# Lab 2 I/O and Interrupts

## Deadlines & Grading

- **Code and report submission**: Friday, March 10 at 5:00 PM on CMS, **groups of 2**
- **Grading**: 5% of total grade

## Section I: Overview

**Goal.** The purpose of this lab is to give you experience with I/O and interrupts on the FRDM-K64F microcontroller. To successfully complete this lab, you will need to understand the following:

- Memory-mapped I/O
- Polling
- Interrupts

> **NOTE 1** For each part of the lab, we recommend that you create a separate project in uVision. To do this, refer to lab 0.

**Precautions.**

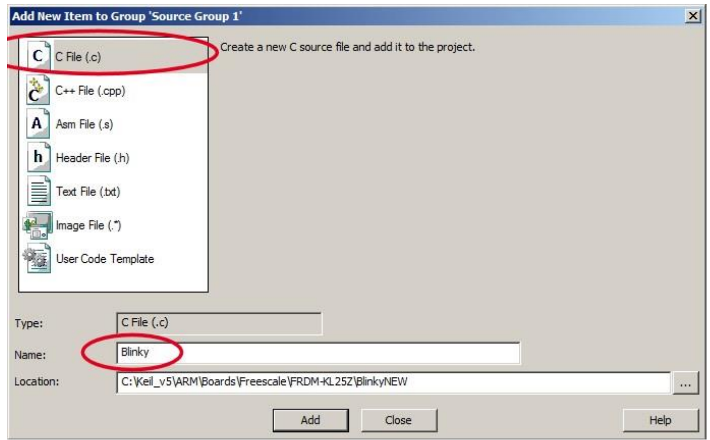
- The micro-controller boards should be handled with care. Misuse such as incorrectly connecting the boards is likely to damage the device.
- These devices are *static sensitive*. This means that you can "zap" them with static electricity (a bigger problem in the winter months). Be very careful about handling boards that are not in their package. Your body should be at the same potential as the boards to avoid damaging them. For more information, check wikipedia.
- It is your responsibility to ensure that the boards are returned in the same condition as you received them. If you damage the boards, it is your responsibility to get a replacement ($35).

## Section II: Tutorials

### Tutorial 1: Creating and Debugging C Files

#### Create a blank C Source File:

1. Right click on *Source Group 1* in the Project window and select




2. This window opens up:
3. Highlight the upper left icon: *C file (.c)*
4. In the *Name:* field, enter a name.
5. Click on *Add* to close this window.
6. Click on *File/Save All* or 
7. Expand *Source Group 1* in the Project window and <*your_name.c*> will now display.
8. It will also open in the Source window.

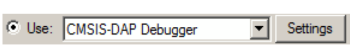
As a test, try copying the following code. Read it through so you understand it first!

```
#include <fsl_device_registers.h>
unsigned int counter = 0;

int main (void) {
     while (1) {
          counter++;
          if (counter > 0xFF)
          counter = 0;
     }
}
```

**Configure the Target CMSIS-DAP:**

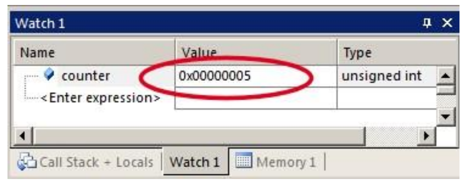
1. Select the Target Options icon . Select the *Target* tab.
2. Click on the *Debug* tab. Select *CMSIS-DAP Debugger* in the *Use:* box:




3. Select *Settings:* icon beside *Use: CMSIS-DAP Debugger*.
4. Click on *OK* twice to return to the main menu.
5. Click on *File/Save All* or 
6. Build the files.  There will be no errors or warnings if all was entered correctly. If there are, please fix them!

**Running Your Program:**

1. Program the flash by clicking on the Load icon: . Progress will be indicated in the *Output Window*.
2. Enter Debug mode by clicking on the Debug icon.
3. Click on the RUN icon.
4. Right click on counter in <*your_name.c*> (the word "counter" inside of your code!) and select *Add counter to …* and select *Watch 1*.
5. Counter should be updating as shown here:
6. You can also set a breakpoint in <*your_name.c*> and the program should stop at this point if it is running properly. If it works, remove the breakpoint.
7. You should now be able to add your own source code to create a meaningful project.




**NOTE 2** *Watch 1* is updated periodically, not when a variable value changes. Since this counter is running very fast without any time delays inserted, the values in *Watch 1* will appear to jump and skip sequential values you would expect to occur.

**NOTE 3** You can stop the program with the STOP icon. You can also run any program after loading it by pressing the RESET button on the board itself.

