



# Report

## Laboratory 1



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# 1 Introduction

In the process of working with the laboratory assignments we started by doing research about the AVR Assembly language and the STK600 in order to better understand how to solve the different assignments. In each assignment we first created a pseudocode solution which we converted to flowchart diagrams, then it was rather simple to convert this into Assembly code. Common for all assignments is also that we have been using the simulations to confirm that the program is working and completing the correct tasks.

When we tested the Assembly programs on hardware we had trouble with the LEDs outputting inversed values. For example the program for assignment 1, which is supposed light LED2, lit all LEDs except LED2. If we understood this correctly, this was due to the pull-up resistor being activated on `PORTB` which made the LEDs light when the corresponding bit on `PORTB` was 0 (as opposed to 1). We fixed this by changing the bit string values we wrote to the LEDs in each assignment.

Another small issue we encountered was that we had assumed that `PORTD` would be the port connected to the switches on the STK600, as this is the configuration described in the STK600 User Guide. In the hardware we tested on though, the switches were connected to `PORTC`. To fix this we simply replaced all references of `PORTD`, `PIND` and `DDRD` to `PORTC`, `PINC` and `DDRC` in our Assembly code.

## 2 Assignment 1 - Light LED2

In the first assignment we were to write an Assembly program that lights up LED2 (which is the third light counting from the right).

### 2.1 Pseudo code

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**Algorithm 1** Light LED2

---

**procedure** PSEUDOCODE

*PortB* = *output*

*Led2* *bitstring* → *PortB*

---

### 2.2 Flowchart

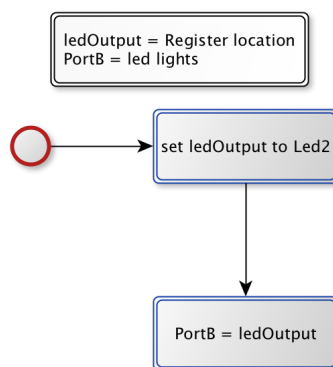


Figure 1: Basic flow in order to light LED2

### 2.3 Method

The pseudocode (see algorithm 1) and the flowchart (see figure 1) shows that we first set PORTB as an output port. To light up LED2 we then only need to write a 0 to the bit on PORTB that corresponds to LED2.

The minimal number of lines required to write this program we think are four. Two lines are required to set the LED port as output: one to write a value to a register and the other to write that value to the data direction register. The final two lines are for turning on the LED: one to write the LED state to a register and the other to write the LED state to the output port. One could try to write the program in three lines, by reusing the value written to the data direction register when writing to the output port. But in this case the LED will not turn on because of the pull-up resistor which will require that a zero is written to the bit corresponding to the LED that we want to light.

## 2.4 Assembly Program

[illegible]

### 3 Assignment 2 - Switch light corresponding LED

In the second assignment we were to write a program that waits for a switch to be pressed and then lights up the corresponding LED. For example if switch 3 is pressed LED 3 should light up. The way we interpreted the assignment was that the LED should stay on for as long as the switch is pressed down and turn off when the switch is released.

#### 3.1 Pseudo code

---

**Algorithm 2** Switches pressed lights corresponding LED

---

**procedure** PSEUDOCODE

*PortB* = output

*PortC* = input

**repeat**

*PortC* value  $\rightarrow$  *switchState*  $\triangleright$  *switchState* = register location

*switchState*  $\rightarrow$  *PortB*

**until**  $\infty$

---

#### 3.2 Flowchart

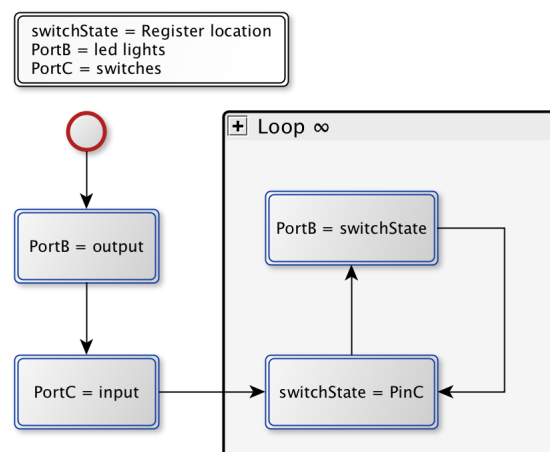


Figure 2: Basic flow in order to read switches and light corresponding LED

#### 3.3 Method

We figured the simplest way to solve this problem was to redirect the input from the switches to the LEDs repeatedly in a loop. We start by setting PORTB as output and PORTC as input. Then, in an infinite loop, we read the value of the pins on PORTC to a register and output the value of that register to PORTB.

