; Convert $FF
    mov R1,rmp
    rcall fpconv8 ; call the conversion routine
no_end: ; unlimited loop, when done
    rjmp no_end
; Conversion routine wrapper, calls the different conversion steps
fpconv8:
    rcall fpconv8m ; multiply by 502
    rcall fpconv8r ; round and divide by 256
    rcall fpconv8a ; convert to ASCII string
    ldi rmp',' ; set decimal char
    mov R6,rmp
    ret ; all done
; Subroutine multiplication by 502
fpconv8m:
    clr R4 ; set the multiplicand to 502
    ldi rmp,$01
    mov R3,rmp
    ldi rmp,$F6
    mov R2,rmp
    clr R7 ; clear the result
    clr R6
    clr R5
fpconv8m1:
    or R1,R1 ; check if the number is all zeros
    brne fpconv8m2 ; still one's, go on convert
    ret ; ready, return back
fpconv8m2:
    lsr R1 ; shift number to the right (div by 2)
    brcc fpconv8m3 ; if the lowest bit was 0, then skip adding
    add R5,R2 ; add the number in R6:R5:R4:R3 to the result
    adc R6,R3
    adc R7,R4
fpconv8m3:
    lsl R2 ; multiply R4:R3:R2 by 2
    rol R3
    rol R4
    rjmp fpconv8m1 ; repeat for next bit
; Round the value in R7:R6 with the value in bit 7 of R5
fpconv8r:
    clr rmp ; put zero to rmp
    lsl R5 ; rotate bit 7 to carry
    adc R6,rmp ; add LSB with carry
    adc R7,rmp ; add MSB with carry
    mov R2,R7 ; copy the value to R2:R1 (divide by 256)
    mov R1,R6
    ret
; Convert the word in R2:R1 to an ASCII string in R5:R6:R7:R8
fpconv8a:
    clr R4 ; Set the decimal divider value to 100
    ldi rmp,100
    mov R3,rmp
    rcall fpconv8d ; get ASCII digit by repeated subtraction
    mov R5,rmp ; set hundreds string char
    ldi rmp,10 ; Set the decimal divider value to 10
    mov R3,rmp
    rcall fpconv8d ; get the next ASCII digit
    mov R7,rmp ; set tens string char
    ldi rmp,'0' ; convert the rest to an ASCII char
    add rmp,R1
    mov R8,rmp ; set ones string char
    ret

```

```
; Convert binary word in R2:R1 to a decimal digit by subtracting the decimal divider value in R4:R3 (100, 10)
fpconv8d:
    ldi rmp,'0' ; start with decimal value 0
fpconv8d1:
    cp R1,R3 ; Compare word with decimal divider value
    cpc R2,R4
    brcc fpconv8d2 ; Carry clear, subtract divider value
    ret ; done subtraction
fpconv8d2:
    sub R1,R3 ; subtract divider value
    sbc R2,R4
    inc rmp ; up one digit
    rjmp fpconv8d1 ; once again
; End of conversion test routine
```

## Example 2: 10-bit-AD-converter with fixed decimal output

This example is a bit more complicated. Refer to the website if you need it.

# Annex

## Commands sorted by function

For the abbreviations used see the list of abbreviations.

