Lab 4: Interrupts, Timers

Learning objectives

The purpose of the laboratory exercise is to understand the function of the interrupt, interrupt service routine, and the functionality of timer units. Another goal is to practice finding information in the MCU manual; specifically setting timer control registers.

Table for given 5 prescaler values.

Module	Number of bits	1	8	32	64	128	256	1024
Timer/Counter0	8	16u	128u	--	1.024m	--	4.096ms	16.384m
Timer/Counter1	16	4.096m	32.786m	--	262m	--	1.048	4.194
Timer/Counter2	8	16u	128u	512u	1.024m	2.048m	4.096m	16.384m

Connection of LEDs and Push Buttons

LED/Button	PORT[pin]
D1	PB5[13]
D2	PB4[12]
D3	PB3[-11]
D4	PB2[-10]
S1-A1	PC1[A1]
S2-A2	PC2[A2]
S3-A3	PC3[A3]

Overview of register for configuration of timer modules

Module	Operation	I/O register(s)	Bit(s)
Timer/Counter0	Prescaler	TCCR0B	CS02, CS01, CS00 (000: stopped, 001: 1, 010: 8, 011: 64, 100: 256, 101: 1024)
	8-bit data value	TCNT0	TCNT[7:0]
	Overflow interrupt enable	TIMSK0	TOIE0 (1: enable, 0: disable)

Module	Operation	I/O register(s)	Bit(s)
Timer/Counter1	Prescaler	TCCR1B	CS12, CS11, CS10 (000: stopped, 001: 1, 010: 8, 011: 64, 100: 256, 101: 1024)
	16-bit data value	TCNT1H, TCNT1L	TCNT1[15:0]
	Overflow interrupt enable	TIMSK1	TOIE1 (1: enable, 0: disable)
Timer/Counter2	Prescaler	TCCR2B	CS22, CS21, CS20 (000: stopped, 001: 1, 010: 8, 011: 32, 100: 64, 101: 128, 110: 256, 111: 1024)
	8-bit data value	TCNT2	TCNT[7:0]
	Overflow interrupt enable	TIMSK2	TOIE2 (1: enable, 0: disable)

Table of interruption sources

Program address	Source	Vector name	Description
0x0000	RESET	--	Reset of the system
0x0002	INT0	`INT0_vect`	External interrupt request number 0
0x0004	INT1	`INT1_vect`	External interrupt request number 1
0x0006	PCINT0	`PCINT0_vect`	Pin change interrupt Request 0
0x0008	PCINT1	`PCINT1_vect`	Pin Change Interrupt Request 1
0x000A	PCINT2	`PCINT2_vect`	Pin Change Interrupt Request 2
0x000C	WDT	--	Watchdog Time-out Interrupt
0x0012	TIMER2_OVF	`TIMER2_OVF_vect`	Timer/counter 2 Overflow
0x0018	TIMER1_COMPB	`TIMER1_COMPB_vect`	Compare match between Timer/Counter1 value and channel B compare value
0x001A	TIMER1_OVF	`TIMER1_OVF_vect`	Overflow of Timer/Counter1 value
0x0020	TIMER0_OVF	`TIMER0_OVF_vect`	Timer/Counter 0 Overflow
0x0024	USART_RX	--	USART Rx Complete
0x002A	ADC	`ADC_vect`	ADC Conversion Complete
0x0030	TWI	`TWI_vect`	2-wire Serial Interface

Table of Arduino pins that can be used to generate PWM signal

Module	Description	MCU pin	Arduino pin
Timer/Counter0	OC0A	PD6	6

Module	Description	MCU pin	Arduino pin
	OC0B	PD5	5
Timer/Counter1	OC1A	PB1	9
	OC1B	PB2	10
Timer/Counter2	OC2A	PB3	11
	OC2B	PD3	3