### 3.4 Assembly Program

[illegible]

## 4 Assignment 3 - Switch 5 lights LED0

In the third assignment we were to write an Assembly program that turns on LED0 when the switch SW5 is pressed. Nothing should happen when the other switches are pressed. We assumed that the way the program should work is that the LED would stay lit for as long as SW5 was pressed down and turn off when the switch was released.

### 4.1 Pseudo code

---

**Algorithm 3** Light LED0 when switch5 is pressed

---

**procedure** PSEUDOCODE

*PortB = output*

*PortC = input*

**repeat**

*reset ledState*

▷ *ledState = register location*

**if** *Switch5 is pressed* **then**

*ledState = LED0 bit string*

*ledState → PortB*

**until** ∞

---

### 4.2 Flowchart

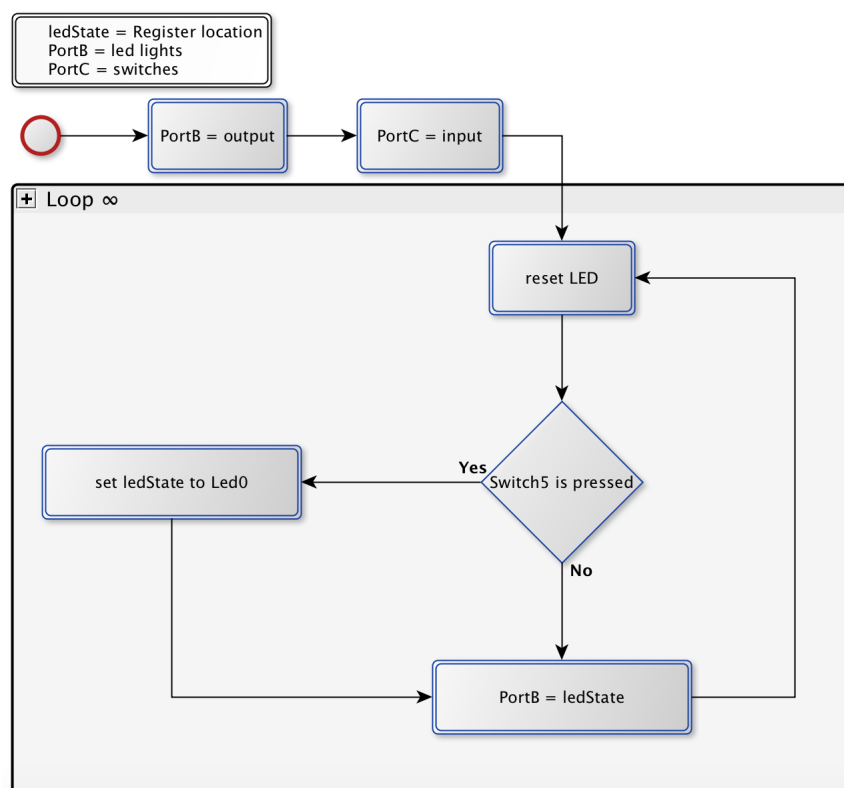


Figure 3: Basic flow in order to light LED 0 when switch 5 is pressed



### 4.3 Method

As with the previous assignment, we figured the first thing that needed to be done was to set the LED port, `PORTB`, as output and the switch port, `PORTC`, as input. In a loop, we then reset the value to write to the leds before checking if `SW5` is pressed down. If the switch is pressed down we clear the least significant bit in the LED output value to indicate that we want `LED0` to turn on before writing the value out to the LEDs.

## 4.4 Assembly Program

[illegible]

## 5 Assignment 4 - Using the AVR simulator

For this assignment, we were to take the program we wrote for the previous assignment, that lights LED0 when SW5 is pressed down, and run it in the AVR simulator that is included in Atmel Studio.

### 5.1 Method

First, we needed to setup the debugger to run the program on the simulator which is done by selecting "Simulator" in *Project* → *Properties* → *Tool*. To start stepping through the program we then clicked *Debug* → *Start debugging and break*. To be able to see what happens in the simulator as the program runs, we opened the *Processor Status* and *I/O* windows by clicking on their respective icons. Finally, because values from the pins on the switches have a default value of 1 we needed to set all `PINC` bits, which we did by selecting *I/O Port (PORTC)* in the *I/O* window and filling in the bits to the right of *PINC* by clicking on them.