Function	Subfunction	Command	Flags	Clk
Register set	0	<a href="#">CLR r1</a>	Z N V	1
	255	<a href="#">SER rh</a>		1
	Constant	<a href="#">LDI rh,c255</a>		1
Copy	Register => Register	<a href="#">MOV r1,r2</a>		1
	SRAM => Register, direct	<a href="#">LDS r1,c65535</a>		2
	SRAM => Register	<a href="#">LD r1,rp</a>		2
	SRAM => Register and INC	<a href="#">LD r1,rp+</a>		2
	DEC, SRAM => Register	<a href="#">LD r1,-rp</a>		2
	SRAM, displaced => Register	<a href="#">LDD r1,ry+k63</a>		2
	Port => Register	<a href="#">IN r1,p1</a>		1
	Stack => Register	<a href="#">POP r1</a>		2
	Program storage Z => R0	<a href="#">LPM</a>		3
	Register => SRAM, direct	<a href="#">STS c65535,r1</a>		2
	Register => SRAM	<a href="#">ST rp,r1</a>		2
	Register => SRAM and INC	<a href="#">ST rp+,r1</a>		2
	DEC, Register => SRAM	<a href="#">ST -rp,r1</a>		2
	Register => SRAM, displaced	<a href="#">STD ry+k63,r1</a>		2
	Register => Port	<a href="#">OUT p1,r1</a>		1
	Register => Stack	<a href="#">PUSH r1</a>		2
Add	8 Bit, +1	<a href="#">INC r1</a>	Z N V	1
	8 Bit	<a href="#">ADD r1,r2</a>	Z C N V H	1
	8 Bit + Carry	<a href="#">ADC r1,r2</a>	Z C N V H	1
	16 Bit, constant	<a href="#">ADIW rd,k63</a>	Z C N V S	2
Subtract	8 Bit, -1	<a href="#">DEC r1</a>	Z N V	1
	8 Bit	<a href="#">SUB r1,r2</a>	Z C N V H	1
	8 Bit, constant	<a href="#">SUBI rh,c255</a>	Z C N V H	1
	8 Bit - Carry	<a href="#">SBC r1,r2</a>	Z C N V H	1
	8 Bit - Carry, constant	<a href="#">SBCI rh,c255</a>	Z C N V H	1
	16 Bit	<a href="#">SBIW rd,k63</a>	Z C N V S	2
Shift	logic, left	<a href="#">LSL r1</a>	Z C N V	1
	logic, right	<a href="#">LSR r1</a>	Z C N V	1
	Rotate, left over Carry	<a href="#">ROL r1</a>	Z C N V	1
	Rotate, right over Carry	<a href="#">ROR r1</a>	Z C N V	1
	Arithmetic, right	<a href="#">ASR r1</a>	Z C N V	1
	Nibble exchange	<a href="#">SWAP r1</a>		1
Binary	And	<a href="#">AND r1,r2</a>	Z N V	1
	And, constant	<a href="#">ANDI rh,c255</a>	Z N V	1
	Or	<a href="#">OR r1,r2</a>	Z N V	1
	Or, constant	<a href="#">ORI rh,c255</a>	Z N V	1
	Exclusive-Or	<a href="#">EOR r1,r2</a>	Z N V	1
	Ones-complement	<a href="#">COM r1</a>	Z C N V	1
	Twos-complement	<a href="#">NEG r1</a>	Z C N V H	1

Function	Subfunction	Command	Flags	Clk
Bits change	Register, set	<a href="#">SBR rh,c255</a>	Z N V	1
	Register, clear	<a href="#">CBR rh,255</a>	Z N V	1
	Register, copy to T-Flag	<a href="#">BST r1,b7</a>	T	1
	Register, copy from T-Flag	<a href="#">BLD r1,b7</a>		1
	Port, set	<a href="#">SBI pl,b7</a>		2
	Port, clear	<a href="#">CBI pl,b7</a>		2
Statusbit set	Zero-Flag	<a href="#">SEZ</a>	Z	1
	Carry Flag	<a href="#">SEC</a>	C	1
	Negative Flag	<a href="#">SEN</a>	N	1
	Twos complement carry Flag	<a href="#">SEV</a>	V	1
	Half carry Flag	<a href="#">SEH</a>	H	1
	Signed Flag	<a href="#">SES</a>	S	1
	Transfer Flag	<a href="#">SET</a>	T	1
	Interrupt Enable Flag	<a href="#">SEI</a>	I	1