Listing of library header file `timer.h`

```
/* Defines -----------------------------------------------------------*/
/**
 * @brief Defines prescaler CPU frequency values for Timer/Counter0.
 * @note  F_CPU = 16 MHz
  */
 #define TIM0_stop()             TCCR0B &= ~((1<<CS02) | (1<<CS01) | (1<<CS00));
 #define TIM0_overflow_16us()     TCCR0B &= ~((1<<CS02) | (1<<CS01)); TCCR0B |=
(1<<CS00);
 #define TIM0_overflow_128us()    TCCR0B &= ~((1<<CS02) | (1<<CS00)); TCCR0B |=
(1<<CS01);
 #define TIM0_overflow_1ms()   TCCR0B &= ~(1<<CS02); TCCR0B |= (1<<CS01) |
(1<<CS00);
 #define TIM0_overflow_4ms()      TCCR0B &= ~((1<<CS01) | (1<<CS00)); TCCR0B |=
(1<<CS02);
 #define TIM0_overflow_16ms()      TCCR0B &= ~(1<<CS01); TCCR0B |= (1<<CS02) |
(1<<CS00);
/**
 * @brief Defines interrupt enable/disable modes for Timer/Counter0.
 */
#define TIM0_overflow_interrupt_enable()    TIMSK0 |= (1<<TOIE0);
#define TIM0_overflow_interrupt_disable()   TIMSK0 &= ~(1<<TOIE0);
/**
 * @brief Defines prescaler CPU frequency values for Timer/Counter1.
 * @note  F_CPU = 16 MHz
  */
#define TIM1_stop()             TCCR1B &= ~((1<<CS12) | (1<<CS11) | (1<<CS10));
#define TIM1_overflow_4ms()     TCCR1B &= ~((1<<CS12) | (1<<CS11)); TCCR1B |=
(1<<CS10);
#define TIM1_overflow_33ms()    TCCR1B &= ~((1<<CS12) | (1<<CS10)); TCCR1B |=
(1<<CS11);
#define TIM1_overflow_262ms()   TCCR1B &= ~(1<<CS12); TCCR1B |= (1<<CS11) |
(1<<CS10);
#define TIM1_overflow_1s()      TCCR1B &= ~((1<<CS11) | (1<<CS10)); TCCR1B |=
(1<<CS12);
#define TIM1_overflow_4s()      TCCR1B &= ~(1<<CS11); TCCR1B |= (1<<CS12) |
(1<<CS10);

/**
 * @brief Defines interrupt enable/disable modes for Timer/Counter1.
```

```
 */
#define TIM1_overflow_interrupt_enable()    TIMSK1 |= (1<<TOIE1);
#define TIM1_overflow_interrupt_disable()   TIMSK1 &= ~(1<<TOIE1);

/**
 * @brief Defines prescaler CPU frequency values for Timer/Counter1.
 * @note  F_CPU = 16 MHz
  */
#define TIM2_stop()             TCCR2B &= ~((1<<CS22) | (1<<CS21) | (1<<CS20));
#define TIM2_overflow_16us()     TCCR2B &= ~((1<<CS22) | (1<<CS21)); TCCR2B |=
(1<<CS20);
#define TIM2_overflow_128us()    TCCR2B &= ~((1<<CS22) | (1<<CS20)); TCCR2B |=
(1<<CS21);
#define TIM2_overflow_512us()   TCCR2B &= ~(1<<CS22); TCCR2B |= (1<<CS21) |
(1<<CS20);
#define TIM2_overflow_1ms()   TCCR2B &= ~((1<<CS21) | (1<<CS20)); TCCR2B |=
(1<<CS22);
#define TIM2_overflow_2ms()     TCCR2B &= ~(1<<CS21); TCCR2B |= (1<<CS22) |
(1<<CS20);
#define TIM2_overflow_4ms()      TCCR2B &= ~(1<<CS20); TCCR2B |= (1<<CS22) |
(1<<CS21);
#define TIM2_overflow_16ms()      TCCR2B |= ((1<<CS22) | (1<<CS21) | (1<<CS20));

/**
 * @brief Defines interrupt enable/disable modes for Timer/Counter1.
 */
#define TIM2_overflow_interrupt_enable()    TIMSK2 |= (1<<TOIE2);
#define TIM2_overflow_interrupt_disable()   TIMSK2 &= ~(1<<TOIE2);
#endif
```