We then started stepping through the program. The first few lines sets `PORTB` as output (line 42-43) and `PORTC` to input (line 46-47) and this can be seen in the simulator by keeping an eye on *PORTB* → *DDRB*, which bits are set to 1, and *PORTC* → *DDRC*, which are set to 0, as the debugger executes the instructions. When the debugger executes line 50, which sets all bits in register 17, we can see this in the *Processor Status* window in that *r17* gets set to `0xFF`. We tested that the instruction on line 53, which checks if SW5 is pressed down, works by manually clearing bit 5 on *PINC* through the *I/O* window. The instruction that gets executed if this is true, can be seen in the simulator in that register 17 changes value from `0xFF` to `0xFE`. The result of line 56, which writes the value of register 17 to `PORTB`, can be seen by clicking on *PORTB* in the *I/O* window where the bits next to *PORTB* and *PINB* are updated accordingly. We could also see that the *Program Counter* value in the *Processor Status* window gets updated when the final line `rcall loop` gets executed.

## 6 Assignment 5 - Waterfall

### 6.1 Assignment description

The fifth assignment was to write an Assembly program that outputs a ring counter to the LEDs. Between each value in the counter, there should be a delay of approximately 0.5 seconds. Since the delay should be a subroutine in the program, the stack pointer *SP* needs to be initialized as instructed in the description of the assignment.

### 6.2 Pseudo code

---

**Algorithm 4** Display Ring counter on LEDs

---

**procedure** PSEUDOCODE

*Initialize stack pointer*

*PortB = output*

*Initialize ledState*

▷ *ledState = register location*

**repeat**

*ledState* → *PortB*

*Delay*

*rotate ledState to left*

**until** ∞

---

### 6.3 Flowchart

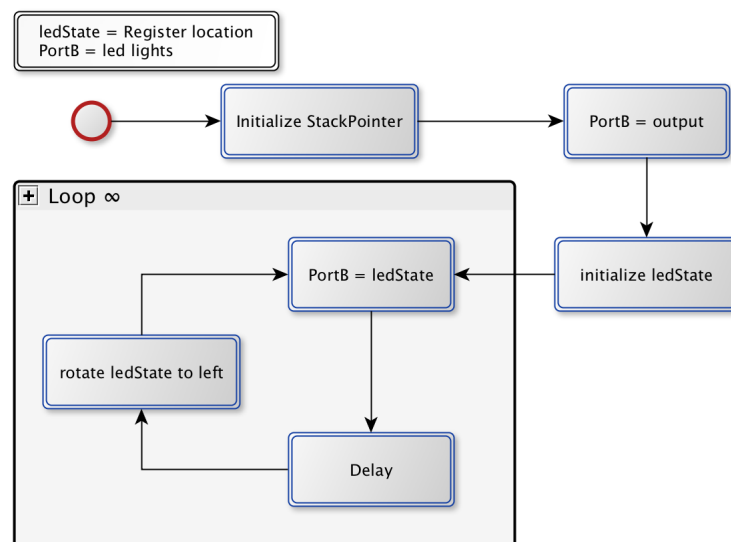


Figure 4: Basic flow in order to display a Ring counter on the LEDs

## 6.4 Method

The first thing we needed to do, as described above, was to initialize the stack pointer. This is done by setting `SP` to the end of SRAM (`RAMEND`). Since `SP` is a 16-bit register we needed to set both `SPL` and `SPH`. `SPL` is set to the least significant 8 bits of `RAMEND` and `SPH` is set to the most significant 8 bits of `RAMEND`. As always, we also set `PORTB` as output so we can write values to the LEDs.

The main part of the program consists of a loop where the current LED state is first written to the LEDs. We then delay execution of the program for ~0.5 seconds and finally rotate the bits in the LED state to the left using the `rol` instruction.

The delay functionality is as described in the assignment description implemented in a subroutine which we have calculated using the *AVR Delay Loop Calculator*.<sup>1</sup> We calculated a delay of 500 ms for 1.0 MHz, which is the default clock speed of the AVR ATmega2560.<sup>2</sup> We modified the subroutine slightly to push the registers that are used in it to the stack at the start of the subroutine and pop them before returning. This is done so we do not accidentally overwrite any values in the registers that the subroutine is using. These additional instructions do of course make the delay slightly longer, particularly since the CPU will need to write to and read from SRAM, but we did not think that mattered that much in this case.

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<sup>1</sup> <http://www.bretmulvey.com/avrdelay.html>

<sup>2</sup> *Atmel ATmega640/V-1280/V-1281/V-2560/V-2561/V DATASHEET*, Atmel Corporation, San Jose, CA, 2014, pp. 40

## 6.5 Assembly Program

[illegible]

## 7 Assignment 6 - Johnson counter

The final assignment was to write a program that displays a *Johnson counter* to the LEDs in an infinite loop. A Johnson counter is a counter that sets all bits in a bit string one-by-one and, when all bits are set, clears the bits one-by-one. Of course, this program will also need a delay after each value in the Johnson counter has been written to the LEDs. Otherwise the program would run so fast that all LEDs would most likely appear to be lit all the time.