Statusbit clear	Zero-Flag	<a href="#">CLZ</a>	Z	1
	Carry Flag	<a href="#">CLC</a>	C	1
	Negative Flag	<a href="#">CLN</a>	N	1
	Twos complement carry Flag	<a href="#">CLV</a>	V	1
	Half carry Flag	<a href="#">CLH</a>	H	1
	Signed Flag	<a href="#">CLS</a>	S	1
	Transfer Flag	<a href="#">CLT</a>	T	1
	Interrupt Enable Flag	<a href="#">CLI</a>	I	1
Compare	Register, Register	<a href="#">CP r1,r2</a>	Z C N V H	1
	Register, Register + Carry	<a href="#">CPC r1,r2</a>	Z C N V H	1
	Register, constant	<a href="#">CPI rh,c255</a>	Z C N V H	1
	Register, ≤0	<a href="#">TST r1</a>	Z N V	1
Immediate Jump	Relative	<a href="#">RJMP c4096</a>		2
	Indirect, Address in Z	<a href="#">IJMP</a>		2
	Subroutine, relative	<a href="#">RCALL c4096</a>		3
	Subroutine, Address in Z	<a href="#">ICALL</a>		3
	Return from Subroutine	<a href="#">RET</a>		4
	Return from Interrupt	<a href="#">RETI</a>	I	4

Function	Subfunction	Command	Flags	Clk
Conditioned Jump	Statusbit set	<a href="#">BRBS b7,c127</a>		1/2
	Statusbit clear	<a href="#">BRBC b7,c127</a>		1/2
	Jump if equal	<a href="#">BREQ c127</a>		1/2
	Jump if equal	<a href="#">BRNE c127</a>		1/2
	Jump if carry	<a href="#">BRCS c127</a>		1/2
	Jump if carry clear	<a href="#">BRCC c127</a>		1/2
	Jump if equal or greater	<a href="#">BRSH c127</a>		1/2
	Jump if lower	<a href="#">BRLO c127</a>		1/2
	Jump if negative	<a href="#">BRMI c127</a>		1/2
	Jump if positive	<a href="#">BRPL c127</a>		1/2
	Jump if greater or equal (Signed)	<a href="#">BRGE c127</a>		1/2
	Jump if lower than zero (Signed)	<a href="#">BRLT c127</a>		1/2
	Jump on half carry set	<a href="#">BRHS c127</a>		1/2
	Jump if half carry clear	<a href="#">BRHC c127</a>		1/2
	Jump if T-Flag set	<a href="#">BRTS c127</a>		1/2
	Jump if T-Flag clear	<a href="#">BRTC c127</a>		1/2
	Jump if Twos complement carry set	<a href="#">BRVS c127</a>		1/2
	Jump if Twos complement carry clear	<a href="#">BRVC c127</a>		1/2
	Jump if Interrupts enabled	<a href="#">BRIE c127</a>		1/2
	Jump if Interrupts disabled	<a href="#">BRID c127</a>		1/2
Conditioned Jumps	Registerbit=0	<a href="#">SBRC r1,b7</a>		1/2/3
	Registerbit=1	<a href="#">SBRS r1,b7</a>		1/2/3
	Portbit=0	<a href="#">SBIC pl,b7</a>		1/2/3
	Portbit=1	<a href="#">SBIS pl,b7</a>		1/2/3
	Compare, jump if equal	<a href="#">CPSE r1,r2</a>		1/2/3
Others	No Operation	<a href="#">NOP</a>		1
	Sleep	<a href="#">SLEEP</a>		1
	Watchdog Reset	<a href="#">WDR</a>		1

## Command list in alphabetic order

### Assembler directives

[.CSEG](#)  
[.DB](#)  
[.DEF](#)  
[.DW](#)  
[.ENDMACRO](#)  
[.ESEG](#)  
[.EQU](#)  
[.INCLUDE](#)  
[.MACRO](#)  
[.ORG](#)

### Commands

[ADC r1,r2](#)  
[ADD r1,r2](#)  
[ADIW rd,k63](#)  
[AND r1,r2](#)  
[ANDI rh,c255, Register](#)  
[ASR r1](#)  
[BLD r1,b7](#)  
[BRCC c127](#)  
[BRCS c127](#)  
[BREQ c127](#)  
[BRGE c127](#)  
[BRHC c127](#)  