## Tutorial 2: Understanding the LEDs

To start, let's look at how the RGB LED is implemented in the board. Navigate [here] to the FRDM-K64F User's Guide, which contains overviews of the various modules. Search the User's Guide for information relevant to the LED, including this circuit schematic shown below:

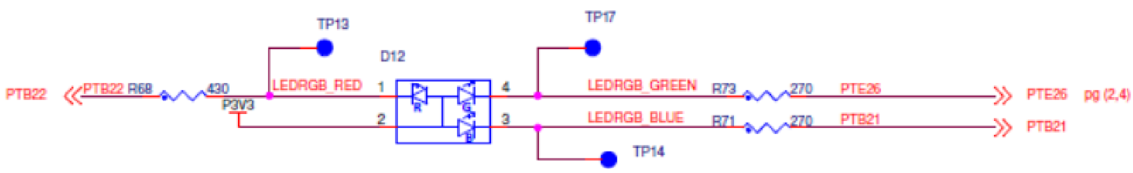


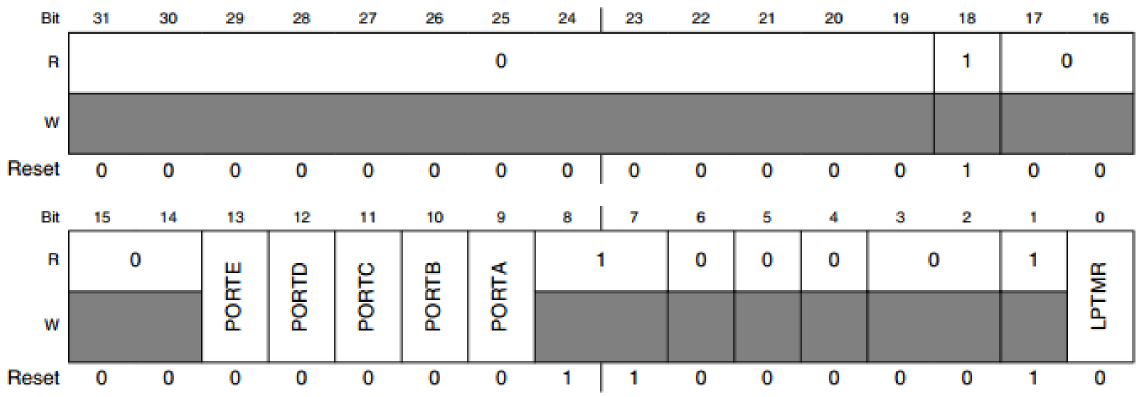

**Figure 14. Tricolor LED**

The schematic from that document shows us that the red LED is attached to PTB22. PTB22 is a single pin from one of the ports (PTA, PTB, PTC, PTD, PTE). Each port has 32 pins. This means that to turn the red LED on or off, you need to change the 22nd pin of port B. Before we can do this, however, we have to enable the clock. By default, the gates to all the ports are switched off to save energy. In order to use port B (to enable the red LED), we have to turn them on.

To do so, we have to set some bits inside of the SIM (System Integration Module). If you look at page 314 in the reference manual for the K64F (link here), you will see the diagram below with explanations of each of the pins. As you can see, some of the bits of the SIM » SCGC5 register control power to ports A through E. More specifically, bit 9 is the Port A clock gate control, bit 10 is the Port B clock gate control, and so on.

### 12.2.12 System Clock Gating Control Register 5 (SIM_SCGC5)

Address: 4004_7000h base + 1038h offset = 4004_8038h




Since, at least for now, we care about the red LED, we need to set the 10th bit to 1.  The table below the diagram on page 314 shows that we need to use 1, not 0, to enable the clock.

The following line of C code will accomplish this:

```
SIM->SCGC5 |= (1 << 10); //Enable the clock to port B
```

While this code works, `(1 << 10)` isn't that easy to understand. Luckily, there are certain masks defined to make our lives easier in *MK64F12.h* (the header file).

On the *Project* window (on the left), expand *Device » system_MK64F12.c (Startup)* and open *MK64F12.h*. You can see a ton of macros which may be helpful for the rest of the course.

