

Lab 2: Quadrature Decoding using the eTPU

1 Overview

The purpose of this lab is to learn about quadrature decoding and apply knowledge of sampling. To do so, we will use the Quadrature Decoding function of the MPC5553 enhanced Time Processor Unit (eTPU) as an angular position sensor.

1.1 Encoder

When developing a controller for a mechanical device with moving parts, it is often necessary to gather information about the motion of the device by using an encoder. The haptic device we will be using in lab has an optical encoder for the purpose of obtaining position and velocity information. Optical encoders typically use optical gratings to produce two square-wave signals that are 90 degrees out of phase. This is an example of a quadrature-encoded signal. The graph below shows how the two signals vary as the shaft rotates in one direction.

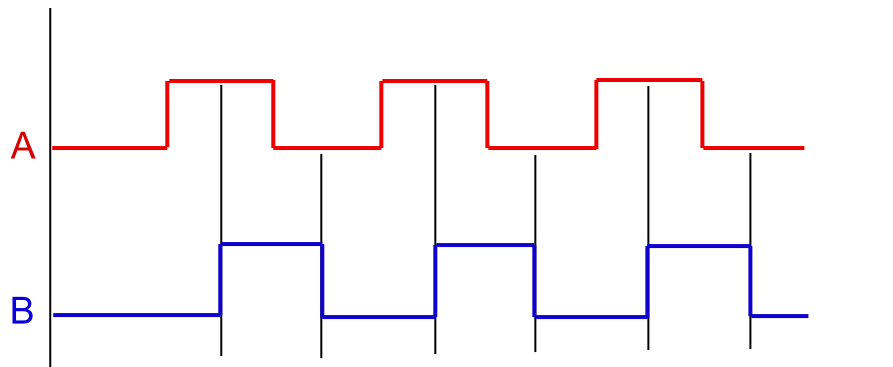


Figure 1: Output for a 2 channel optical encoder rotating in one direction

1.2 Time Processor Unit (eTPU)

The time processor unit is described in the [MPC5553 User's Manual](#) in Chapter 18:

The enhanced time processing unit (eTPU) is a new timing unit featured on the MPC5553/MPC5554 microcontroller that operates in parallel with the MPC5553/MPC5554 core (CPU). The eTPU does the following:

- Executes programs independently from the host core
- Detects and precisely records timing of input events
- Generates complex output waveforms

- Is controlled by the core without a requirement for real-time host processing

Software for specific eTPU functions may be written by the user, or, for common functions, obtained from Freescale. Freescale Application Note AN2842 (on the course website) describes the quadrature decode function. Read the application note, and look over Chapter 18 of the user's manual before coming to the lab. You can find the necessary information concerning TPU configuration registers in Section 18.4.

1.3 Quadrature Decoding eTPU Function

The MPC5553 eTPU operates in one of three modes: slow, normal or fast. We will operate the eTPU in the slow quadrature decode mode. The quadrature decode function uses two eTPU channels to decode quadrature signals into a 24-bit counter. **Note:** In this lab we will use only 16 bits of the count register.

When in slow mode, the quadrature decode function is able to determine direction by looking at both the rising and falling edges of each signal. If the primary channel is leading the secondary channel, the 24-bit counter increments. If the primary channel is trailing the secondary channel, the counter is decremented. The function does this by comparing the current state of the two channels with the state before the most recent rising/falling edge. For example, when channel B goes from low to high and channel A remains high, the counter is incremented since B is trailing A. This creates 16 possible transitions: 4 increment the counter, 4 decrement the counter, and 8 are errors (see the prelab, below, for more information). When the function receives a sequence that is an error, the counter is unchanged.

You can also program the function to switch to normal and fast modes, based on the speed of the encoder wheel. Normal mode applies when the speed is greater than a defined slow-to-normal threshold, but less than a specified normal-to-fast threshold. In normal mode, the counter is updated by one for each valid transition on either channel as in slow mode, but the direction is not calculated (the last direction calculated in the slow mode is kept). When in fast mode, the function only monitors the signal on the primary channel, and updates the counter by 4 on each rising edge transition.