[BRHS c127](#)

[BRID c127](#)  
[BRIE c127](#)  
[BRLO c127](#)  
[BRLT c127](#)  
[BRMI c127](#)  
[BRNE c127](#)  
[BRPL c127](#)  
[BRSH c127](#)  
[BRTC c127](#)  
[BRTS c127](#)  
[BRVC c127](#)  
[BRVS c127](#)  
[BST r1,b7](#)  
[CBI pl,b7](#)  
[CBR rh,255, Register](#)  
[CLC](#)  
[CLH](#)  
[CLI](#)  
[CLN](#)  
[CLR r1](#)  
[CLS](#)  
[CLT, \(command example\)](#)  
[CLV](#)  
[CLZ](#)  
[COM r1](#)  
[CP r1,r2](#)  
[CPC r1,r2](#)  
[CPI rh,c255, Register](#)  
[CPSE r1,r2](#)  
[DEC r1](#)  
[EOR r1,r2](#)  
[ICALL](#)  
[IJMP IN r1,p1](#)  
[INC r1](#)  
[LD rp,\(rp,rp+,-rp\) \(Register\), \(SRAM access\), Ports](#)  
[LDD r1,ry+k63](#)  
[LDI rh,c255 \(Register\), Pointer](#)  
[LDS r1,c65535](#)  
[LPM](#)  
[LSL r1](#)  
[LSR r1](#)  
[MOV r1,r2](#)  
[NEG r1](#)  
[NOP](#)  
[OR r1,r2 ORI rh,c255 OUT p1,r1](#)  
[POP r1, \(in Int-routine\)](#)  
[PUSH r1, \(in Int-routine\)](#)  
[RCALL c4096](#)  
[RET, \(in Int-routine\)](#)  
[RETI](#)  
[RJMP c4096](#)  
[ROL r1](#)  
[ROR r1](#)  
[SBC r1,r2](#)  
[SBCI rh,c255](#)  
[SBI pl,b7](#)  
[SBIC pl,b7](#)  
[SBS pl,b7](#)  
[SBIW rd,k63](#)  
[SBR rh,255, Register](#)  
[SBRC r1,b7](#)  
[SBRS r1,b7](#)  
[SEC](#)  
[SEH](#)  
[SEI, \(in Int-routine\)](#)  
[SEN](#)  
[SER rh](#)  
[SES](#)  
[SET, \(example\)](#)  
[SEV](#)  
[SEZ](#)  
[SLEEP](#)  
[ST \(rp/rp+/-rp\),r1 \(Register\), SRAM access, Ports](#)  
[STD ry+k63,r1](#)  
[STS c65535,r1](#)  
[SUB r1,r2](#)  
[SUBI rh,c255](#)  
[SWAP r1](#)  
[TST r1](#)  
[WDR](#)



# Port details

The table of the relevant ports in the ATMEL AVR types AT90S2313, 2323 and 8515. Byte-wise accessible ports or register pairs are not displayed in detail. No warranty for correctness, see the original data sheets!

## Status-Register, Accumulator flags

Port	Function	Port-Address	RAM-Address
SREG	Status Register Accumulator	0x3F	0x5F

7	6	5	4	3	2	1	0
I	T	H	S	V	N	Z	C

Bit	Name	Meaning	Opportunities	Command
7	I	Global Interrupt Flag	0: Interrupts disabled	CLI
			1: Interrupts enabled	SEI
6	T	Bit storage	0: Stored bit is 0	CLT
			1: Stored bit is 1	SET
5	H	Halfcarry-Flag	0: No halfcarry occured	CLH
			1: Halfcarry occured	SEH
4	S	Sign-Flag	0: Sign positive	CLS
			1: Sign negative	SES
3	V	Two's complement-Flag	0: No carry occured	CLV
			1: Carry occured	SEV
2	N	Negative-Flag	0: Result was not negative/smaller	CLN
			1: Result was negative/smaller	SEN
1	Z	Zero-Flag	0: Result was not zero/unequal	CLZ
			1: Result was zero/equal	SEZ
0	C	Carry-Flag	0: No carry occured	CLC
			1: Carry occured	SEC

## Stackpointer

Port	Function	Port-Address	RAM-Address
SPL/SPH	Stackpointer	003D/0x3E	0x5D/0x5E

Name	Meaning	Availability
SPL	Low-Byte of Stackpointer	From AT90S2313 upwards, not in 1200
SPH	High-Byte of Stackpointer	From AT90S8515 upwards, only in devices with >256 bytes internal SRAM

