**Lab 4 Report**

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3360:0001 - Embedded Systems

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## Introduction

Embedded Systems Lab 4 introduces a new concept in programming at the hardware level: interrupts. An interrupt is implemented using software to configure a path from an interrupt vector (we used external ATmega328p pins in lab 4) to the processor. This enables the processor to map the incoming signal to its corresponding interrupt service routine in memory. An ISR is simply a subroutine which momentarily stops - or interrupts - the programs current execution to execute the instructions inside of the subroutine jumped to by the interrupt vector.

Lab 4 utilizes this new concept to more easily program the user interface of an embedded system. In previous labs, we have utilized extremely fast polling rates using timers to perceive any change in signals at external pins. The overhead of coordinating timers is drastically reduced using interrupts, not to mention it reduces the latency from a user interaction to an output. We applied interrupts in lab 4 to improve the function of a push button and a rotary pulse generator (RPG) used for a user to control the rpm of a fan using pulse width modulation (PWM).

Listed below is an exhaustive list of hardware required to replicate the lab 4 circuit. Please note that an Arduino Uno contains the microcontroller needed and is sufficient for use in lab. We opted to use the Arduino Uno for simplicity when developing the circuit.

|  |  |  |
| --- | --- | --- |
| Hardware | Quantity | Description |
| Atmega 328P µC | 1 | Programmable µC |
| Enable Low Push Button | 1 | Control on/off of PWM Fan |
| Rotary Pulse Generator | 1 | Control duty cycle of PWM Fan |
| 16x2 LCD Display | 1 | Display fan status |
| EFB0412VHD-SP05 Fan | 1 | PWM fan |
| 100KΩ Resistor | 1 | Button debouncing |
| 10KΩ Resistor | 6 | RPG, button, and V0 voltage divider |
| 1KΩ Resistor | 1 | V0 voltage divider |
| 0.01µF Capacitor  Green LED  Red LED  230Ω Resistor | 4  1  1  2 | Decoupling and filtering  Fan on state  Fan off state  Limit LED current |

Figure 1: Materials list

## Schematic

A diagram of a computer

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Figure 2: Electrical circuit schematic created using KiCAD

The schematic for our circuit used many components from previous labs, mainly the active low push button and the RPG. We used similar hardware debounce techniques that were implemented in Lab 3. The red and green LEDs were outside the scope of this lab, but they were found to be helpful when debugging to see the state of the fan.

The fan was connected as follows: The voltage wire of the fan was connected to Vin which provides a voltage between 5 to 13 volts as stated in the EFB0412VHD-SP05-1 datasheet. To utilize this voltage, it was necessary to use the wall wart plug that comes with the microcontroller. The fan was also connected to a separate ground pin from the rest of the circuitry. To control the fan via timer counter 2 PWM we connected the signal wire to pin PD5 or OCR2B. The tachometer, an optional portion of this lab was not connected to the microcontroller and no code was written for this feature.

The connections for the LCD were as follows: The enable line was tied to PB2, this line is important as you have to strobe the enable line anytime you want to pass data to the LCD from the microcontroller. The read and write line was set to ground as for this lab, the LCD is only ever written to. The RS line was connected to PB5, this line is used to tell the LCD when it is receiving commands or displaying characters. The LCD was operated in 4-bit mode as this is much more efficient and requires half the connections of the 8-bit mode. Data lines D4-7 were connected to the microcontroller pins PC0-3 respectively. Anytime data in the form of commands or characters was sent to the LCD, these lines were utilized. To see the display of the LCD the contrast voltage had to be set. To do this we created a simple voltage divider with a 100KΩ resistor to 5V and a 10KΩ resistor to ground on pin 3 of the LCD. In an effort to make viewing the LCD even easier, the backlight was turned on by pulling pin 16 of the LCD to ground and connecting pin 15 to VCC via a 330Ω current limiting resistor.

As we progressed through this lab there was a constant challenge of keeping our circuit clean and managing cables. To combat this a 3D printed case was created to house the LCD, fan, microcontroller, and breadboard. With the use of this case and precise wire placement, it was much easier to keep track of wires and their specific uses. An image of the circuit and the case can be seen below. The 3d models used for the Arduino enclosure can be found in Appendix B.

A electronic device with wires and a display

AI-generated content may be incorrect.

Figure 3: Finished project enclosure

## 3. Discussion

The code for this lab can be split up into three significant sections. The implementation of interrupts, utilizing the PWM functionality of the on-board timer counters, and the use of the LCD. First the use of interrupts will be addressed.

## 3.1 Interrupts

Our program utilized 3 external interrupts, one for the active low push button, and two for the RPG. The active low push button interrupt was used to toggle the fan on and off, subsequently displaying to the LCD the state the fan was in. To make this interrupt we utilized external interrupt INT0. This interrupt was configured as follows:

|  |  |
| --- | --- |
| EIRCA | 1<<ISC01 |
| EIMSK | 1<<INT0 |
|  |  |

Figure 4: Interrupt register configurations for external interrupt INT0

To configure the external interrupt as falling edge, a 1 in the ISC01 bit was passed to the external interrupt control register A. Then to enable the interrupt the a 1 in the INT0 bit was passed to the external interrupt mask register. When an interrupt is triggered within the program you are taken to the address of the interrupt from the interrupt vector table. The vector address of INT0 is 0x002. At this address a rjmp command is utilized to send the code to the ISR that handles the logic that is to occur from the interrupt. It is very important to rjmp over this vector table as if the microcontroller were to run through this code issues would occur.