### 7.1 Pseudo code

---

**Algorithm 5** Johnson counter simulation using LEDs

---

**procedure** PSEUDOCODE

*PortB* = output ▷ *complement* = register location

Initialize *currentValue* ▷ *currentValue* = register location

**repeat** ▷ *Loop\_1* (count up)

**if** *LED7* is lit **then**

        Continue at *Loop\_2*

**else**

*currentValue* = *currentValue* × 2

        Increase *currentValue* by 1

*complement* = complement of *currentValue*

*complement* → *PortB*

        Delay

**until** ∞

**repeat** ▷ *Loop\_2* (count down)

**if** *LED0* is lit **then**

        Continue at *Loop\_1*

**else**

*currentValue* = Shift right

*complement* = complement of *currentValue*

*complement* → *PortB*

        Delay

**until** ∞

---

## 7.2 Flowchart

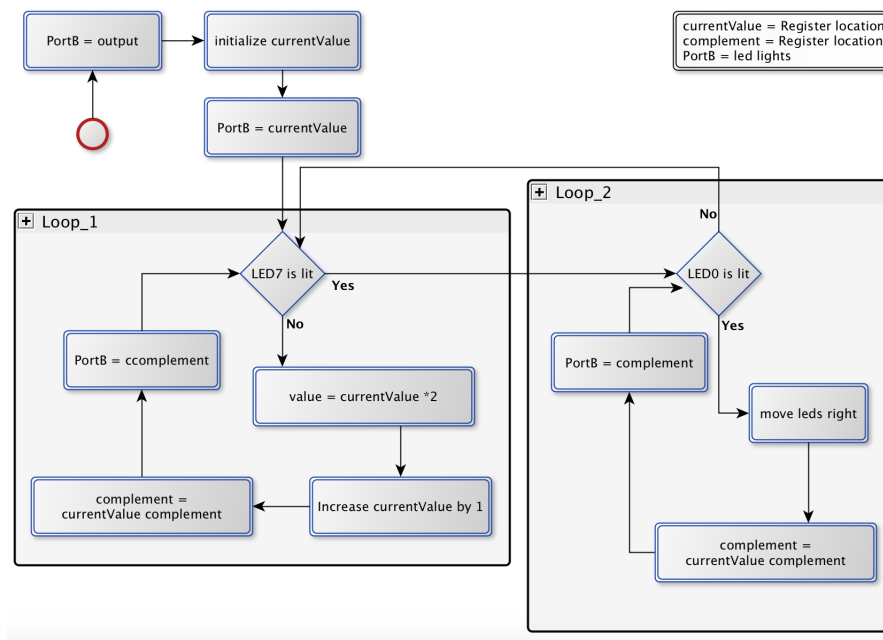


Figure 5: Basic flow in order to display a Johnson counter on LEDs

## 7.3 Method

We started by trying to figure out the mathematical formula for finding Johnson values. In decimal, the values for an 8-bit Johnson counter are: 0, 1, 3, 7, 15, 31, 63, 127 and 255. We realized that we could get the next value by multiplying by 2 and adding 1, which gives the recurrence relation

$$J_n = J_{n-1} \cdot 2 + 1, \quad n \in \mathbb{N}_0$$

With this we could get both the next and previous Johnson value. In the case of getting the previous value, we considered that we are dealing with integers, which because of truncating means we only needed to divide the current value by 2 to count down the counter.

As with assignment 5, we start by setting the stack pointer since we are going to use a subroutine for the delay function. We also set PORTB as output. To count the Johnson counter up and down, we created two loops: `count_up` and `count_down`. In `count_up` we multiply the current counter value by 2 by shifting it to the left and then increment it by 1 before outputting the value to the LEDs. We repeat this until all the LEDs are lit, upon which execution jumps to `count_down`. In this loop, we divide the current counter value by 2 by shifting it to the right and then output the value to the LEDs. This is in turn repeated until all the LEDs are turned off, upon which the execution jumps back to `count_up` and the process starts again.



## 7.4 Assembly Program

[illegible]

```

100
101      ldi  r18, 3
102      ldi  r19, 138
103      ldi  r20, 86
104  L1:  dec  r20
105      brne L1
106      dec  r19
107      brne L1
108      dec  r18
109      brne L1
110      rjmp PC+1
111
112      pop  r20
113      pop  r19
114      pop  r18
115      ret

```