Quadrature Encoder Decoding

Version 2: Added examples of state transition and output tables for the decoder state machine. Version 3: corrected list clockwise rotation transitions.

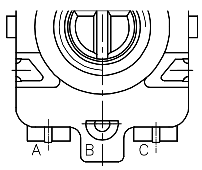
Introduction

A quadrature encoder is a mechanical motion-input device that can measure rotation or linear displacement. It has two logic outputs that are offset so that an interface circuit can determine both the direction and amount of motion as described below.

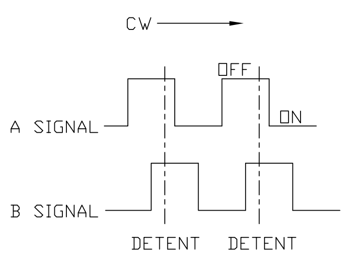
Typical applications are digital controls and position measurement.

In this lab you will use a sequence detector and an up/down counter to track the shaft angle of the EN16-H rotary quadrature encoder included in your ELEX 2117 parts kit[1].

The encoder has two switch contacts labelled A and B and a common connection labelled C:



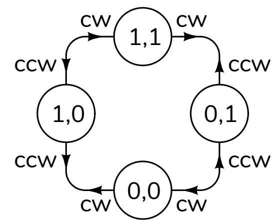
The two switches turn on and off as the shaft rotates:



The encoder has 24 detent positions per revolution.

If pull-up resistors are used on A and B so they are low when the switches are ON, then when the shaft moves clockwise (cw) from one detent position to another the Gray-coded sequence of values on AB is: 11, 01, 00, 10, 11,... When moving in the counterclockwise (ccw) direction the sequence is reversed (11, 10, 00, 01, 11, ..):

[1] The EN16 datasheet is available on the course web site.

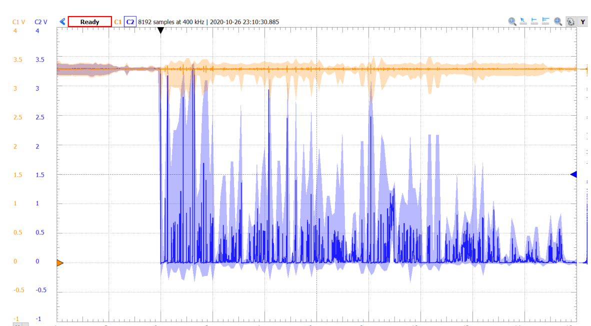


Thus each transition allows us to determine the direction of motion:

- transitions from 10 to 11, 11 to 01, 01 to 00 and 00 to 10 indicate clockwise rotation, while
- transitions from 00 to 01, 01 to 11, 11 to 10 and 10 to 00 indicate counterclockwise rotation, and
- transitions from 00 to 11 or 01 to 10 should not be possible.

A sequence detector with two bits of memory can determine the direction of motion: comparing the current value to the previous value we can determine when the shaft has moved and in which direction.

This rotary encoder uses mechanical switches and these have contact bounce. The following example shows that it can last over 10 ms:



At high rotation rates the duration of the contact bounce may be long enough to appear as rotation. Debouncing the switch inputs can help prevent this.

State Machine Description

The state machine that implements the decoder has two bits of input (`A`,`B`) and two bits of output (`up` and `enable`). It can be described as a Mealy state machine with two bits of state and two bits of input or as a Moore state machine with four bits of state.

For a Mealy state machine the state transition table would be:

current state	input	next state
`ab`	`xy`	`xy`

where `ab` and `xy` can be any two-bit values. The output table might include lines such as:

state	input	output (`enable`, `up`)
11	01	1,1
01	11	1,0
11	00	0,0

For a Moore state machine the state transition table would be:

current state	input	next state
`abcd`	`xy`	`cdxy`

where `abcd`, `cdxy` and `xy` can be any four- and two-bit values. The output table might include lines such as:

state	output (`enable`, `up`)
1101	1,1
0111	1,0
1100	0,0

Specifications

Your circuit should display the shaft position in steps (each step being 1/96 of a full rotation). Turning clockwise should increment the count and turning counterclockwise should decrement the count. Returning the shaft to its starting position should restore the display to the starting value.

Components

You will need the same components as in the previous lab with the rotary encoder substituted for the two pushbutton switches.

Procedure

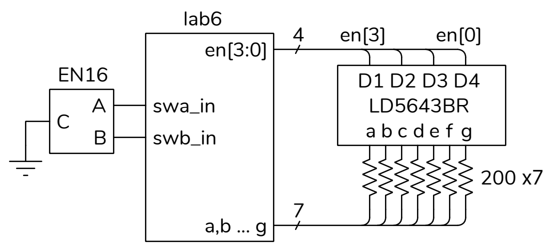
Design a sequence detector that generates `up` and `enable` signals based on the A and B switch inputs. These signals will control the BCD counter you designed in the previous lab which will display the shaft position.

Use the `debounce.sv` component supplied with a previous lab on each switch input. This will remove pulses with a duration less than 1 ms.

You should be able to use most of the previous lab's code and pin assignments (Assignments > Import Assignments...).