When first trying to implement interrupts in this lab there were various issues. The main one being that one button press was being treated as multiple presses, causing the ISR to be ran multiple times. To combat this a debounce solution was integrating utilizing delays and the interrupt flags. Once this delay, the service routine checks if the fan is in the on or off state. If in the on state the current duty cycle of the fan is saved, and the fan is set to off by sending 0 to OCR2B. After this occurs the LCD cursor is set to the address to write the state (ON or OFF) and OFF is written. When the fan is turned on, the previous duty cycle value is loaded back into OCR2B and the display is updated accordingly. When the fan is on the green LED will be illuminated and when the fan is off the red LED is illuminated. The message displayed was in the second row and can be viewed in the image below.

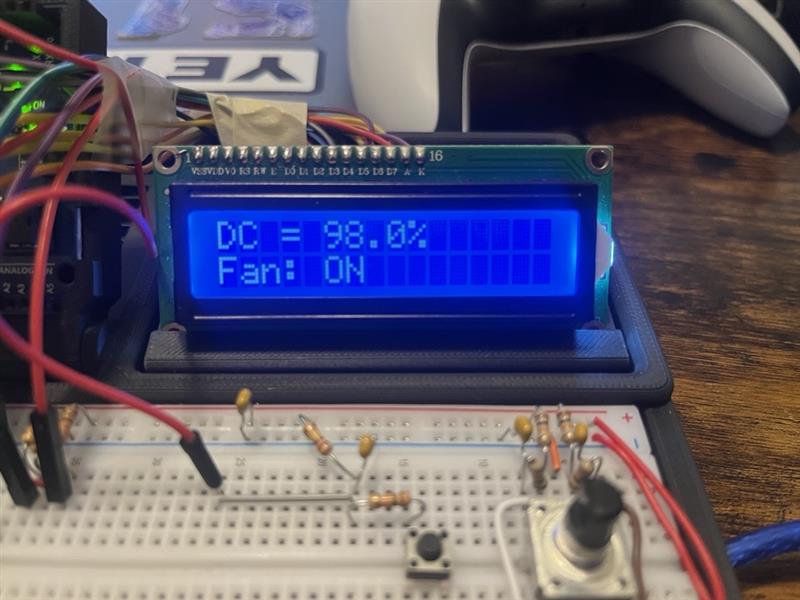


Figure 5: Fan status output to LCD

The two other interrupts utilized in this lab were pin change interrupts, specifically pin change interrupts 0 and 1 (PCINT0 & PCINT1). These interrupts are triggered whenever a change is detected on a pin, namely a switch from 0 to 1 or vice versa. PCINT0 and PCINT1 are located on PB0 and PB1 of the microcontroller. Whenever a logic change was detected on either of these pins, coming from the RPG the interrupt was triggered. The configuration of these two interrupts is shown below.

|  |  |  |
| --- | --- | --- |
| PCICR | (1<<PCIF0) |  |
| PCMSK0 | (1<<PCINT1) | (1<<PCINT0) |
|  |  |  |

Figure 6: Interrupt registers for external Pin Change PCINT0 and PCINT1 interrupts

A 1 bit was passed to the pin change interrupt control register in the location of PCIF0 to enable pin change interrupts 0-7. Then a 1 is passed to the location of PCINT1 and PCINT0 in the pin change mask register 0. This is done to mask out all other interrupts. The vector addresses of these two interrupts are 0x0006 and 0x0008 so the rjmp commands to the ISR were placed there.

Inside the RPG ISR similar logic was implemented as was in lab 3. In the initialization stage of the code, the current RPG state is read and moved to the previous RPG state. When the interrupt is triggered the RPG is at a new state. There is a small debounce delay in the ISR and then we jump into the logic. The entire PINB is read in masking out all other bits besides those connected to the RPG, then by using logical shifts we get the current RPG and previous RPG states in the same register for comparisons to find if we are turning clockwise or counterclockwise. These comparisons can be seen in the table below (in the form prev prev curr curr).

|  |  |
| --- | --- |
| 0b0001 | Counter-clockwise |
| 0b0111 | Counter-clockwise |
| 0b1000 | Counter-clockwise |
| 0b1110 | Counter-clockwise |
| 0b0010 | Clockwise |
| 0b0100 | Clockwise |
| 0b1011 | Clockwise |
| 0b1101 | Clockwise |
|  |  |

Figure 7: rotation encodings checked during PCINT0 and PCINT1 interrupts

Once figuring out what direction we are rotating we utilized an accumulator and threshold to keep RPG turns to only incrementing and decrementing the duty cycle by 0.5%. Each turn without the threshold incremented by around 2%. A threshold of 4 was set so that 4 changes of state had to be detected before the duty cycle was updated. The duty cycle was incremented or decremented by 1 for a turn. This is later divided by 200 to find the DC percentage. After incrementing or decrementing the duty cycle a cursor is set to the location where the percentage is written to the LCD. Then by using some arithmetic logic from the AVR200 library the fraction of OCR2B / OCR2A is performed to get the percent in the form of 0-999 as a percent. Then by dividing by 10 and passing digits to the LCD we can display the current percentage. A limit of 100% was set and a minimum of 1% was set inside the ISR. A separate display routine was created for the 100% display as it is more digits. Everytime the duty cycle of the fan is updated the display percentage was updated in turn. An image of the duty cycle percentage on the LCD is below.

A electronic device with wires and a display

AI-generated content may be incorrect.

Figure 8: Duty cycle output to LCD

## 3.2 PWM

PWM allows us to simulate analog voltage levels by rapidly toggling a digital output. By adjusting the portion of time the signal remains high in each period, known as the “duty cycle” we can control the current delivered to devices like motors or fans. In this lab, the goal was to use PWM to regulate a cooling fan's speed via Timer/Counter2 on the ATmega328P by creating a pulse width modulated square wave that alters the average voltage, and more importantly current, into the fan.