## SRAM and External Interrupt control

Port	Function	Port-Address	RAM-Address
MCUCR	MCU General Control Register	0x35	0x55

7	6	5	4	3	2	1	0
SRE	SRW	SE	SM	ISC11	ISC10	ISC01	ISC00

Bit	Name	Meaning	Opportunities
7	SRE	Ext.SRAM Enable	0=No external SRAM connected
			1=External SRAM connected

Bit	Name	Meaning	Opportunities
6	SRW	Ext.SRAM Wait States	0=No extra wait state on external SRAM
			1=Additional wait state on external SRAM
5	SE	Sleep Enable	0=Ignore SLEEP commands
			1=SLEEP on command
4	SM	Sleep Mode	0=Idle Mode (Half sleep)
			1=Power Down Mode (Full sleep)
3	ISC11	Interrupt control Pin INT1 (connected to GIMSK)	00: Low-level initiates Interrupt
2	ISC10		01: Undefined
			10: Falling edge triggers interrupt
			11: Rising edge triggers interrupt
1	ISC01	Interrupt control Pin INTO (connected to GIMSK)	00: Low-level initiates interrupt
0	ISC00		01: Undefined
			10: Falling edge triggers interrupt
			11: Rising edge triggers interrupt

External Interrupt Control

Port	Function	Port-Address	RAM-Address
GIMSK	General Interrupt Maskregister	0x3B	0x5B

7	6	5	4	3	2	1	0
INT1	INT0	-	-	-	-	-	-

Bit	Name	Meaning	Opportunities
7	INT1	Interrupt by external pin INT1 (connected to mode in MCUCR)	0: External INT1 disabled
			1: External INT1 enabled
6	INT0	Interrupt by external Pin INT0 (connected to mode in MCUCR)	0: External INT0 disabled
			1: External INT0 enabled
0...5	(Not used)		

Port	Function	Port-Address	RAM-Address
GIFR	General Interrupt Flag Register	0x3A	0x5A

7	6	5	4	3	2	1	0
INTF1	INTF0	-	-	-	-	-	-

Bit	Name	Meaning	Opportunities
7	INTF1	Interrupt by external pin INT1 occured	Automatic clear by execution of the Int-Routine or Clear by command
6	INTF0	Interrupt by external pin INT0 occured	
0...5	(Not used)		

Timer Interrupt Control

Port	Function	Port-Address	RAM-Address
TIMSK	Timer Interrupt Maskregister	0x39	0x59

7	6	5	4	3	2	1	0
TOIE1	OCIE1A	OCIE1B	-	TICIE1	-	TOIE0	-

Bit	Name	Meaning	Opportunities
7	TOIE1	Timer/Counter 1 Overflow-Interrupt	0: No Int at overflow 1: Int at overflow
6	OCIE1A	Timer/Counter 1 Compare A Interrupt	0: No Int at equal A 1: Int at equal A
5	OCIE1B	Timer/Counter 1 Compare B Interrupt	0: No Int at B 1: Int at equal B
4	(Not used)		
3	TICIE1	Timer/Counter 1 Capture Interrupt	0: No Int at Capture 1: Int at Capture
2	(Not used)		
1	TOIE0	Timer/Counter 0 Overflow-Interrupt	0: No Int at overflow 1: Int at overflow
0	(Not used)		

Port	Function	Port-Address	RAM-Address
TIFR	Timer Interrupt Flag Register	0x38	0x58

7	6	5	4	3	2	1	0
TOV1	OCF1A	OCF1B	-	ICF1	-	TOV0	-

Bit	Name	Meaning	Opportunities
7	TOV1	Timer/Counter 1 Overflow reached	Interrupt-Mode: Automatic Clear by execution of the Int-Routine
6	OCF1A	Timer/Counter 1 Compare A reached	
5	OCF1B	Timer/Counter 1 Compare B reached	
4	(Not used)		
3	ICF1	Timer/Counter 1 Capture-Event occurred	OR
2	(not used)		Polling-Mode: Clear by command
