Ali Tejani, amt3639
Caroline Yao, chy253

Lab 3 Preparation

1. Overview

1.1. Objectives: Why are we doing this project? What is the purpose?

The objectives of this project are to design, build and test an alarm clock. Educationally, students are learning how to design and test modular software and how to perform switch input in the background.

1.2. Process: How will the project be developed?

The project will be developed using the TM4C123 board. There will be switches and a variable resistor. The system will be built on a solderless breadboard and run on the usual USB power. The system may use the on board switches and/or the on board LEDs. Alternatively, the system may include external switches. The speaker will be external. There will be at least four hardware/software modules: switch/keypad input, time management, LCD graphics, and sound output. The process will be to design and test each module independently from the other modules. After each module is tested, the system will be built and tested.

1.3. Roles and Responsibilities: Who will do what? Who are the clients?

EE445L students are the engineers and the TA is the client. Students are expected to modify this document to clarify exactly what they plan to build. Students are allowed to divide responsibilities of the project however they wish, but, at the time of demonstration, both students are expected to understand all aspects of the design.

1.4. Interactions with Existing Systems: How will it fit in?

The system will use the TM4C123 board, a ST7735 color LCD, a solderless breadboard, and be powered using the USB cable.

1.5. Terminology: Define terms used in the document.

Power budget: estimate of operation time of a battery powered system by dividing energy storage by average current required to run the system

Device driver: A collection of software routines that perform IO functions

Critical section: Locations in a software module, which if an interrupt were to occur at one of these locations, an error would occur

Latency: Response time of a computer to external events

Time jitter: Noise in time measurement

Modular programming: Style of software development that divides the software problem into distinct and independent modules

1.6. Security: How will intellectual property be managed?

The system may include software from Tivaware and from the book. No software written for this project may be transmitted, viewed, or communicated with any other EE445L student past, present, or future (other than the lab partner of course). It is the responsibility of the team to keep its EE445L lab solutions secure.

2. Function Description

2.1. Functionality: What will the system do precisely?

The clock must be able to perform five functions. 1) It will display hours and minutes in both graphical and numeric forms on the LCD. The graphical output will include the 12 numbers around a circle, the hour hand, and the minute hand. The numerical output will be easy to read. 2) It will allow the operator to set the current time using switches or a keypad. 3) It will allow the operator to set the alarm time including enabling/disabling alarms. 4) It will make a sound at the alarm time. 5) It will allow the operator to stop the sound. An LED heartbeat will show when the system is running.

2.2. Scope: List the phases and what will be delivered in each phase.

Phase 1 is the preparation; phase 2 is the demonstration; and phase 3 is the lab report. Details can be found in the lab manual.

2.3. Prototypes: How will intermediate progress be demonstrated?

A prototype system running on the TM4C123 board, ST7735 color LCD, and solderless breadboard will be demonstrated. Progress will be judged by the preparation, demonstration and lab report.

2.4. Performance: Define the measures and describe how they will be determined.

The system will be judged by three qualitative measures. First, the software modules must be easy to understand and well-organized. Second, the clock display should be beautiful and effective in telling time. Third, the operation of setting the time and alarm should be simple and intuitive. The system should not have critical sections. All shared global variables must be identified with documentation that a critical section does not exist. Backward jumps in the ISR should be avoided if possible. The interrupt service routine used to maintain time must complete in as short a time as possible. This means all LCD I/O occurs in the main program. The average current on the +5V power will be measured with and without the alarm sounding.

2.5. Usability: Describe the interfaces. Be quantitative if possible.

There will be two to four switch inputs. In the main menu, the switches can be used to activate 1) set time; 2) set alarm; 3) turn on/off alarm; and 4) display mode. The user should be able to set the time (hours, minutes) and be able to set the alarm (hour, minute) using the variable resistor. After some amount of inactivity the system reverts to the main menu. The user should be about to control some aspects of the display configuring the look and feel of the device. The switches MUST be debounced, so only one action occurs when the operator touches a switch once.

The LCD display shows the time using graphical display typical of a standard on the wall clock. The 12 numbers, the minute hand, and the hour hand are large and easy to see. The clock can also display the time in numeric mode using numbers.

The alarm sound can be a simple square wave. The sound amplitude will be just loud enough for the TA to hear when within 3 feet.

2.6. Safety: Explain any safety requirements and how they will be measured.

The alarm sound will be VERY quiet in order to respect other people in the room during testing. Connecting or disconnecting wires on the protoboard while power is applied may damage the board.

3. Deliverables

3.1. Reports: How will the system be described?

A lab report described below is due by the due date listed in the syllabus. This report includes the final requirements document.