2 Design Specifications

2.1 Hardware

On the interface board, you will see a header bank labeled TPU A [0..7] next to the DIP switches. These channels can interface with up to four quadrature encoders (the chip itself supports up to 32 channels per TPU; 8 channels are made available on the interface board, and two channels are needed for each quadrature encoder). The pins for TPU A channels 0 and 1 are connected to the haptic wheel over the parallel cable. You may use the header bank to measure the voltage signals coming from the quadrature encoder channels. Test loops for channels 0 and 1 are located next to the header bank for easy connection of oscilloscope probes.

The digital I/O interface from Lab 1 will be used again.

2.2 Software

fqd.h and fqd.c

You need to make a C file called *fqd.c* from the *fqd_template.c* file that contains four functions named `init_FQD`, `ReadFQD_pc`, `updateCounter` and `updateAngle` (see "Notes on Casting" below). The prototypes and details of these functions can be found in the *fqd.h* file. It is very important that you follow these prototypes and the comments in the *fqd_template.c* file closely. Place *fqd.c* file in your `lib/` directory and the *fqd.h* file in your `include/` directory.

Makefile

To simplify the compilation process, a makefile has been provided to you. Note that for the makefile to work, you need to make sure that all of your files are in their proper directories, as specified in the lab handouts. The `gmake` command must be run from your `lab2/` directory.

Freescale header files used in this lab: `etpu_qd.h`, `etpu_set.h`.

2.3 Notes on Casting

In previous years students have sometimes observed a peculiar problem in which their `updateCounter` function failed to update the position correctly. The specific behavior observed was that the top 8 bits of the bar LEDs would alternate between being all on (`0xFFXX`) or all off (`0x00XX`). In the following exercise, we will see that this problem is due to the subtleties involved in typecasting correctly.

The following code does not work correctly. `NEW_TOTAL` and `LAST_TOTAL` are `int32_ts` and `CURR_FQDPC` and `PREV_FQDPC` are `uint16_ts`:

```
int32_t updateCounter()
{ /* setup */
  return (LAST_TOTAL + (CURR_FQDPC - PREV_FQDPC));
}
```

This code will work:

```
int32_t updateCounter()
{ /* setup */
  return (LAST_TOTAL + (int16_t)(CURR_FQDPC - PREV_FQDPC));
}
```

Note the difference between these two examples: they are identical except that the quantity (`CURR_FQDPC - PREV_FQDPC`), of type `uint16_t`, is cast to an `int16_t` before being added to total. This is needed so that the quantity is sign-extended when it is turned into a long (so as to be added with total). For more information on sign extension, read section 4.2 of *Computer Organization and Design: The Hardware/Software Interface*. By John L. Hennessy and David A. Patterson. For more information of casting, read section 2.7 of *The C Programming Language*, by Brian W. Kernighan and Dennis M. Ritchie.

To make this clearer, here is an example:

`LAST_TOTAL = 0x00007FFF` `CURR_FQDPC = 0xFFFF` `PREV_FQDPC = 0x0000`

`CURR_FQDPC - PREV_FQDPC` yields the unsigned quantity `0xFFFF`, which when changed to an `int32_t` (a signed value) becomes `0x0000FFFF`. This is not the desired result. It now represents a large positive number, instead of -1. If the quantity `CURR_FQDPC - PREV_FQDPC` is first cast as an `int16_t`, as in the second example, then when it is converted to an `int32_t` it is sign-extended to `0xFFFFFFFF`, or -1, the desired value. Note that the quantity (`CURR_FQDPC - PREV_FQDPC`) can be changed to (`PREV_FQDPC - CURR_FQDPC`). This will only change the directions for turning the wheel to increment or decrement the counter.

Note that `LAST_TOTAL` and `PREV_FQDPC` will have to be `static` variables in order to maintain their values between calls to `updateCounter`. **Note also that `PREV_FQDPC` must have the same initial value as the position count register in `fqd.c` or there will be an initial offset in the count.**

3 Pre-Lab Assignment

*Pre-lab questions must be done **individually** and handed in at the start of your lab section. You must also, **with your partner**, design an initial version of your software before you come to your lab section. Your*

software does not need to be completely debugged, but obviously more debugging before coming to lab means less time you will spend in the lab.