1	TOV0	Timer/Counter 0 Overflow occurred	
0	(not used)		

Timer/Counter 0

Port	Function	Port-Address	RAM-Address
TCCR0	Timer/Counter 0 Control Register	0x33	0x53

7	6	5	4	3	2	1	0
-	-	-	-	-	CS02	CS01	CS00

Bit	Name	Meaning	Opportunities
2..0	CS02..CS00	Timer Clock	000: Stop Timer
			001: Clock = Chip clock
			010: Clock = Chip clock / 8
			011: Clock = Chip clock / 64
			100: Clock = Chip clock / 256
			101: Clock = Chip clock / 1024
			110: Clock = falling edge of external Pin T0
			111: Clock = rising edge of external Pin T0
3..7	(not used)		

Port	Function	Port-Address	RAM-Address
TCNT0	Timer/Counter 0 count register	0x32	0x52

Timer/Counter 1

Port	Function	Port-Address	RAM-Address
TCCR1A	Timer/Counter 1 Control Register A	0x2F	0x4F

7	6	5	4	3	2	1	0
COM1A1	COM1A0	COM1B1	COM1B0	-	-	PWM11	PWM10

Bit	Name	Meaning	Opportunities
7	COM1A1	Compare Output A	00: OC1A/B not connected 01: OC1A/B changes polarity 10: OC1A/B to zero 11: OC1A/B to one
6	COM1A0		
5	COM1B1	Compare Output B	
4	COM1B0		
3	(not used)		
2			
1..0	PWM11 PWM10	Pulse width modulator	00: PWM off 01: 8-Bit PWM 10: 9-Bit PWM 11: 10-Bit PWM

Port	Function	Port-Address	RAM-Address
TCCR1B	Timer/Counter 1 Control Register B	0x2E	0x4E

7	6	5	4	3	2	1	0
ICNC1	ICES1	-	-	CTC1	CS12	CS11	CS10

Bit	Name	Meaning	Opportunities
7	ICNC1	Noise Canceler on ICP-Pin	0: disabled, first edge starts sampling 1: enabled, min four clock cycles
6	ICES1	Edge selection on Capture	0: falling edge triggers Capture 1: rising edge triggers Capture
5..4	(not used)		
3	CTC1	Clear at Compare Match A	1: Counter set to zero if equal
2..0	CS12..CS10	Clock select	000: Counter stopped 001: Clock 010: Clock / 8 011: Clock / 64 100: Clock / 256 101: Clock / 1024 110: falling edge external Pin T1 111: rising edge external Pin T1

Port	Function	Port-Address	RAM-Address
TCNT1L/H	Timer/Counter 1 count register	0x2C/0x2D	0x4C/0x4D

Port	Function	Port-Address	RAM-Address
OCR1AL/H	Timer/Counter 1 Output Compare register A	0x2A/0x2B	0x4A/0x4B hex

Port	Function	Port-Address	RAM-Address
OCR1BL/H	Timer/Counter 1 Output Compare register B	0x28/0x29	0x48/0x49

Port	Function	Port-Address	RAM-Address
ICR1L/H	Timer/Counter 1 Input Capture Register	0x24/0x25	0x44/0x45

Watchdog-Timer

Port	Function	Port-Address	RAM-Address
WDTCR	Watchdog Timer Control Register	0x21	0x41

7	6	5	4	3	2	1	0
-	-	-	WDTOE	WDE	WDP2	WDP1	WDP0

Bit	Name	Meaning	WDT-cycle at 5.0 Volt
7..5	(not used)		
4	WDTOE	Watchdog Turnoff Enable	Previous set to disabling of WDE required
3	WDE	Watchdog Enable	1: Watchdog aktive
2..0	WDP2..WDP0	Watchdog Timer Prescaler	000: 15 ms 001: 30 ms 010: 60 ms 011: 120 ms 100: 240 ms 101: 490 ms 110: 970 ms 111: 1,9 s

EEPROM

Port	Function	Port-Address	RAM-Address
EEARL/H	EEPROM Address Register	0x1E/0x1F	0x3E/0x3F

EEARH only in types with more than 256 Bytes EEPROM (from AT90S8515 upwards)