Figure 9: Duty cycle equation

To utilize and control the fan speed it was essential to understand how PWM works within the microcontroller. There were two main aspects to PWM control in our code, the initialization and then updating of the percentage. In the lab description a frequency of 80Khz was to be used. To calculate this the following formula was utilized.

Figure 10: PWM frequency equation

The frequency our microcontroller operates at is 16Mhz and we are solving for a PWM frequency of 80Khz. By doing some simplification we find that using a prescalar of 1 and a top value of 199 will work for our application. Having a top value of 199 also allows us to modify the duty cycle by increments that are less than 1%.

When configuring the PWM we opted to use timer counter 2 as timer counter 1 was already being used to generate our base delay. To utilize timer counter 2, sts commands must be used as timer registers are located in the extended I/O registers. Register 16 is first loaded with the corresponding bits to our configuration and then sts is used to move this registers contents into TCCR2A and TCCR2B. The configuration for the timer counter is shown below.

|  |  |  |  |
| --- | --- | --- | --- |
| TCCR2A | (1<< COM2B1) | (1<<WGM21) | (1<<WGM20) |
| TCCR2B | (1<<WGM22) | (1<<CS20) |  |
| OCR2A | 199 |  |  |
| OCR2B | 99 |  |  |
|  |  |  |  |

Figure 11: Timer2 configurations for non-inverting, fast-PWM mode

We configured in non-inverting PWM mode by passing a 1 to COM2B1 and have a pre scalar of 1 by passing a 1 to the location of CS20. Fast PWM mode is configured by passing 1’s to the locations of WGM22, WGM21, and WGM20. The top value OCR2A is set to 199 to reach the 80Khz frequency and the bottom value of OCR2B is set to 100 to start at a duty cycle of 50%.

When the RPG interrupt is triggered, it is OCR2B that is updated and the remaining configurations stay static. To calculate the duty cycle percentage OCR2B+1 is divided by OCR2A+1 to offset the 0-based indexing of the timer2. It is this percentage that is being displayed and updated on the LCD. An example duty cycle is calculated as shown below:

OCR2A = 199. Let OCR2B = 98

Figure 12: Example duty cycle generated by timer2

Because AVR microcontroller does not have native instructions for multiplication and division of numbers, we used subroutines mpy16u and div16u taken from ATMEL AVR200.asm to achieve multiplication of two unsigned integers. Please refer to code for subroutine instructions. Here are the respective register transfer notations (RTN) for each mpy16u and div16u subroutines:

Figure 12: Register transfer for multiplication and division subroutines

In mpy16u, r19:r18 is the multiplier while r17:r16 is the multiplicand. The product then overwrites r17:r16. In contrast, in div16u, r19:r18 is the divisor while r17:r16 is the dividend. For div16u, there are two outputs: r17:r16 is overwritten with the quotient and r15:r14 stores the remainder. These routines are called after a rpg turn inside of the rpg\_change ISR to calculate the duty cycle percentage. The resulting register contents from the mpy16u and div16u are unpacked individually inside of our LCD display functions to write each individual number as a char to the LCD.

## 3.3 LCD

Writing to and configuring the LCD in this lab is very dependent on timing and accurate reading of the datasheet. To configure the LCD to 4-bit mode a specific formula was followed. This formula consisted of setting the LCD to 8-bit mode 3 times and then finally setting the LCD to 4-bit mode. The formula is given below.

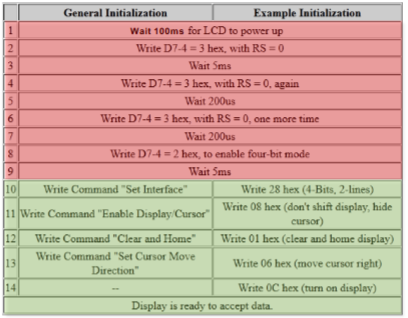


Figure 12: Initialization sequence for 4-bit LCD interface

Sending information to the LCD is done by setting the D4-D7 bits and having the RS line set to 0 as we are in command mode. To initialize and send data to the LCD various delay routines were implemented with timer counter 1. To send data with 4 data lines one has to send the upper nibble and then the lower nibble as the LCD can only read data in 8 bit groups. Once the formula was completed we have an LCD that is initialized, on, and ready to receive characters to display.

Displaying to the LCD can be done with single characters or strings of information. Two different subroutines were utilized to send each of these. We used strings for “DC =”, “Fan: “, “ON”, and “OFF”, while we used the character display for the duty cycle display percentage. To display these strings the address of the strings is stored in registers R30 and R31 and our string display subroutine is called. All commands and characters must be sent with the enable line strobe subroutine. This ensures that the LCD can accept commands and data.

To display the variable duty cycle percentage utilizing characters instead of strings was required. Each time the duty cycle was updated and then the percentage was calculated in the form of 0-999, the display function was called. First the display address cursor must be set to the location to which you want to write to. The addresses of the LCD are pictured below.

A diagram of a display

AI-generated content may be incorrect.

Figure 13: DDRAM addresses of LCD

By correctly setting the cursor address you can avoid having to write the entire display every time there is an update. This looks much better to the user as only certain parts of the display have visual changes. The duty cycle percentage display works by displaying the digits and decimal points in order followed by a percentage sign. When switching between changing the ON and OFF states and the percentage the cursor address has to move between the first and second LCD rows. For the variable duty cycle string, we started writing to address 05. For the variable fan status string, the cursor started at address 45

A screen shot of a computer

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Figure 14: Superimposed DDRAM addressing on LCD. Highlighted addresses depicting starting addresses of variable strings.

Once configuring the LCD and understanding how the timing and enable lines work, using the peripheral becomes relatively straightforward. This provides a viable alternative to the 7-segment display utilized in previous labs.