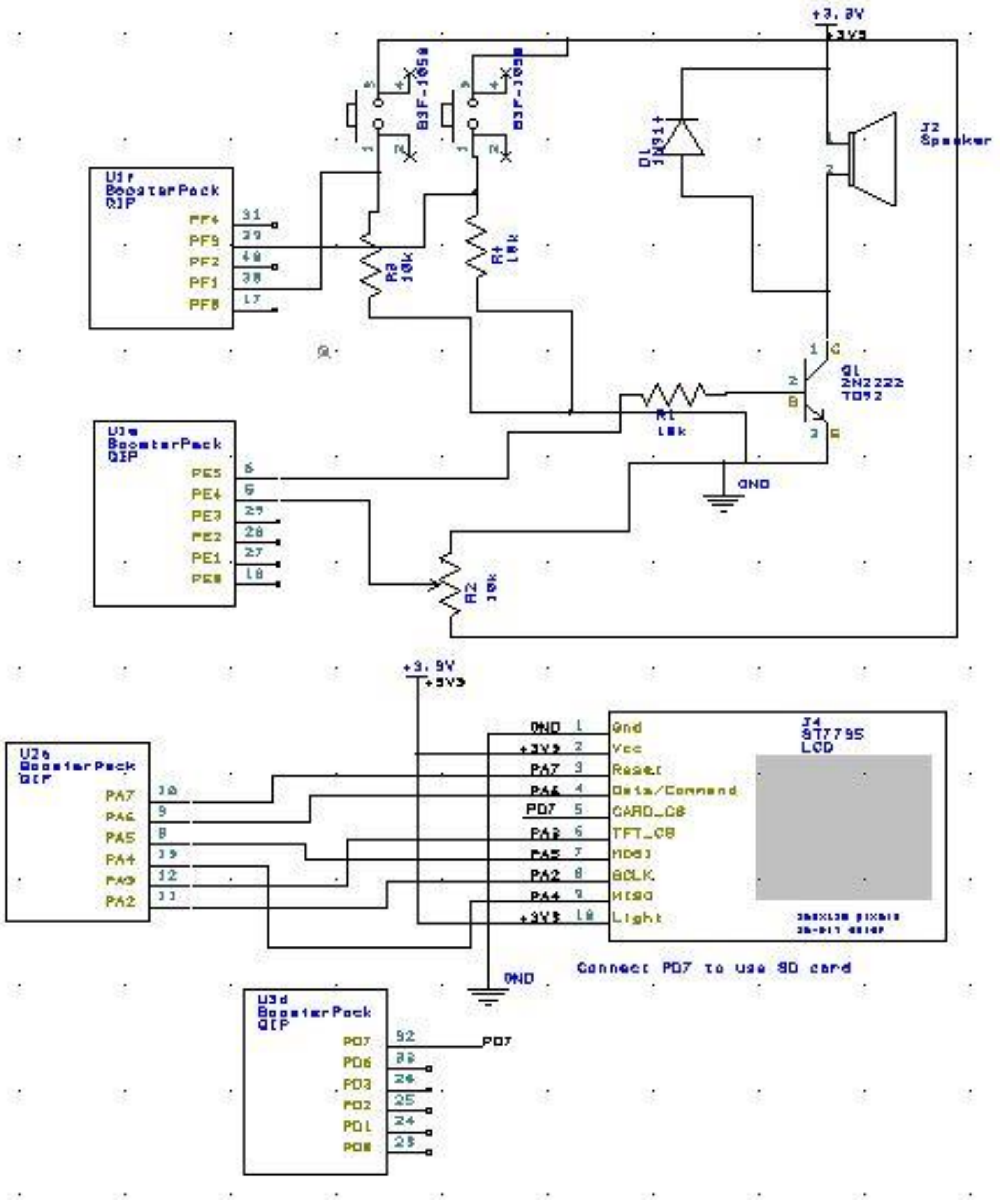
3.2. Audits: How will the clients evaluate progress?

The preparation is due at the beginning of the lab period on the date listed in the syllabus.

3.3. Outcomes: What are the deliverables? How do we know when it is done?

There are three deliverables: preparation, demonstration, and report.