Port	Function	Port-Address	RAM-Address
EEDR	EEPROM Data Register	0x1D	0x3D

Port	Function	Port-Address	RAM-Address
EECR	EEPROM Control Register	0x1C	0x3C

7	6	5	4	3	2	1	0
-	-	-	-	-	EEMWE	EEWE	EERE

Bit	Name	Meaning	Function
7..3	(not used)		
2	EEMWE	EEPROM Master Write Enable	Previous set enables write cycle
1	EEWE	EEPROM Write Enable	Set to initiate write
0	EERE	EEPROM Read Enable	Set initiates read

Serial Peripheral Interface SPI

Port	Function	Port-Address	RAM-Address
SPCR	SPI Control Register	0x0D	0x2D

7	6	5	4	3	2	1	0
SPIE	SPE	DORD	MSTR	CPOL	CPHA	SPR1	SPR0

Bit	Name	Meaning	Function
7	SPIE	SPI Interrupt Enable	0: Interrupts disabled
			1: Interrupts enabled
6	SPE	SPI Enable	0: SPI disabled
			1: SPI enabled
5	DORD	Data Order	0: MSB first
			1: LSB first
4	MSTR	Master/Slave Select	0: Slave
			1: Master
3	CPOL	Clock Polarity	0: Positive Clock Phase
			1: Negative Clock Phase
2	CPHA	Clock Phase	0: Sampling at beginning of Clock Phase
			1: Sampling at end of Clock Phase
1	SPR1	SCK clock frequency	00: Clock / 4
0	SPR0		01: Clock / 16
			10: Clock / 64
			11: Clock / 128

Port	Function	Port-Address	RAM-Address
SPSR	SPI Status Register	0x0E	0x2E

7	6	5	4	3	2	1	0
SPIF	WCOL	-	-	-	-	-	-

Bit	Name	Meaning	Function
7	SPIF	SPI Interrupt Flag	Interrupt request
6	WCOL	Write Collision Flag	Write collision occurred
5..0	(not used)		

Port	Function	Port-Address	RAM-Address
SPDR	SPI Data Register	0x0F	0x2F

## UART

Port	Function	Port-Address	RAM-Address
UDR	UART I/O Data Register	0x0C	0x2C

Port	Function	Port-Address	RAM-Address
USR	UART Status Register	0x0B	0x2B

7	6	5	4	3	2	1	0
RXC	TXC	UDRE	FE	OR	-	-	-

Bit	Name	Meaning	Function
7	RXC	UART Receive Complete	1: Char received
6	TXC	UART Transmit Complete	1: Shift register empty
5	UDRE	UART Data Register Empty	1: Transmit register available
4	FE	Framing Error	1: Illegal Stop-Bit
3	OR	Overrun	1: Lost char
2..0	(not used)		

Port	Function	Port-Address	RAM-Address
UCR	UART Control Register	0x0A	0x2A

7	6	5	4	3	2	1	0
RXCIE	TXCIE	UDRIE	RXEN	TXEN	CHR9	RXB8	TXB8

Bit	Name	Meaning	Function
7	RXCIE	RX Complete Interrupt Enable	1: Interrupt on received char
6	TXCIE	TX Complete Interrupt Enable	1: Interrupt at transmit complete
5	UDRIE	Data Register Empty Interrupt Enable	1: Interrupt on transmit buffer empty
4	RXEN	Receiver Enabled	1: Receiver enabled
3	TXEN	Transmitter Enable	1: Transmitter enabled
2	CHR9	9-bit Characters	1: Char length 9 Bit
1	RXB8	Receive Data Bit 8	9th Data bit on receive
0	TXB8	Transmit Data Bit 8	9.Data bit on transmit

Port	Function	Port-Address	RAM-Address
UBRR	UART Baud Rate Register	0x09	0x29

## Analog Comparator

Port	Function	Port-Address	RAM-Address
ACSR	Analog Comparator Control and Status Register	0x08	0x28

7	6	5	4	3	2	1	0
ACD	-	ACO	ACI	ACIE	ACIC	ACIS1	ACIS0

Bit	Name	Meaning	Function
7	ACD	Disable	Disable Comparators