## 4. Conclusion

Following the brief interruption of the Embedded Systems midterm, we applied our new-found knowledge of interrupts to build a fan monitoring system. Already having learned the lowest level of program flow of using timers to do routine checks on the status of input pins, interrupts were easily picked up. This change in program flow can be treated conceptually as a higher level: functions responding to events. Though we move towards more abstract logic, the fundamentals of coding remain the same - the processing and transfer of bits. This lab provided more valuable insight into real-world applications such as PWM control and LCDs. The move to C code following this lab is a bittersweet one as many code segments will be much easier to implement and libraries will make our lives much easier. However, over the past weeks, we have grown to love the accurate timing and low-level logic assembly code offers.

## 5. Appendix A: Source Code

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; Lab 4: ECE:3360 Embedded Systems

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; Authors:

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; Sage Marks & Matt Krueger

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; Project Statement:

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; This AVR program controls a pwm cooling fan, LCD display,

; active-Low pushbutton, and RPG Encoder to create a fan monitoring system.

; ;

;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;

.include "m328pdef.inc"

;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;

; Register Aliases ;

;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;

.def dc\_high = r29 ; Y reg

.def dc\_low = r28 ; Y reg

.def tmp2 = r24 ; temporary register

.def tmp1 = r23 ; temporary register

.def count = r22 ; stores counter for timer0

.def rpg\_current\_state = r21

.def rpg\_previous\_state = r20

.def fan\_state = r19 ; boolean flag for fan on/off

.def previous\_dc\_divisor = r18 ; tracks previous duty cycle divisor

.def current\_dc\_divisor = r17 ; tracks current duty cycle divisor

.def rpg\_accumulator = r5 ; accumulator for our rpg <1% change per turn

.def rpg\_threshold = r4 ; max for accumulator

.cseg

.org 0x0000

rjmp reset ; jump over interrupts & LUTs

;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;

; Interrupt Vectors ;

;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;

.org 0x0002

rjmp toggle\_fan

.org 0x0006

rjmp rpg\_change

.org 0x0008

rjmp rpg\_change

.org 0x0034 ; end of interrupt vector

;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;

; Lookup Tables ;

;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;

prefix\_string:

.db "DC = ", 0x00

suffix\_string:

.db "%", 0x00

fan\_string:

.db "Fan: ", 0x00

on\_string:

.db "ON ", 0x00

off\_string:

.db "OFF", 0x00

space\_string:

.db " ", 0x00

;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;

; Component Configuration ;

;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;

configure\_outputs:

; port B

sbi DDRB, 5 ; R/S on LCD (Instruction/register selection) (arduino pin 13)

sbi DDRB, 2 ; E on LCD (arduino pin ~10)

; port C

sbi DDRC, 3 ; D7 on LCD (arduino pin A3)

sbi DDRC, 2 ; D6 on LCD (arduino pin A2)

sbi DDRC, 1 ; D5 on LCD (arduino pin A1)

sbi DDRC, 0 ; D4 on LCD (arduino pin A0)

; port D

sbi DDRD, 3 ; pwm fan signal (arduino pin ~3)

sbi DDRD, 5 ; green LED indicator for fan ON (arduino pin ~5)

sbi DDRD, 7 ; red LED indicator for fan OFF(arduino pin ~7)

ret

configure\_inputs:

; port B

cbi DDRB, 1 ; A signal from RPG (arduino pin 4)

cbi DDRB, 0 ; B signal from RPG (arduino pin ~5)

; port d

cbi DDRD, 2 ; Pushbutton input signal

ret

configure\_timer0:

; TCCR0A:

; -------------------------------------------------------------- ---------------------------------

; | COM0A1 | COM0A0 | COM0B1 | COM0B0 | - | - | WGM01 | WGM00 | ---> | 0 | 0 | 0 | 0 | - | - | 0 | 0 |

; -------------------------------------------------------------- ---------------------------------

; TCCR0B:

; ------------------------------------------------------ ---------------------------------

; | FOC0A | FOC0B | - | - | WGM02 | CS02 | CS01 | CS00 | ---> | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 |

; ------------------------------------------------------ ---------------------------------

;

; Configuration:

; - clock source: 16MHz prescaled by 8 to yield a 2MHz tick

; 1/2MHz = 0.5us per tick

;

; - counter operation: normal with top of 0xFF, counting up from `count` (56 decimal)

; 256 - 56 = 200 ticks before overflow,

; 200 ticks \* 0.5us = 100us

; this means that timer overflows every 100us, yeilding a delay of 100us

;

; - \*important note\* because we are passing a count into the tcnt0 register, tcnt0 resets at turnover.

; Therefore, we must reload at every overflow (see delay section for details)

ldi count, 0x38

ldi tmp1, (1 << CS01)

out TCNT0, count

out TCCR0B, tmp1

ret

configure\_timer2:

; TCCR2A:

; -------------------------------------------------------------- ---------------------------------

; | COM2A1 | COM2A0 | COM2B1 | COM2B0 | - | - | WGM21 | WGM20 | ---> | 0 | 0 | 1 | 0 | - | - | 1 | 1 |

; -------------------------------------------------------------- ---------------------------------

; TCCR2B:

; ----------------------------------------------------- ---------------------------------

; | FOC2A | FOC2B | - | - | WGM22 | CS22 | CS21 | CS20| ---> | 0 | 0 | - | - | 1 | 0 | 0 | 1 |

; ----------------------------------------------------- ---------------------------------

;

; Configuration:

; - counter operation: Clear OC2B on compare match, set OC2B at BOTTOM (0). All wgm bits set, so top is fast-pwm with a top of OCR2A

; With these selections, we can simlpy increment/decrement OCR2B to achieve the duty cycle.