Complete code of `main.c`

```
/************************************************************************
 *
 * Control LEDs using functions from GPIO and Timer libraries. Do not
 * use delay library any more.
 * ATmega328P (Arduino Uno), 16 MHz, AVR 8-bit Toolchain 3.6.2
 *
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 * Dept. of Radio Electronics, Brno University of Technology, Czechia
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 *
 ************************************************************************/

/* Defines -----------------------------------------------------------*/
#define LED_D1  PB5
#define LED_D2  PB4
#define LED_D3  PB3

/* Includes ----------------------------------------------------------*/
#include <avr/io.h>         // AVR device-specific IO definitions
```
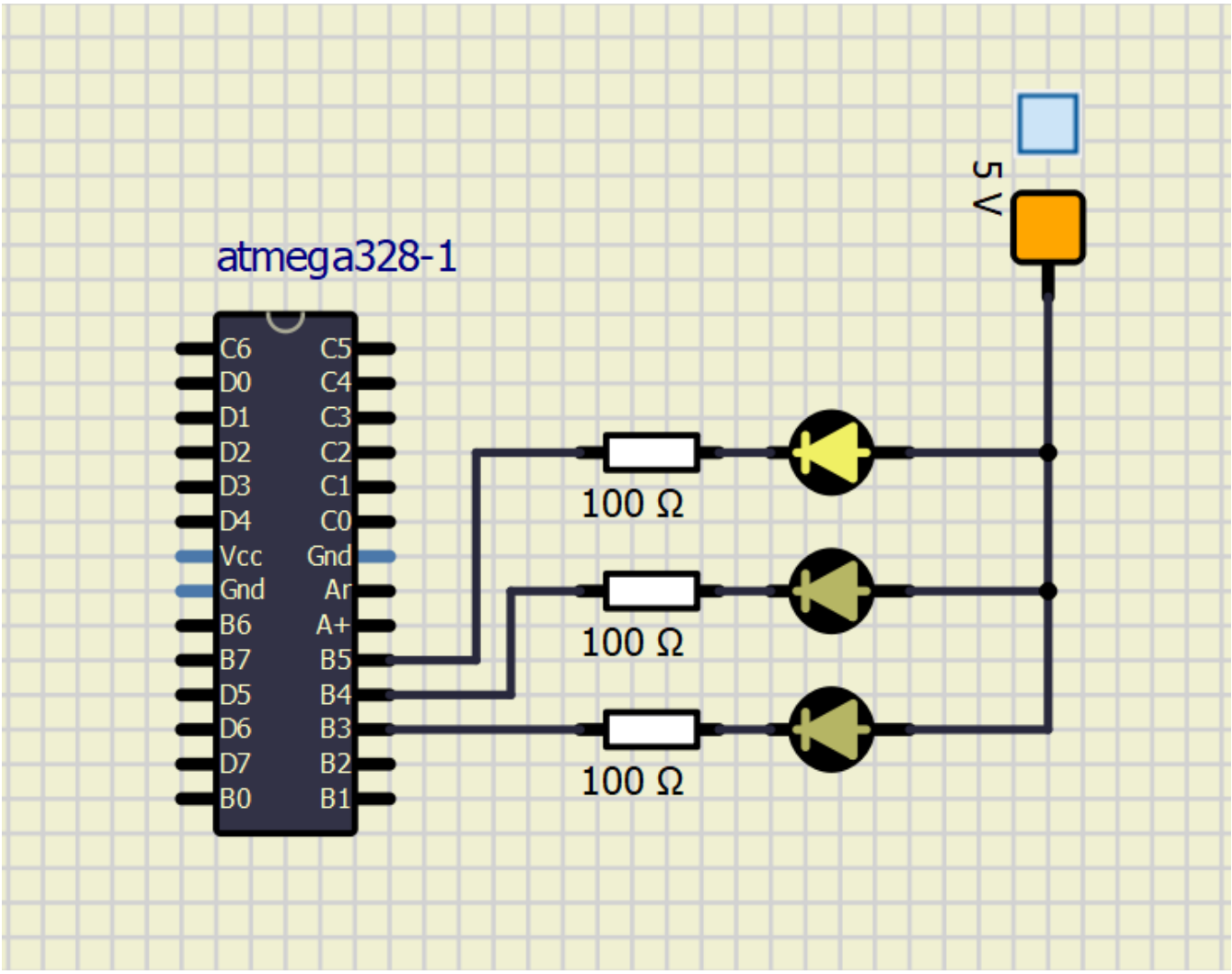

```
#include <avr/interrupt.h>  // Interrupts standard C library for AVR-GCC
#include "gpio.h"           // GPIO library for AVR-GCC
#include "timer.h"          // Timer library for AVR-GCC

/* Function definitions ----------------------------------------------*/
/**
 * Main function where the program execution begins. Toggle three LEDs
 * on Multi-function shield with internal 8- and 16-bit timer modules.
 */
int main(void)
{
    /* Configuration of three LEDs */

    GPIO_config_output(&DDRB, LED_D1);
    GPIO_write_low(&PORTB, LED_D1);
    GPIO_config_output(&DDRB, LED_D2);
    GPIO_write_low(&PORTB, LED_D2);
    GPIO_config_output(&DDRB, LED_D3);
    GPIO_write_low(&PORTB, LED_D3);

    /* Configuration of 8-bit Timer/Counter0 */
    TIM0_overflow_16ms();
    TIM0_overflow_interrupt_enable();

    /* Configuration of 16-bit Timer/Counter1
     * Set prescaler and enable overflow interrupt */
    TIM1_overflow_262ms();
    TIM1_overflow_interrupt_enable();

    /* Configuration of 8-bit Timer/Counter2 */
    TIM2_overflow_4ms();
    TIM2_overflow_interrupt_enable();

    // Enables interrupts by setting the global interrupt mask
    sei();

    // Infinite loop
    while (1)
    {
        /* Empty loop. All subsequent operations are performed exclusively
         * inside interrupt service routines ISRs */
    }

    // Will never reach this
    return 0;
}

/* Interrupt service routines ----------------------------------------*/
/**
 * ISR starts when Timer/Counter1 overflows. Toggle LED D2 on
 * Multi-function shield. */
ISR(TIMER1_OVF_vect)
{
    GPIO_toggle(&PORTB, LED_D1);
```

```
}
ISR(TIMER0_OVF_vect)
{
    GPIO_toggle(&PORTB, LED_D2);
}
ISR(TIMER2_OVF_vect)
{
    GPIO_toggle(&PORTB, LED_D3);
}
```