PCB Circuit


+3.3V
+3V3
B3F-1050
B3F-1050
D1
1N914
J2
Speaker
U1f
BoosterPack
DIP
PF4
PF3
PF2
PF1
PF0
31
39
40
38
17
R3
10k
R4
10k
1 C
Q1
2N2222
TO92
2 B
3 E
R1
10k
GND
U1e
BoosterPack
DIP
PE5
PE4
PE3
PE2
PE1
PE0
6
5
29
28
27
18
R2
10k
+3.3V
+3V3
U2a
BoosterPack
DIP
PA7
PA6
PA5
PA4
PA3
PA2
10
9
8
13
12
11
GND
+3V3
PA7
PA6
PD7
PA3
PA5
PA2
PA4
+3V3
1 Gnd
2 Vcc
3 Reset
4 Data/Command
5 CARD_CS
6 TFT_CS
7 MOSI
8 SCLK
9 MISO
10 Light
J4
ST7735
LCD
160X128 pixels
16-bit color
Connect PD7 to use SD card
GND
U3d
BoosterPack
DIP
PD7
PD6
PD3
PD2
PD1
PD0
32
33
24
25
24
23
PD7

```c
// ******** ClockMain.c **************
// Ali Tejani and Caroline Yao
// amt3639 and chy253
// Creation Date: 2/8/2017
// Main to test modules for clock
// Runs on TM4C123
// Lab section: Tue/Thur 12:30 - 2 PM
// TA: Lavanya
// Last Revision: 2/9/2017


#include <stdint.h>
#include "ST7735.h"
#include "PLL.h"
#include "SysTickDriver.h"
#include "SpeakerDriver.h"
#include "ST7735.h"
#include "SwitchDriver.h"
#include "ADCSWTrigger.h"
#include "../inc/tm4c123gh6pm.h"

// state values
const uint32_t DISPLAY_CLOCK = 0;
const uint32_t SET_TIME_HOUR = 1;
const uint32_t SET_TIME_MINUTE = 2;
const uint32_t SET_ALARM_HOUR = 3;
const uint32_t SET_ALARM_MINUTE = 4;

static uint32_t State = DISPLAY_CLOCK;              // current state
static uint32_t AlarmOn = 0;                                          // 1 if alarm is on
static uint32_t AlarmTime = 0;                                        // time of alarm
static volatile uint32_t ADCValue = 0;              // adc value
extern uint32_t AtomicTime;                                                // current time

// start set time state, or move to next state
void button1SetTime(void) {
	if(State != SET_TIME_HOUR && State != SET_TIME_MINUTE) {
		State = SET_TIME_HOUR;
	} else {
		State = DISPLAY_CLOCK;
	}
}

// start set alarm state, or move to next state
void button2SetAlarm(void) {
	if(State != SET_ALARM_HOUR && State != SET_ALARM_MINUTE) {
			State = SET_ALARM_HOUR;
		} else {
			State = DISPLAY_CLOCK;
		}
	}

	// enable/disable alarm
	void buttton3ToggleAlarm(void) {
		AlarmOn = 1 - AlarmOn;
	}

	// move to next state
	void button4ChangeMode(void) {
		if(State == SET_TIME_HOUR) {
			State = SET_TIME_MINUTE;
		} else if(State == SET_TIME_MINUTE) {
			State = DISPLAY_CLOCK;
			// set AtomicTime
		} else if(State == SET_ALARM_HOUR) {
			State = SET_ALARM_MINUTE;
		} else if(State == SET_ALARM_MINUTE) {
			State = DISPLAY_CLOCK;
			// set AlarmTime
		}
	}

	// draw clock and lines
	void drawClock(char* title, uint32_t time) {
		// clear old values

		// draw title
		ST7735_SetCursor(0,0);
		ST7735_OutString(title);
		ST7735_OutString("\rAlarm ");
		if(AlarmOn) {
			ST7735_OutString("On");
		} else {

		ST7735_OutString("Off");
		}
		// draw analog clock face
		// draw digital clock
		ST7735_OutUDec(time/100);
		ST7735_OutString(":");
		ST7735_OutUDec(time%100);
```

```
}

int main(void) {
	PLL_Init(Bus80MHz);					// init modules
	SysTick_Init();
	Speaker_Init();
	ST7735_InitR(INITR_REDTAB);
	Switch_Init(button1SetTime, button2SetAlarm, buttton3ToggleAlarm,
			button4ChangeMode);
	ADC0_InitSWTriggerSeq3_Ch9();

	while(1) {
		uint32_t time = AtomicTime;
		if(State == DISPLAY_CLOCK) {		// draw clock with time from systick
			drawClock("Clock", time);
		} else if(State == SET_TIME_HOUR) {	// draw clock with time from start
time

							// from systick offset by adc
			// sample adc
			uint32_t hour = ADCValue / 24;
			time = hour *100 + time%100;
			drawClock("Set Time - Hours", time);
		} else if(State == SET_TIME_MINUTE) {	// draw clock with time from start
time

							// from systick offset by adc
			// sample adc
			uint32_t minute = ADCValue / 60;
			time = time /100 + minute;
			drawClock("Set Time - Minutes",time);
		} else if(State == SET_ALARM_HOUR) {	// draw clock with alarm time offset
by adc
			uint32_t hour = ADCValue / 24;
			time = hour /100 + AlarmTime%100;
			drawClock("Set Alarm - Hours",time);
		} else if(State == SET_ALARM_MINUTE) {		// draw clock with alarm time
offset by adc
			uint32_t minute = ADCValue / 60;
			time = AlarmTime /100 + minute;
			drawClock("Set Alarm - Minutes",time);
		}
	}
}
```

```
// ******** SysTickDriver.h **************
// Ali Tejani and Caroline Yao
// amt3639 and chy253
// Creation Date: 2/8/2017
// Creates a clock timer which increments every second
// Runs on TM4C123
// Lab section: Tue/Thur 12:30 - 2 PM