; Setting OCR2A to 199, we can increment/decrement OCR2B from 0 to 199 to achieve a duty cycle of 0-99%

; Thus, an increment/decrement of 1 in OCR2B will change the duty cycle by +/-0.5%

;

; - clock source: no prescaling. 16MHz clock, so 1 tick = 0.0625us

ldi r16, (1 << COM2B1) | (1 << WGM21) | (1 << WGM20) ; Fast pwm, non-inverting (COM0B1=1), TOP=OCR0A (Mode 7)

sts TCCR2A, r16

ldi r16, (1 << WGM22) | ( 1<< CS20) ; Prescaler=1 (CS20=1), Fast pwm with TOP=OCR0A (WGM02=1)

sts TCCR2B, r16

ldi r16, 199

sts OCR2A, r16

ldi current\_dc\_divisor, 195 ; initial duty cycle is 195/200 = 97.5%

sts OCR2B, current\_dc\_divisor

ret

configure\_pushbutton\_interrupt:

; configure INT0 interrupt to trigger on falling edge

; this is used to control on/off of fan

ldi r16, (1 << ISC01) ; falling edge

sts EICRA, r16

ldi r16, (1 << INT0) ; enable int0

out EIMSK, r16

ret

configure\_rpg\_interrupt:

; configure PCINT0 and PCINT1

; this is used to control the duty cycle of the fan

ldi r16, (1 << PCIE0) ; enable PCINT 7..0

sts PCICR, r16

ldi r16, (1 << PCINT1) | (1 << PCINT0) ; PCINT1..0 mask

sts PCMSK0, r16

ret

configure\_lcd:

; LCD power-up sequence

rcall delay\_100ms ; wait >40ms

cbi PORTB, 5 ; set R/S to low (data transferred is treated as commands)

; set 8-bit mode by sending 0011 0000 3 times

rcall set\_8\_bit\_mode

rcall lcd\_strobe

rcall delay\_10ms ; wait for >4.1ms after setting 8-bit (via datasheet pg 45)

rcall set\_8\_bit\_mode

rcall lcd\_strobe

rcall delay\_1ms ; subsequent delays >100us.

rcall set\_8\_bit\_mode

rcall lcd\_strobe

rcall delay\_1ms ; delay between commands >100us

; set 4-bit mode

set\_4\_bit\_mode:

ldi r17, 0x02

out PORTC, r17

rcall lcd\_strobe

rcall delay\_10ms

; finilize 4-bit mode

set\_interface:

ldi r17, 0x02

out PORTC, r17

rcall lcd\_strobe

rcall delay\_100us

ldi r17, 0x08

out PORTC, r17

rcall lcd\_strobe

rcall delay\_1ms

; now 4 bit mode is set

rcall delay\_10ms

; enable\_display\_cursor:

; ldi r17, 0x00;

; out PORTC, r17;

; rcall lcd\_strobe; ; additional strobe included inside of slides:

; rcall delay\_100us; ; not needed as it is overwritten by turn on display

; ldi r17, 0x08; ; delaying before next command to ensure not busy is sufficient

; out PORTC, r17;

; rcall lcd\_strobe;

; rcall delay\_10ms

; reset cursor to home

clear\_home:

ldi r17, 0x00

out PORTC, r17

rcall lcd\_strobe

rcall delay\_100us

ldi r17, 0x01 ; 0000 0001 -> return cursor to home

out PORTC, r17

rcall lcd\_strobe

rcall delay\_10ms

; set cursor move direction to right

set\_cursor\_move\_direction:

ldi r17, 0x00

out PORTC, r17

rcall lcd\_strobe

rcall delay\_100us

ldi r17, 0x06 ; 0000 0110 -> cursor move direction to right

out PORTC, r17

rcall lcd\_strobe

rcall delay\_1ms

; turn on display... overwrites display off command enable\_display\_cursor

turn\_on\_display:

ldi r17, 0x00

out PORTC, r17

rcall lcd\_strobe

rcall delay\_100us

ldi r17, 0x0C ; 0000 1100 -> display on, cursor off, blink off

out PORTC, r17

rcall lcd\_strobe

rcall delay\_1ms

; The following code is for displaying static strings. these are overwritten by the dynamic strings in isrs

; ---------------------------------------------------

; | D | C | \_ | = | \_ | | | | | | | | | | |

; | F | a | n | : | \_ | | | | | | | | | | |

; ---------------------------------------------------

; display prefix on first row

display\_dc\_prefix:

sbi PORTB, 5

ldi r30, LOW(2 \* prefix\_string) ; "DC = "

ldi r31, HIGH(2 \* prefix\_string) ; obtain address of prefix string

rcall write\_string\_to\_lcd

;move the cursor to the second row

move\_cursor\_to\_second\_row:

cbi PORTB, 5

ldi r17, 0x0C

out PORTC, r17

rcall lcd\_strobe

rcall delay\_100us

ldi r17, 0x00 ; move cursor to beginning of second row (ddram 40)

out PORTC, r17

rcall lcd\_strobe

rcall delay\_1ms

; display fan status on second row

display\_fan\_status:

sbi PORTB, 5

ldi r30, LOW(2 \* fan\_string) ; "Fan: "

ldi r31, HIGH(2 \* fan\_string) ; obtain address of fan string

rcall write\_string\_to\_lcd

rcall delay\_1ms

ret

set\_rpg\_accumulator: ;Sets the value of the rpg accumulator to 0

push r16 ;sets the threshold to 4

ldi r16, 0; ;This way each rpg turn only increments OCR2B one time (checking for intermediate states)

mov rpg\_accumulator, r16;

ldi r16, 4;

mov rpg\_threshold, r16

pop r16

ret

;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;