1. **Fill in the truth table** in Table 1 for quadrature decoding. X_{i-1} and Y_{i-1} refer to the previous state while X_i and Y_i refer to the current state. The valid actions are increment, decrement, and error. A few have already been done for you.
2. A 32 pulse encoder is an encoder that provides a square wave signal with 32 periods (or 64 edges, rising and falling) on each channel per revolution. **What is the resolution (smallest measurable amount) in degrees of the quadrature decode function operating in slow mode with a 32 pulse encoder? With a 512 pulse encoder?**
3.
 - a. On Figure 2, **draw lines where the quadrature decode function would update the counter and label each line with the value the counter would hold.** Assume the function is operating in slow mode.
 - b. **Repeat Part (a) for Figure 3**, but assume that the function is running in fast mode now.
4. Briefly (not more than 60 words) **summarize the differences between slow, normal, and fast decoding.**
5. The eTPU is a separate co-processor that operates in parallel with the 5553 core. **What is the advantage of having a separate processor?**
6. Complete *fqd.c*.

4 In-Lab Assignment

4.1 Reading the Counter

1. Write a simple C program called *lab2.c* that uses the `init_FQD` and `ReadFQD_pc` functions from *fqd.c*. Create a `uint16_t` variable, `counter`, in your program and store the values returned by `ReadFQD_pc` in this variable. You will be able to examine the count value of the decoder by looking at this variable when debugging.
2. Compile and debug your *lab2.c* program using the makefile by entering `gmake` at an DOS prompt. Make sure that all your files are in their respective directories, or the compilation will fail.
3. Power up the board and use the P&E Debugger to download the *lab2.elf* file to the board. Make sure you have the encoder connected to the interface board correctly; ask the GSI if you are unsure.
4. In the debugger, add the variable `counter` to the Variables Window. Right click in the Variables Window and select Add Variable, then type the variable name `counter` into the menu. Display the value in Decimal, and use the Default data type. Click OK and you should now see `counter` in the Variables Window.
5. Run the *lab2.c* program by clicking the High Level Go button in the debugger. Move the wheel of the haptic device slightly. Then, stop running *lab2.c* by clicking the ‘Stop’ button in the debugger, which is shown as a black square. The value of `counter` in the Variables Window should have changed. If not, correct the problem before proceeding.
6. Reset the target by clicking on the ‘Reset’ lightning bolt button in the debugger. You may have to press the button twice, until you see code run by in the Status Window and the Source Window is cleared. Download and run *lab2.elf* again and turn the wheel of the haptic device one full revolution. How much does the FQD function increment during one full revolution of the haptic wheel?

4.2 Overflow and Underflow

7. Use your knowledge from the Digital I/O Lab to output the value of `counter` to the 16 LEDs. Recompile your code using the same command as above. Download and run your code.
8. With your new code running, turn the wheel until the LED counter shows 0x8000. This is the center position for the counter. Now, turn the wheel until the LED counter either underflows or overflows. How many revolutions of the wheel does it take to overflow a 16-bit register starting at this center value?

4.3 Faulty Casting

9. Modify your code so that you use your `updateCounter` function to keep track of the position count. Output the middle 16 bits of your position counter to the LEDs. You can do this by using a bitwise shift. Verify that your `updateCounter` function works correctly.
10. Repeat step 9, but modify `updateCounter` to use the faulty casting method from the ‘Notes on Casting’ section of this lab. Verify that there is in fact a problem with this code and show that problem to the GSI.

4.4 Angle Calculation

11. Write a simple C program called *lab2angle.c* that outputs how much the haptic wheel turned **counterclockwise**, in degrees, to the LEDs by using the `updateAngle` function in *fqd.c*. Note that, similar to what you did in `updateCounter`, you will need a `static float` in `updateAngle` to remember the current angle. Do not call the function `updateCounter` from `updateAngle`. Compile your program by entering `gmake angle` at an DOS prompt. Download the *lab2angle.elf* file to the board and demonstrate the functionality to the GSI.

12. The post-lab asks questions about why the quadrature decode function may fail to correctly keep track of position when the wheel is running at sufficiently high speeds. Before you leave the lab you might want to discuss possible reasons for such a failure.