// TA: Lavanya
// Last Revision: 2/9/2017


#ifndef __SYSTICKDRIVER_H__ // do not include more than once
#define __SYSTICKDRIVER_H__

// **************SysTick_Init*********************
// Initialize Systick periodic interrupts
// Input: interrupt period
//        Units of period are 12.5ns (assuming 80 MHz clock)
//        Maximum is 2^24-1
//        Minimum is determined by lenght of ISR
// Output: none
void SysTick_Init(void);

// **************SysTick_Handler******************
// Interrupt service routine
// increment seconds, minutes, and hours at appropriate time
// Executed every second
void SysTick_Handler(void);

#endif // __SYSTICKINTS_H__
```

```
// ******** SysTickDriver.c **************
// Ali Tejani and Caroline Yao
// amt3639 and chy253
// Creation Date: 2/8/2017
// Creates a clock timer which increments every second
// Runs on TM4C123
// Lab section: Tue/Thur 12:30 - 2 PM
// TA: Lavanya
// Last Revision: 2/9/2017


/* This example accompanies the book
   "Embedded Systems: Real Time Interfacing to Arm Cortex M Microcontrollers",
   ISBN: 978-1463590154, Jonathan Valvano, copyright (c) 2015

 Copyright 2015 by Jonathan W. Valvano, valvano@mail.utexas.edu
    You may use, edit, run or distribute this file
    as long as the above copyright notice remains
 THIS SOFTWARE IS PROVIDED "AS IS".  NO WARRANTIES, WHETHER EXPRESS, 
IMPLIED
 OR STATUTORY, INCLUDING, BUT NOT LIMITED TO, IMPLIED WARRANTIES OF
 MERCHANTABILITY AND FITNESS FOR A PARTICULAR PURPOSE APPLY TO THIS 
SOFTWARE.
 VALVANO SHALL NOT, IN ANY CIRCUMSTANCES, BE LIABLE FOR SPECIAL, 
INCIDENTAL,
 OR CONSEQUENTIAL DAMAGES, FOR ANY REASON WHATSOEVER.
 For more information about my classes, my research, and my books, see
 http://users.ece.utexas.edu/~valvano/
 */


#include <stdint.h>
#include "../inc/tm4c123gh6pm.h"
#include "SysTickDriver.h"

#define PF2             (*((volatile uint32_t *)0x40025010))

static uint32_t Seconds;
static uint32_t Minutes;
static uint32_t Hours;
volatile uint32_t AtomicTime;

void DisableInterrupts(void); // Disable interrupts
void EnableInterrupts(void);  // Enable interrupts
long StartCritical (void);    // previous I bit, disable interrupts
void EndCritical(long sr);    // restore I bit to previous value
void WaitForInterrupt(void);  // low power mode

// **************SysTick_Init*********************
// Initialize SysTick periodic interrupts
// Input: interrupt period
//        Units of period are 12.5ns (assuming 50 MHz clock)
//        Maximum is 2^24-1
//        Minimum is determined by length of ISR
// Output: none
void SysTick_Init(){long sr;
  sr = StartCritical();
  NVIC_ST_CTRL_R = 0;         // disable SysTick during setup
  NVIC_ST_RELOAD_R = 79999999;// reload value
  NVIC_ST_CURRENT_R = 0;      // any write to current clears it
  NVIC_SYS_PRI3_R = (NVIC_SYS_PRI3_R&0x00FFFFFF)|0x40000000; // priority 2
                              // enable SysTick with core clock and interrupts
  NVIC_ST_CTRL_R = 0x07;
        Seconds = 0;
        Minutes = 0;
        Hours = 0;
        AtomicTime = 0;
  EndCritical(sr);
}



// **************SysTick_Handler******************
// Interrupt service routine
// increment seconds, minutes, and hours at appropriate time
// Executed every second
void SysTick_Handler(void) {
        PF2 ^= 0x04; // heartbeat
        Seconds = (Seconds + 1) % 60;           // increment seconds
        if (Seconds == 0) {
                Minutes = (Minutes + 1) % 60;   // increment minutes if 60 seconds have
passed
                if(Minutes == 0) {
                        Hours = (Hours + 1) % 24;       // increment hours if 60 minutes have
passed
                }
        }
        AtomicTime = Hours*100 + Minutes;
}
```

```
// ******** SpeakerDriver.h **************
// Ali Tejani and Caroline Yao
// amt3639 and chy253
// Creation Date: 2/8/2017
// Driver to interface with speaker
// Runs on TM4C123
// Lab section: Tue/Thur 12:30 - 2 PM
// TA: Lavanya
// Last Revision: 2/9/2017


#ifndef __SPEAKERDRIVER_H__ // do not include more than once
#define __SPEAKERDRIVER_H__

// initialize PE5 to output pulse to speaker
// start timer to play A note
void Speaker_Init(void);

// toggles value at PE5, creating square wave
void Timer2A_Handler(void);


#endif // __SPEAKERDRIVER_H__
```

```
// ******** SpeakerDriver.c **************
// Ali Tejani and Caroline Yao
// amt3639 and chy253
// Creation Date: 2/8/2017
// Driver to interface with speaker