; MAIN CODE ;

;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;

reset:

; configure components

rcall configure\_outputs

rcall configure\_inputs

rcall configure\_timer0

rcall configure\_timer2

rcall configure\_pushbutton\_interrupt

rcall configure\_rpg\_interrupt

rcall configure\_lcd

rcall set\_rpg\_accumulator

; read initial rpg state

in rpg\_previous\_state, PINB

andi rpg\_previous\_state, 0x03 ; mask to get pins 5 (A) and 4 (B)

; initialie fan to on with current duty cycle quotient set in configuration subroutine

mov previous\_dc\_divisor, current\_dc\_divisor

ldi fan\_state, 0xff ; set fan state to on (1)

rcall fan\_on

; initial LED indicators used on circuit

sbi PORTD, 5

cbi PORTD, 7

; enable global interrupts

sei

; display initial pwm value

rcall move\_cursor\_to\_dc\_addr\_lcd

rcall convert\_dc\_to\_percentage

rcall write\_dc\_to\_lcd

; program loop. because this is an interrupt-driven program, nothing is in main loop

main:

rjmp main

;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;

; Pushbutton Interrupt Service Routine ;

;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;

toggle\_fan:

push r17

in r17, SREG

push r17

;debouncing (issue with manufacturing uc, fixed by prof Beichel)

rcall delay\_100ms

ldi r20, (1<< INTF0)

out EIFR, r20

sbic PIND,2

rjmp exit\_toggle

toggle\_code:

lds r17, OCR2B ; get current pwm value

tst fan\_state ; if fan state is 0 (off)

brne turn\_off ; if currently ON (0xFF), turn OFF (0x00)

turn\_on:

; change indicator LEDs (simply to let user know if button has worked correctly)

sbi PORTD, 5 ; turn green led on

cbi PORTD, 7 ; turn red led off

; set fan state to on and restore saved duty cycle

ldi fan\_state, 0xFF

mov r17, previous\_dc\_divisor

in rpg\_previous\_state, PINB

andi rpg\_previous\_state, 0x03

rjmp update\_pwm

turn\_off:

; change indicator LEDs (simply to let user know if button has worked correctly)

cbi PORTD, 5 ; turn green led off

sbi PORTD, 7 ; turn red led on

; set fan state to off and save current duty cycle

clr fan\_state ; set state to OFF

mov previous\_dc\_divisor, r17 ; save current duty cycle

ldi r17, 0 ; set duty to 0

update\_pwm:

sts OCR2B, r17 ; update pwm register with the stored value

update\_fan\_display:

tst fan\_state

brne display\_on

rcall move\_cursor\_to\_onoff\_addr\_lcd

rcall fan\_off

rjmp exit\_toggle

display\_on:

rcall move\_cursor\_to\_onoff\_addr\_lcd

rcall fan\_on

exit\_toggle:

pop r17

out SREG, r17

pop r17

reti

;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;

; RPG Interrupt Service Routine ;

;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;

rpg\_change:

; save registers that will be operated on

push r16

in r16, SREG

push r16

push r17

push r30

; exit if fan is off

rcall delay\_100us

tst fan\_state

breq exit\_rpg\_isr

; detect state of RPG pins

; ------------------------------------------

; | 0 | 0 | 0 | 0 | 0 | 0 | currA | currB |

; ------------------------------------------

in r17, PINB

andi r17, 0x03

; build sequence

; previous state bits are shifted twice, and then combined.

; because rpg A and B are two bits, shifting twice will result:

; ------------------------------------------

; | 0 | 0 | 0 | 0 | prevA | prevB | 0 | 0 |

; ------------------------------------------

; then applying bitwise or with current A and current B (without shifting), will result:

; --------------------------------------------------

; | 0 | 0 | 0 | 0 | prevA | prevB | currA | currB |

; --------------------------------------------------

; now, register 16 is in the form of a unique gray code encoding a cw or ccw turn.

mov r16, rpg\_previous\_state

lsl r16

lsl r16

or r16, r17

; update previous state

mov rpg\_previous\_state, r17

; cases:

; - counter-clockwise: 0b0001, 0b0111, 0b1000, 0b1110

; - clockwise: 0b0010, 0b0100, 0b1011, 0b1101

; if none of these cases, jumps to exit

; if ccw

cpi r16, 0b0001

breq counter\_clockwise

cpi r16, 0b0111

breq counter\_clockwise

cpi r16, 0b1000

breq counter\_clockwise

cpi r16, 0b1110

breq counter\_clockwise

; if cw

cpi r16, 0b0010

breq clockwise

cpi r16, 0b0100

breq clockwise

cpi r16, 0b1011

breq clockwise

cpi r16, 0b1101

breq clockwise

; if other

rjmp exit\_rpg\_isr

clockwise:

inc rpg\_accumulator ; increment accumulator and compare with threshold

mov r30, rpg\_accumulator

cp r30, rpg\_threshold

brne exit\_rpg\_isr ; if threshold not reached, skip OCR2B update

clr rpg\_accumulator ; reset accumulator

lds r30, OCR2B ; get current duty cycle

cpi r30, 198 ; check if newest turn reaches max dc

breq full\_speed\_call ; if at max, don't increment and exit

cpi r30, 199

breq exit\_rpg\_isr

inc r30 ; increment

sts OCR2B, r30 ; update ocr2b

rjmp exit\_rpg\_update

counter\_clockwise:

inc rpg\_accumulator ; increment the accumulator

mov r30, rpg\_accumulator ; use r30 as temporary register

cp r30, rpg\_threshold ; compare with threshold

brne exit\_rpg\_isr ; if not reached threshold, skip OCR2B update

clr rpg\_accumulator ; reset accumulator

lds r30, OCR2B ; get current duty cycle

cpi r30, 2 ; check if at min (2 or 1%)

breq exit\_rpg\_isr ; if at min, don't decrement

dec r30 ; decrease duty cycle

sts OCR2B, r30 ; update pwm register

rjmp exit\_rpg\_update

exit\_rpg\_update:

rcall move\_cursor\_to\_dc\_addr\_lcd ; move cursor to dc address

rcall convert\_dc\_to\_percentage ; convert pwm to percent

rcall write\_dc\_to\_lcd ; display pwm

rjmp exit\_rpg\_isr

full\_speed\_call:

rcall pwm\_full\_speed

exit\_rpg\_isr:

pop r30

pop r17

pop r16

out SREG, r16

pop r16

reti

;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;