Screenshot of SimulIDE:



Difference between a regular C function and interrupt service routine

Firstly, a common C function has determined conditions for it to be called, whereas ISR is called at anytime, when a hardware interrupt occurs. ISRs are controlled by a coprocessor. When a coprocessor registers a hardware input, it allerts the processor via kernel service which saves its current state for later and executes the related interrupt code. Then the main processor countinues in its previous task. Also ISRs do not, on opposition to common functions, return values and also cannot have arguments passed on them.

8-bit Timer Counter0 with PWM - Modes of Operation

Normal Mode

In this mode, the counter is always incrementing without clearing itself (in other words repeats itself). The TOV0 flag sets itself, when counter becomes zero (acts as a ninth bit), thus it doesn't reset itself. Reseting the flag can be accomplished by combining with the timer overflow interrupt.

Clear Timer on Compare Match (CTC) Mode

The resolution of the timer is set by OCR0A register value. The timer resets, when its value matches mentioned registers value.

Fast PWM Mode

Option suitable for a high frequency PWM waveform generation. The counter counts form BOTTOM value and restarts at the TOP value back to BOTTOM. Value of TOP depends on WGM2:0 value. Fastest of all, suitable for power regulation, rectification and DAC applications.

Phase Correct PWM Mode

Provides a high resolution phase correct PWM waveform generation based on dual-slope operation. Based on the polarity of wave formation (inverted *x* non-inverted) increments from BOTTOM to TOP and decrements from TOP to BOTTOM or the other way around.