CPLD I/O

The connections to the CPLD are shown in the following diagram:



The pin assignments for the LED are the same as in the previous lab. Use internal pull-up resistors on the A and B switch inputs. Connect terminal C to ground. The pin assignments are shown below:

To	Assignment Name	Value
a	Location	PIN_33
b	Location	PIN_44
c	Location	PIN_38
d	Location	PIN_34
dp	Location	PIN_36
e	Location	PIN_30
en[3]	Location	PIN_35
en[2]	Location	PIN_50
en[1]	Location	PIN_48
en[0]	Location	PIN_42
f	Location	PIN_52
g	Location	PIN_40
clock	Location	PIN_12
swa_in	Location	PIN_99
swb_in	Location	PIN_97
swa_in	Weak Pull-Up Resistor	On
swb_in	Weak Pull-Up Resistor	On

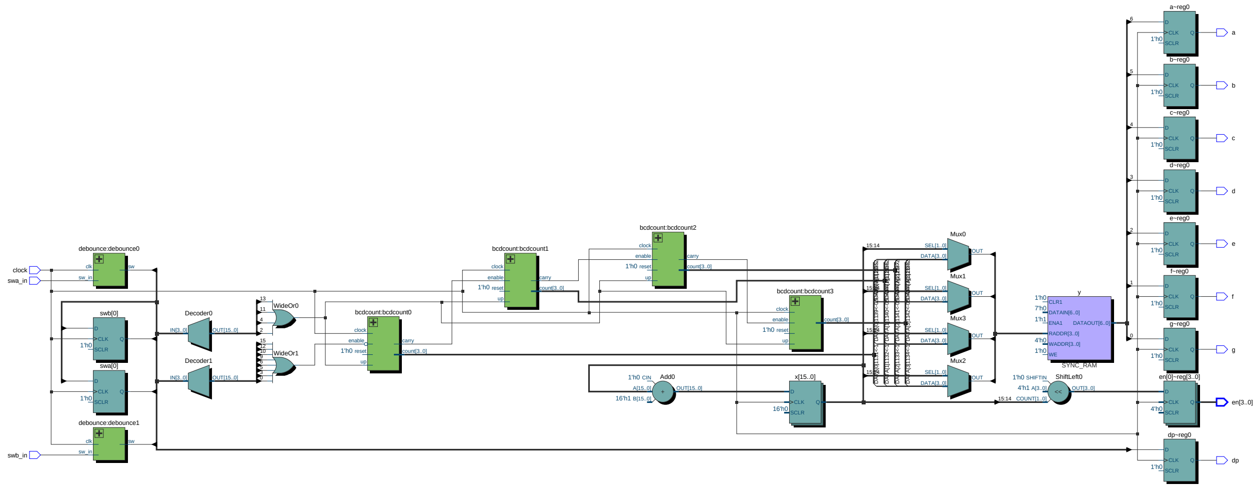
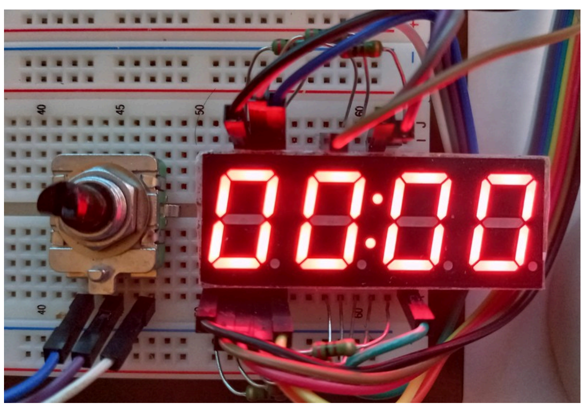


Figure 1: Example RTL Schematic for Lab 6.

The wiring to the 7-segment LED and rotary encoder is shown below:



and the connections to the CPLD pin headers are the same as in the previous lab.

Submission

To get credit for completing this lab, submit the following to the Assignment folder for this lab on the course website:

1. A PDF document containing:

    - Your name, BCIT ID, course number and lab number.
    - A listing of your System Verilog file. You need not include the `debounce.sv` file or the `bcdcount.sv` file if it has not changed from the previous lab. You must follow the coding guidelines given on the "Course Information" section of the course website. Note that these may have changed.

      The listing should be included as text rather than an image.
    - a screen capture of your compilation report (**Window** > **Compilation Report**) similar to: this:

Flow Summary	
<<Filter>>	
Flow Status	Successful - Tue Oct 27 00:29:46 2020
Quartus Prime Version	20.1.0 Build 711 06/05/2020 SJ Lite Edition
Revision Name	lab6
Top-level Entity Name	lab6
Family	MAX II
Device	EPM240T100C5
Timing Models	Final
Total logic elements	147 / 240 (61 %)
Total pins	15 / 80 (19 %)
Total virtual pins	0
UFM blocks	0 / 1 (0 %)

2. The PDF file containing the schematic created by **Tools > Netlist Viewers > RTL Viewer**, and then **File > Export...** . The file should look similar to Figure 1.

3. A video of your breadboard showing:

    - an initial count value
    - the count increasing by at least 100 as the shaft turns clockwise more than one revolution
    - the count decreasing by at least 200 as the shaft is turned counterclockwise more

than two revolutions

- the count increasing back to the original value as the shaft returns to the original angle

Use an indicator such as a piece of tape as shown in the sample video to make it easy to see the shaft angle.