6	(not used)		
5	ACO	Comparator Output	Read: Output of the Comparators
4	ACI	Interrupt Flag	1: Interrupt request

Bit	Name	Meaning	Function
3	ACIE	Interrupt Enable	1: Interrupts enabled
2	ACIC	Input Capture Enable	1: Connect to Timer 1 Capture
1	ACIS1	Input Capture Enable	00: Interrupt on edge change
0	ACIS0		01: not used)
			10: Interrupt on falling edge
			11: Interrupt on rising edge

I/O Ports

Port	Register	Function	Port-Address	RAM-Address
A	PORTA	Data Register	0x1B	0x3B
	DDRA	Data Direction Register	0x1A	0x3A
	PINA	Input Pins Address	0x19	0x39
B	PORTB	Data Register	0x18	0x38
	DDRB	Data Direction Register	0x17	0x37
	PINB	Input Pins Address	0x16	0x36
C	PORTC	Data Register	0x15	0x35
	DDRC	Data Direction Register	0x14	0x34
	PINC	Input Pins Address	0x13	0x33
D	PORTD	Data Register	0x12	0x32
	DDRD	Data Direction Register	0x11	0x31
	PIND	Input Pins Address	0x10	0x30

Ports, alphabetic order

- ACSR, Analog Comparator Control and Status Register  
DDRx, Port x Data Direction Register  
EEAR, EEPROM Address Register  
EECR, EEPROM Control Register  
EEDR, EEPROM Data Register  
GIFR, General Interrupt Flag Register  
GIMSK, General Interrupt Mask Register  
ICR1L/H, Input Capture Register 1  
MCUCR, MCU General Control Register  
OCR1A, Output Compare Register 1 A  
OCR1B, Output Compare Register 1 B  
PINx, Port Input Access  
PORTx, Port x Output Register  
SPL/SPH, Stackpointer  
SPCR, Serial Peripheral Control Register  
SPDR, Serial Peripheral Data Register  
SPSR, Serial Peripheral Status Register  
SREG, Status Register  
TCCR0, Timer/Counter Control Register, Timer 0  
TCCR1A, Timer/Counter Control Register 1 A  
TCCR1B, Timer/Counter Control Register 1 B  
TCNT0, Timer/Counter Register, Counter 0  
TCNT1, Timer/Counter Register, Counter 1  
TIFR, Timer Interrupt Flag Register  
TIMSK, Timer Interrupt Mask Register  
UBRR, UART Baud Rate Register  
UCR, UART Control Register  
UDR, UART Data Register  
WDTCSR, Watchdog Timer Control Register



# List of abbreviations

The abbreviations used are chosen to include the value range. Register pairs are named by the lower of the two registers. Constants in jump commands are automatically calculated from the respective labels during assembly.

Category	Abbrev.	Means ...	Value range
Register	r1	Ordinary Source and Target register	R0..R31
	r2	Ordinary Source register	
	rh	Upper page register	R16..R31
	rd	Twin register	R24(R25), R26(R27), R28(R29), R30(R31)
	rp	Pointer register	X=R26(R27), Y=R28(R29), Z=R30(R31)
	ry	Pointer register with displacement	Y=R28(R29), Z=R30(R31)
Constant	k63	Pointer-constant	0..63
	c127	Conditioned jump distance	-64..+63
	c255	8-Bit-Constant	0..255
	c4096	Relative jump distance	-2048..+2047
	c65535	16-Bit-Address	0..65535
Bit	b7	Bit position	0..7
Port	p1	Ordinary Port	0..63
	pl	Lower page port	0..31