// Runs on TM4C123
// Lab section: Tue/Thur 12:30 - 2 PM
// TA: Lavanya
// Last Revision: 2/9/2017

#include "../inc/tm4c123gh6pm.h"
#include <stdint.h>
#include "SpeakerDriver.h"

#define PE5             (*((volatile uint32_t *)0x40024080))

void DisableInterrupts(void);           // Disable interrupts
void EnableInterrupts(void);            // Enable interrupts
long StartCritical (void);              // previous I bit, disable interrupts
void EndCritical(long sr);              // restore I bit to previous value
void WaitForInterrupt(void);                    // low power mode

// starts timer 2 and interrupts
// sets timer to play A note
static void Timer2_Init(void){
  volatile uint32_t delay;
  DisableInterrupts();
  // **** general initialization ****
  SYSCTL_RCGCTIMER_R |= 0x04;      // activate timer0
  delay = SYSCTL_RCGCTIMER_R;      // allow time to finish activating
  TIMER2_CTL_R &= ~TIMER_CTL_TAEN; // disable timer0A during setup
  TIMER2_CFG_R = 0;               // configure for 32-bit timer mode
  // **** timer0A initialization ****
                              // configure for periodic mode
  TIMER2_TAMR_R = TIMER_TAMR_TAMR_PERIOD;
  TIMER2_TAILR_R = 90908;        // start value for 880 Hz interrupts
  TIMER2_IMR_R |= TIMER_IMR_TATOIM;// enable timeout (rollover) interrupt
  TIMER2_ICR_R = TIMER_ICR_TATOCINT;// clear timer0A timeout flag
  TIMER2_CTL_R |= TIMER_CTL_TAEN;  // enable timer0A 32-b, periodic, interrupts
  // **** interrupt initialization ****
                              // Timer2=priority 1
  NVIC_PRI5_R = (NVIC_PRI5_R&0x00FFFFFF)|0x20000000; // top 3 bits
  NVIC_EN0_R = 1<<23;             // enable interrupt 19 in NVIC
}

// initialize PE5 to output pulse to speaker
// start timer
void Speaker_Init(void) {
  volatile unsigned long delay;
        SYSCTL_RCGCGPIO_R  |= 0x00000010;        // enable port E
        delay              = SYSCTL_RCGCGPIO_R;
        GPIO_PORTE_DIR_R   |= 0x20;              // Make PE5 in
        GPIO_PORTE_AFSEL_R &= ~0x20;             // Disable Alternate Function on PE5
        GPIO_PORTE_DEN_R   |= 0x20;              // Enable digital I/O for PE5
        GPIO_PORTE_AMSEL_R &= ~0x20;             // Disable analog functionality
        Timer2_Init();
}


// toggles value at PE5, creating square wave
void Timer2A_Handler(void) {
        TIMER2_ICR_R = 0x01; // acknowledge timer2a timeout
        PE5 ^= 0x20;
}
```

```
// ******** SwitchDriver.h **************
// Ali Tejani and Caroline Yao
// amt3639 and chy253
// Creation Date: 2/8/2017
// Driver to interface with speaker
// Runs on TM4C123
// Lab section: Tue/Thur 12:30 - 2 PM
// TA: Lavanya
// Last Revision: 2/9/2017


// Initialize switch interface on PF4
// Inputs:  pointer to a function to call on touch (falling edge),
//          pointer to a function to call on release (rising edge)
// Outputs: none
void Switch_Init(void(*button1Task)(void), void(*button2Task)(void),
                                void(*button3Task)(void), void(*button4Task)(void));

// Interrupt on rising or falling edge of PF4 (CCP0)
void GPIOPortF_Handler(void);

// Interrupt 10 ms after rising edge of PF4
void Timer0A_Handler(void);

// Wait for switch to be pressed
// There will be minimum time delay from touch to when this function returns
// Inputs:  none
// Outputs: none
void Switch_WaitPress1(void);

// Wait for switch to be released
// There will be minimum time delay from release to when this function returns
// Inputs:  none
// Outputs: none
void Switch_WaitRelease1(void);

// Wait for switch to be pressed
// There will be minimum time delay from touch to when this function returns
// Inputs:  none
// Outputs: none
void Switch_WaitPress2(void);

// Wait for switch to be released
// There will be minimum time delay from release to when this function returns
// Inputs:  none
// Outputs: none
```

```
void Switch_WaitRelease2(void);

// Wait for switch to be pressed
// There will be minimum time delay from touch to when this function returns
// Inputs:  none
// Outputs: none
void Switch_WaitPress3(void);

// Wait for switch to be released
// There will be minimum time delay from release to when this function returns
// Inputs:  none
// Outputs: none
void Switch_WaitRelease3(void);

// Wait for switch to be pressed
// There will be minimum time delay from touch to when this function returns
// Inputs:  none
// Outputs: none
void Switch_WaitPress4(void);