5 Post-Lab Assignment

1. **What are two reasons that you think the quadrature decode function might stop working at high speeds?**
2. The MPC5553 eTPU can be programmed to switch automatically from slow to normal to fast mode based on encoder speed. **Why would the quadrature decode function work at a higher speed when in fast mode? Hint:** Read section 3.1 of AN2842 concerning how fast modes work.
3. Using the information about the encoder wheel given to you in *fqd.c*, **what type of encoder are we using in the haptic wheel?** (e.g. 32 pulse, 256 pulse, etc.)
4. We now analyze situations for which the QD function may fail to correctly update the position count.
 - a. The system clock for our setup is 40MHz. Given that we are running the QD function in slow mode, **determine the maximum rate the haptic wheel can reach (revolutions/sec) before the eTPU fails.** See section 3.7 in Application Note AN2842 for eTPU performance.
 - b. Assume that the haptic wheel is running at the maximum speed allowed by the QD function (i.e. at the speed computed in part a). **What is the slowest possible periodic rate that the CPU can read the TPU position counter register while still knowing whether the counter value is increasing or decreasing?** You may assume that the wheel will be spinning at this maximum rate in one direction. Calculate this rate based on both a 16-bit (what we used) and 24-bit (what is available in the hardware) position counter size.
 - c. **Relate that periodic rate to the number of processor cycles that can be executed between checks.**
5. Include well-documented copies of your *fqd.c*, *lab2.c* and *lab2angle.c* files.

If you have comments that you feel would help improve the clarity or direction of this assignment, please include them following your postlab solutions.

6 Figures for Pre-Lab Questions

These may be collected at the beginning of lab.

Previous State (X_{i-1}, Y_{i-1})	Current State (X_i, Y_i)	Action Error, Increment, or Decrement
00	00	
00	01	Decrement
00	10	Increment
00	11	
01	00	
01	01	
01	10	
01	11	
10	00	
10	01	
10	10	
10	11	
11	00	
11	01	
11	10	
11	11	Error

Table 1: Encoder Transition Table for pre-lab problem 1.

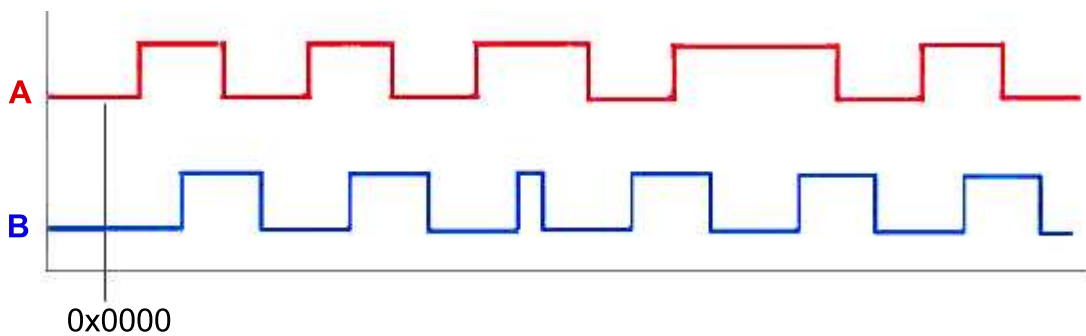


Figure 2: Sample output for pre-lab problem 3a. The 16-bit counter is initialized to 0x0000.

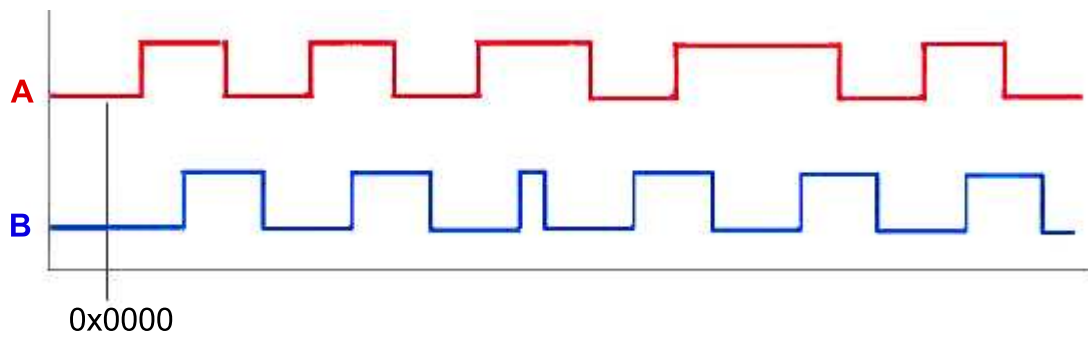


Figure 3: Sample output for pre-lab problem 3b. The 16-bit counter is initialized to 0x0000.