Specifically, on line 11424:

```
#define SIM_SCGC5_PORTB_MASK        0x400u;
```

This means that instead of simply setting a 1 to the 10th bit, we can use the following line:

```
SIM->SCGC5 |= SIM_SCGC5_PORTB_MASK; //Enable the clock to port B
```

There are 2 more things we must do before we can toggle the LED. The first of these is to set PTB22 (the pin we want to use to toggle the LED) as a GPIO pin. In the K64F, some pins can have up to eight different uses. To choose the function we want, we have to set the appropriate control signals to an internal mux. This can be done with the PCR (Pin Control Register) detailed on page 282 of the manual. Again, the table below the chart is very helpful. Towards the bottom of page 283, we see the MUX bits indicate which use the pin will have. We have to set the MUX bits (10-8) to 001 to enable pin 22 as GPIO. This can be done as follows:

```
PORTB->PCR[22] = (1 << 8); //Set up PTB18 as GPIO
```

Or, using macros:

```
PORTB->PCR[22] = PORT_PCR_MUX(001); //Set up PTB18 as GPIO
```

Finally, we have to enable PTB22 as an output. This can be done through the PDDR (Port Data Direction) explained on the very bottom of page 1,763 of the same document. This can be implemented by setting the appropriate bit of the `PTB->PDDR` register. You will have to figure out the C code for yourself.

Once this is done, we can toggle the red LED! Look through the manual around page 1,761 for the `PSOR` and `PCOR` registers which will be used to actually turn the LED on or off. Keep in mind that the way the LED is set up, a logic level of 0 will cause the LED to turn on. You will probably have to assign values to `PTB->PSOR` and `PTB->PCOR`.

Try it out! You should be able to write a few quick C programs that make use of the LED. After the red LED works, try implementing the blue and green LEDs. The green LED comes from a different port, so it may be harder to implement!

> **NOTE 4** It may be helpful to define a few helper functions, for instance `LEDRed_On()`, `LEDRed_Off()`, etc. for use in the lab. It will be up to you to decide what functions you will need.

# Section III: Assignment

## Part 1: Polling the Periodic Interval Timer

The goal of this part of the lab is to implement a polling-based approach to see if the timer has finished. For this lab, we will be using a PIT (periodic interval timer). The K64F has four periodic interval timers, though for this lab we will use the first one: `PIT[0]`. For reference, look near page 1086 in the reference manual. You will most likely need to access the `TCTRL`, `TFLG`, `LDVAL`, and `MCR` registers. For instance, in order to set the load value of the timer (what the timer counts down from), we use:

```
PIT->CHANNEL[0].LDVAL = 0x30000; // Set load value of zeroth PIT
```

In order to implement the PIT, you must first enable the clock to the PIT module. This is done through one line of code (this is actually done through the SIM, the same way we enabled a clock for the LED).

```
SIM->SCGC6 = SIM_SCGC6_PIT_MASK; // Enable clock to PIT module
```

By default, the PIT will count down from the specified value, and will change the value of the `TFLG` when the counter reaches zero. To implement polling, you should periodically check this value to see if you have to reset the timer. The diagrams on page 1,090 may help explain how the timers work on a functional level.

The PIT is connected to the peripheral bus clock. The startup files set an appropriate frequency for this clock. Use this information to choose appropriate load values for the PIT.

**Task**

Using *Framework1.c* as a starting point for your code, write a C program that polls the PIT's `TFLG` register to see when the timer expires. When it does, your program should toggle the **red LED**. Use an appropriate load value so that the LED changes state approximately once every second.

## Part 2: Implementing Interrupts

In order to implement interrupts, you must change some settings in the PIT. The timers can be configured to generate an interrupt when they reach zero, which triggers `PIT_IRQHandler`. Within the interrupt, make sure to clear the interrupt flag, or you'll end up always in the interrupt code.

**Task**

Using *Framework2.c* as a starting point, write a new C program that toggles the **blue LED** about once a second using a `for` loop to create a delay. When a PIT interrupt occurs – again, once every second – flash the **green LED** for approximately a tenth of a second. During and after the interrupt, the **blue LED** should continue to blink.

# Section IV: Submission

The lab requires the following files to be submitted:

- **part1.c**: for part 1
- **part2.c**: for part 2
- **report.pdf**: containing a description of your solution along with the rationale for any design choices you make. We require that you describe in detail, in a separate section titled "Work Distribution", the following:
  a) How did you carry out the project? In your own words, identify the major components that constituted the project and how you conducted the a) design, b)

coding, c) code review, d) testing, and e) documenting/writing. If you followed well-documented techniques (e.g., peer programming), this is the place to describe it.

b) How did you collaborate? In your own words, explain how you divided the work, how you communicated with each other, and whether/how everyone on the team had an opportunity to play an active role in all the major tasks. If you used any sort of tools to facilitate collaboration, describe them here.

We encourage you to use meaningful variable and function names, comments, etc. to enhance code comprehensibility.

All files should be uploaded to CMS before the deadline. Multiple submissions are allowed, but only the latest submission will be graded.