// Wait for switch to be released
// There will be minimum time delay from release to when this function returns
// Inputs:  none
// Outputs: none
void Switch_WaitRelease4(void);
```

```
// ******** SwitchDriver.c **************
// Ali Tejani and Caroline Yao
// amt3639 and chy253
// Creation Date: 2/8/2017
// Driver to interface with speaker
// Runs on TM4C123
// Lab section: Tue/Thur 12:30 - 2 PM
// TA: Lavanya
// Last Revision: 2/9/2017

/* This example accompanies the book
   "Embedded Systems: Real Time Interfacing to Arm Cortex M Microcontrollers",
   ISBN: 978-1463590154, Jonathan Valvano, copyright (c) 2015

 Copyright 2015 by Jonathan W. Valvano, valvano@mail.utexas.edu
    You may use, edit, run or distribute this file
    as long as the above copyright notice remains
 THIS SOFTWARE IS PROVIDED "AS IS".  NO WARRANTIES, WHETHER EXPRESS,
IMPLIED
 OR STATUTORY, INCLUDING, BUT NOT LIMITED TO, IMPLIED WARRANTIES OF
 MERCHANTABILITY AND FITNESS FOR A PARTICULAR PURPOSE APPLY TO THIS
SOFTWARE.
 VALVANO SHALL NOT, IN ANY CIRCUMSTANCES, BE LIABLE FOR SPECIAL,
INCIDENTAL,
 OR CONSEQUENTIAL DAMAGES, FOR ANY REASON WHATSOEVER.
 For more information about my classes, my research, and my books, see
 http://users.ece.utexas.edu/~valvano/
 */

// PF4 connected to a negative logic switch using internal pull-up (trigger on both edges)
#include <stdint.h>
#include "SwitchDriver.h"
#include "../inc/tm4c123gh6pm.h"
#define PF0                     (*((volatile uint32_t *)0x40025004))
#define PF1
            (*((volatile uint32_t *)0x40025008))
#define PF3                     (*((volatile uint32_t *)0x40025020))
#define PF4                     (*((volatile uint32_t *)0x40025040))
void DisableInterrupts(void); // Disable interrupts
void EnableInterrupts(void);  // Enable interrupts
long StartCritical (void);    // previous I bit, disable interrupts
void EndCritical(long sr);    // restore I bit to previous value
void WaitForInterrupt(void);  // low power mode

volatile static unsigned long Touch1;     // true on touch button 1
volatile static unsigned long Release1;   // true on release button 1
volatile static unsigned long Touch2;     // true on touch button 2
volatile static unsigned long Release2;   // true on release button 2
volatile static unsigned long Touch3;     // true on touch button 3
volatile static unsigned long Release3;   // true on release button 3
volatile static unsigned long Touch4;     // true on touch button 4
volatile static unsigned long Release4;   // true on release button 4
volatile static unsigned long Last;      // previous
void (*Button1Task)(void);    // user function to be executed on button 1 touch
void (*Button2Task)(void);    // user function to be executed on button 2 touch
void (*Button3Task)(void);    // user function to be executed on button 3 touch
void (*Button4Task)(void);    // user function to be executed on button 4 touch

// arm timer 0 to time 10ms in oneshot mode
static void Timer0Arm(void){
  TIMER0_CTL_R = 0x00000000;    // 1) disable TIMER0A during setup
  TIMER0_CFG_R = 0x00000000;    // 2) configure for 32-bit mode
  TIMER0_TAMR_R = 0x0000001;    // 3) 1-SHOT mode
  TIMER0_TAILR_R = 160000;      // 4) 10ms reload value
  TIMER0_TAPR_R = 0;            // 5) bus clock resolution
  TIMER0_ICR_R = 0x00000001;    // 6) clear TIMER0A timeout flag
  TIMER0_IMR_R = 0x00000001;    // 7) arm timeout interrupt
  NVIC_PRI4_R = (NVIC_PRI4_R&0x00FFFFFF)|0x80000000; // 8) priority 4
// interrupts enabled in the main program after all devices initialized
// vector number 35, interrupt number 19
  NVIC_EN0_R = 1<<19;           // 9) enable IRQ 19 in NVIC
  TIMER0_CTL_R = 0x00000001;    // 10) enable TIMER0A
}

// arm gpio interrupts
static void GPIOArm(void){
  GPIO_PORTF_ICR_R = 0x1B;      // (e) clear flag4
  GPIO_PORTF_IM_R |= 0x1B;      // (f) arm interrupt on PF4 *** No IME bit as mentioned in
Book ***
  NVIC_PRI7_R = (NVIC_PRI7_R&0xFF00FFFF)|0x00A00000; // (g) priority 5
  NVIC_EN0_R = 0x40000000;      // (h) enable interrupt 30 in NVIC
}
// Initialize switch interface on PF4,3,1,0
// Inputs:  pointer to a function to call on touch (falling edge),
//          pointer to a function to call on release (rising edge)
// Outputs: none
void Switch_Init(void(*button1Task)(void), void(*button2Task)(void),
                                  void(*button3Task)(void), void(*button4Task)(void)){
  // **** general initialization ****