; LCD Display ;

;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;

set\_8\_bit\_mode:

; set 8-bit mode by sending 0011 0000 (this is a subroutine called 3 times to set 8-bit mode)

ldi r17, 0x03

out PORTC, r17

ret

lcd\_strobe:

sbi PORTB, 2 ; set E to high (initiate data transfer)

ldi r27, 0x00

ldi r26, 0x05 ; delay 500us

strobe\_loop:

rcall delay\_100us

sbiw r27:r26, 1

brne strobe\_loop

cbi PORTB, 2 ; set E to low (end of data transfer)

ret

write\_string\_to\_lcd:

lpm r0,Z+ ; start of loaded memory address

tst r0 ; check for terminating character

breq done ; if done, exit

swap r0 ; else, swap nibbles

out PORTC, r0 ; send upper nibble out

rcall lcd\_strobe ; latch nibble

swap r0 ; lower nibble in place

out PORTC,r0 ; send lower nibble out

rcall lcd\_strobe ; latch nibble

rjmp write\_string\_to\_lcd ; continue until done

done:

ret

write\_char1:

push r16

; add 0x30 to r2 and move to r16

ldi r25, 0x30

add r25, r2

mov r16, r25

; mask upper nibble, swap, and send

andi r25, 0xf0

swap r25

out PORTC, r25

rcall lcd\_strobe

rcall delay\_100us

; mask lower nibble, send, and strobe

andi r16, 0x0f

out PORTC, r16

rcall lcd\_strobe

rcall delay\_100us

pop r16

ret

write\_char2:

push r16

; add 0x30 to r1 and move to r16

ldi r25, 0x30

add r25, r1

mov r16, r25

; mask upper nibble, swap, and send

andi r25, 0xf0

swap r25

out PORTC, r25

rcall lcd\_strobe

rcall delay\_100us

; mask lower nibble, send, and strobe

andi r16, 0x0f

out PORTC, r16

rcall lcd\_strobe

rcall delay\_100us

pop r16

ret

write\_char3:

push r16

; load 0x30 into r25 and add r0

ldi r25, 0x30

add r25, r0

mov r16, r25

; mask upper nibble, swap, and send

andi r25, 0xf0

swap r25

out PORTC, r25

rcall lcd\_strobe

rcall delay\_100us

; mask lower nibble, send, and strobe

andi r16, 0x0f

out PORTC, r16

rcall lcd\_strobe

rcall delay\_100us

pop r16

ret

write\_decimal:

; load 0x02 into r25 and send

ldi r25, 0x02

out PORTC,r25

rcall lcd\_strobe

rcall delay\_100us

; load 0x0e into r25 and send

ldi r25,0x0e

out PORTC,r25

rcall lcd\_strobe

rcall delay\_100us

ret

; move cursor to ddram 05 of lcd

move\_cursor\_to\_dc\_addr\_lcd:

cbi PORTB, 5

ldi r17, 0x08

out PORTC, r17

rcall lcd\_strobe

rcall delay\_100us

ldi r17, 0x05 ; move cursor to position 5

out PORTC, r17

rcall lcd\_strobe

rcall delay\_1ms

sbi PORTB, 5

ret

; move cursor to ddram 05 of lcd and display longer string (100.0%)

pwm\_full\_speed:

inc r30

sts OCR2B, r30

rcall move\_cursor\_to\_dc\_addr\_lcd

ldi r16, 1

mov r2, r16

rcall write\_char1

ldi r16, 0

mov r2, r16

rcall write\_char1

rcall write\_char1

rcall write\_decimal

rcall write\_char1

ldi r30,LOW(2 \* suffix\_string) ; "%"

ldi r31,HIGH(2 \* suffix\_string) ; obtain address of suffix string

rcall write\_string\_to\_lcd

exit\_full\_speed:

ldi r16, 3

mov rpg\_accumulator, r16

ret

; move cursor to ddram 45 of lcd

move\_cursor\_to\_onoff\_addr\_lcd:

cbi PORTB, 5

ldi r17, 0x0C

out PORTC, r17

rcall lcd\_strobe

rcall delay\_100us

ldi r17, 0x05 ; move cursor to position 45

out PORTC, r17

rcall lcd\_strobe

rcall delay\_1ms

sbi PORTB, 5

ret

; load address of "ON" in mem for display

fan\_on:

ldi r30,LOW(2 \* on\_string)

ldi r31,HIGH(2 \* on\_string)

rcall write\_string\_to\_lcd

ret

; load address of "OFF" in mem for display

fan\_off:

ldi r30,LOW(2 \* off\_string)

ldi r31,HIGH(2 \* off\_string)

rcall write\_string\_to\_lcd

ret

;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;

; Duty Cycle to LCD Subroutine ;

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; because dc is displayed as a percentage, we need to multiply by 100.

; even though registers are 8 bits and range from 0-255, multiplying 2 8-bit values results in a 16-bit value.