  SYSCTL_RCGCGPIO_R |= 0x00000020; // (a) activate clock for port F
  while((SYSCTL_PRGPIO_R & 0x00000020) == 0){};
  GPIO_PORTF_DIR_R &= ~0x1B;    // (c) make PF4 in (built-in button)
  GPIO_PORTF_AFSEL_R &= ~0x1B;  //     disable alt funct on PF4,3,1,0
  GPIO_PORTF_DEN_R |= 0x1B;     //     enable digital I/O on PF4,3,1,0
  GPIO_PORTF_PCTL_R &= ~0x000FF0FF; // configure PF4 as GPIO
  GPIO_PORTF_AMSEL_R = 0;       //     disable analog functionality on PF
  GPIO_PORTF_PUR_R |= 0x11;     //     enable weak pull-up on PF4, pf1
  GPIO_PORTF_IS_R &= ~0x1B;     // (d) PF4 is edge-sensitive
  GPIO_PORTF_IBE_R |= 0x1B;     //     PF4 is both edges
  GPIOArm();

  SYSCTL_RCGCTIMER_R |= 0x01;   // 0) activate TIMER0
        Button1Task = button1Task;          // user defined methods
        Button2Task = button2Task;
        Button3Task = button3Task;
        Button4Task = button4Task;
  Touch1 = 0;               // touch and release signals
  Release1 = 0;
  Touch2 = 0;
  Release2 = 0;
  Touch3 = 0;
  Release3 = 0;
  Touch4 = 0;
  Release4 = 0;
  Last = PF4 | PF3 | PF1 | PF0;     // initial switch state
 }
// Interrupt on rising or falling edge of PF4 (CCP0)
void GPIOPortF_Handler(void){
  GPIO_PORTF_IM_R &= ~0x10;     // disarm interrupt on PF4
        if(Last & 0x10) {
                Touch4 = 1;
        } else {
                Release4 = 1;
        }
        if(Last & 0x8) {
                Touch3 = 1;
        } else {
                Release3 = 1;
        }
        if(Last & 0x2) {
                Touch2 = 1;
        } else if(!(Last & 0x2)) {
                Release2 = 1;
        }
        if(Last & 0x1) {
                Touch1 = 1;
        } else {
                Release1 = 1;
        }
  if(Last == 0x10){                    // button 4 press
    (*Button1Task)();                  // execute user task
  } else if(Last == 0x8){   // button 3 press
    (*Button2Task)();                  // execute user task
  } else if(Last == 0x2){   // button 2 press
    (*Button3Task)();                  // execute user task
  } else if(Last == 0x1){   // button 1 press
    (*Button4Task)();                  // execute user task
  }
  Timer0Arm(); // start one shot
}
// Interrupt 10 ms after rising edge of PF4
void Timer0A_Handler(void){
  TIMER0_IMR_R = 0x00000000;    // disarm timeout interrupt
  Last = PF4 | PF3 | PF1 | PF0;  // switch state
  GPIOArm();   // start GPIO
}

// Wait for switch to be pressed
// There will be minimum time delay from touch to when this function returns
// Inputs:  none
// Outputs: none
void Switch1_WaitPress(void){
  while(Touch1==0){}; // wait for press
  Touch1 = 0;  // set up for next time
}

// Wait for switch to be released
// There will be minimum time delay from release to when this function returns
// Inputs:  none
// Outputs: none
void Switch1_WaitRelease(void){
  while(Release1==0){}; // wait
  Release1 = 0; // set up for next time
}

// Wait for switch to be pressed
// There will be minimum time delay from touch to when this function returns
// Inputs:  none
// Outputs: none
void Switch2_WaitPress(void){
  while(Touch2==0){}; // wait for press
  Touch2 = 0;  // set up for next time
}
```

```
// Wait for switch to be released
// There will be minimum time delay from release to when this function returns
// Inputs:  none
// Outputs: none
void Switch2_WaitRelease(void){
  while(Release2==0){}; // wait
  Release2 = 0; // set up for next time
}

// Wait for switch to be pressed
// There will be minimum time delay from touch to when this function returns
// Inputs:  none
// Outputs: none
void Switch3_WaitPress(void){
  while(Touch3==0){}; // wait for press
  Touch3 = 0;  // set up for next time
}

// Wait for switch to be released
// There will be minimum time delay from release to when this function returns
// Inputs:  none
// Outputs: none
void Switch3_WaitRelease(void){
  while(Release3==0){}; // wait
  Release3 = 0; // set up for next time
}

// Wait for switch to be pressed
// There will be minimum time delay from touch to when this function returns
// Inputs:  none
// Outputs: none
void Switch4_WaitPress(void){
  while(Touch4==0){}; // wait for press
  Touch4 = 0;  // set up for next time
}

// Wait for switch to be released
// There will be minimum time delay from release to when this function returns
// Inputs:  none
// Outputs: none
void Switch4_WaitRelease(void){
  while(Release4==0){}; // wait
  Release4 = 0; // set up for next time
}
```