; generally, b \* b = 2b

;

; this is the highest resolution that we need for our application. Because we have valid dc divisor

; values from 0-200 our range of values will not exceed 65535 which is represented in 16-bits (2^16)

;

; Application Note AN\_0936 “AVR200: Multiply and Divide Routines”:

; - mpy16u: r17:r16 <- r17:r16 \* r19:r18

; - div16u: r17:r16 <- r17:r16 / r19:r18

convert\_dc\_to\_percentage:

; operation:

; ocr2b / ocr2a \* 100 = percentage

push r1

push r14

push r15

push r16

push r17

push r18

push r19

push r20

push r21

push r22

lds r16, low(OCR2B)

lds r17, high(OCR2B)

inc r16

; multiply by 100

ldi r18, low(100)

ldi r19, high(100)

rcall mpy16u ; r17:r16 = (OCR2B+1) \* 100

; divide by ocr2a + 1 (max pwm value plus 1, divisor)

ldi r18, low(200)

ldi r19, high(200)

rcall div16u ; r17:r16 = quotient, r15:r14 = remainder

; save quotient for display

ldi r18, low(10)

ldi r19, high(10)

rcall mpy16u

mov dc\_low, r16

mov dc\_high, r17

; multiply remainder by 10 and divide again for decimal place

mov r16, r14

mov r17, r15

ldi r18, low(10)

ldi r19, high(10)

rcall mpy16u ; r17:r16 = remainder \* 10

; divide by 200 again to get decimal place

ldi r18, low(200)

ldi r19, high(200)

rcall div16u ; r17:r16 = decimal place

add dc\_low, r16

adc dc\_high, r1

; r16 now has our decimal digit

mov dc\_low, r28 ; store integer part

mov dc\_high, r29

pop r22

pop r21

pop r20

pop r19

pop r18

pop r17

pop r16

pop r15

pop r14

pop r1

ret

write\_dc\_to\_lcd:

push r0

push r1

push r2

push r14

push r15

push r16

push r17

push r18

push r19

push r20

; get duty cycle

mov r16, dc\_low

mov r17, dc\_high

; divide by 10

ldi r18, low(10)

ldi r19, high(10)

rcall div16u

mov r0, r14

rcall div16u

mov r1, r14

rcall div16u

mov r2, r14

rcall write\_char1

rcall write\_char2

rcall write\_decimal

rcall write\_char3

ldi r30,LOW(2 \* suffix\_string) ; "%"

ldi r31,HIGH(2 \* suffix\_string) ; obtain address of suffix string

rcall write\_string\_to\_lcd;

; this handles case where 100.0% and then decremented to some other value in form xx.x%

; this overwrites the "%" with a space

ldi r30,LOW(2 \* space\_string) ; " "

ldi r31,HIGH(2 \* space\_string) ; obtain address of space string

rcall write\_string\_to\_lcd;

pop r20

pop r19

pop r18

pop r17

pop r16

pop r15

pop r14

pop r2

pop r1

pop r0

ret

; division code taken from ATMEL AVR200.asm

div16u:

clr r14 ;clear remainder Low byte

sub r15, r15;clear remainder High byte and carry

ldi r20, 17 ;init loop counter

d16u\_1:

rol r16 ;shift left dividend

rol r17

dec r20 ;decrement counter

brne d16u\_2 ;if done

ret ; return

d16u\_2:

rol r14 ;shift dividend into remainder

rol r15

sub r14, r18 ;remainder = remainder - divisor

sbc r15, r19 ;

brcc d16u\_3 ;if result negative

add r14, r18 ; restore remainder

adc r15, r19

clc ; clear carry to be shifted into result

rjmp d16u\_1 ;else

d16u\_3:

sec ; set carry to be shifted into result

rjmp d16u\_1

; Multiplication for getting value of 0-999, taken from ATMEL AVR200.asm

; mpy16u: r17:r16 <- r17:r16 \* r19:r18

mpy16u:

clr r21 ;clear 2 highest bytes of result

clr r20

ldi r22,16 ;init loop counter

lsr r19

ror r18

m16u\_1:

brcc noad8 ;if bit 0 of multiplier set

add r20,r16 ;add multiplicand Low to byte 2 of res

adc r21,r17 ;add multiplicand high to byte 3 of res

noad8:

ror r21 ;shift right result byte 3

ror r20 ;rotate right result byte 2

ror r19 ;rotate result byte 1 and multiplier High

ror r18 ;rotate result byte 0 and multiplier Low

dec r22 ;decrement loop counter

brne m16u\_1 ;if not done, loop more

mov r16, r18

mov r17, r19

ret

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; Timer0 Delays ;

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delay\_100ms:

ldi r27, 0x03

ldi r26, 0xE8

loop\_100ms:

rcall delay\_100us

sbiw r27:r26, 1

brne loop\_100ms

ret

delay\_10ms:

ldi r27, 0x00

ldi r26, 0x64

loop\_10ms:

rcall delay\_100us

sbiw r27:r26, 1

brne loop\_10ms

ret

delay\_1ms:

ldi r27, 0x00

ldi r26, 0x0a

loop\_1ms:

rcall delay\_100us

sbiw r27:r26, 1

brne loop\_1ms

ret

delay\_100us:

in tmp1, TCCR0B

ldi tmp2, 0x00

out TCCR0B, tmp2

in tmp2, TIFR0

sbr tmp2, (1 << TOV0)

out TIFR0, tmp2

out TCNT0, count ; reload tcnt0 with count (56)

out TCCR0B, tmp1

wait\_for\_overflow:

in tmp2, TIFR0

sbrs tmp2, TOV0

rjmp wait\_for\_overflow

ret

## 6. Appendix B: References

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