// **ST7735**.h excerpt

```
//************* ST7735_Line********************************************
//  Draws one line on the ST7735 color LCD
//  Inputs: (x1,y1) is the start point
//         (x2,y2) is the end point
// x1,x2 are horizontal positions, columns from the left edge
//              must be less than 128
//              0 is on the left, 126 is near the right
// y1,y2 are vertical positions, rows from the top edge
//              must be less than 160
//              159 is near the wires, 0 is the side opposite the wires
//       color 16-bit color, which can be produced by ST7735_Color565()
// Output: none
void ST7735_Line(uint16_t x1, uint16_t y1, uint16_t x2, uint16_t y2,
           uint16_t color);
```

// **ST7735**

```
//************* ST7735_Line*********************************************
//  Draws one line on the ST7735 color LCD
//  Inputs: (x1,y1) is the start point
//         (x2,y2) is the end point
// x1,x2 are horizontal positions, columns from the left edge
//              must be less than 128
//              0 is on the left, 126 is near the right
// y1,y2 are vertical positions, rows from the top edge
//              must be less than 160
//              159 is near the wires, 0 is the side opposite the wires
//       color 16-bit color, which can be produced by ST7735_Color565()
// Output: none
void ST7735_Line(uint16_t x1, uint16_t y1, uint16_t x2, uint16_t y2, uint16_t color) {
		uint16_t* loX = 0;		// find point with lower x value
		uint16_t* loY = 0;
		uint16_t* hiX = 0;
		uint16_t* hiY = 0;
		if(x1 < x2) {
			loX = &x1;
			loY = &y1;
			hiX = &x2;
			hiY = &y2;
		} else {
			loX = &x2;
			loY = &y2;
			hiX = &x1;
			hiY = &y1;
		}
		int32_t slope = ((*hiY-*loY)*128)/(*hiX-*loX);
		int i;
		for(i = *loX; i <= *hiX; i += 1) {
			int absSlope = slope;				// absolute value of scope
			int negative = 1;						// multiplier
for y if *hiX < *loX
			if(slope < 0) {
				absSlope = -1*slope;
				negative = -1;
			}
			for(int j = 0; j < absSlope; j += 1) {			// display
				int y = ((slope*(i - *loX))/128) + *loY +j/128*negative;
				ST7735_DrawPixel(i,y, color);
				if(y == *hiY) { break; }
			}
		}
}
```