KNIGHT RIDER LIGHT SEQUENCER WITH ROTARY ENCODER CONTROL

Contents

1 Introduction: Test Your Knowledge: Knight Rider Light Sequencer with Rotary Encoder Speed Control

Now that you have completed the Knight Rider LED sequencing circuit on the DE10-Lite development kit, we will next introduce the use of a handy piece of hardware called a rotary encoder to control the speed of the LED light sequencer.

This lab assumes you have completed the following self-guided or instructor led lab:

https://www.intel.com/content/www/us/en/programmable/support/training/course/ouwintro.html

Required Items for lab:

Terasic DE10-Lite development kit

Rotary Encoder

Jumper wires

Skills required:

- Basic knowledge of digital electronics including sequential logic and state machines.
- Basic understanding of Verilog coding
- Completion of introductory Quartus course described above

If you worked on the knight_rider project you might have spent a few iterations to derive the parameter COUNTER_SIZE value to come up with the proper clock frequency for the LEDs to change at approximately 10Hz, which makes the LEDs stay on for approximately 1/10 of a second. Each time you change the value of COUNTER_SIZE, you spend 5-10 minutes recompiling your code and downloading the programming image (.sof file) to the DE10-Lite kit. We will investigate a new means to tune the value of clock speed using a rotary encoder switch so that you can quickly change it's value without recompiling your design.

Often when working with designs that require some type of position or rotation sensing, an electro-mechanical device called an *encoder* is used. It may either encode linear position (linear encoder) or rotation (rotary encoder). In this lab you will be

introduced to the *rotary encoder*: a device where using the proper electrical interface you can determine the rotation angle of a shaft. A few example applications are: a) an interface between a motor and a control circuit to provide information to control the speed of the motor; b) a volume or tuner control on a digital audio system.
The goal of this design is to use the encoder signals as inputs to a counter. We will count up or down based on the direction of the rotation. A hex display will show the magnitude of the counter output which will in turn determine the speed of the Knight Rider LED sequencer.

Figure 1: Rotary Encoder

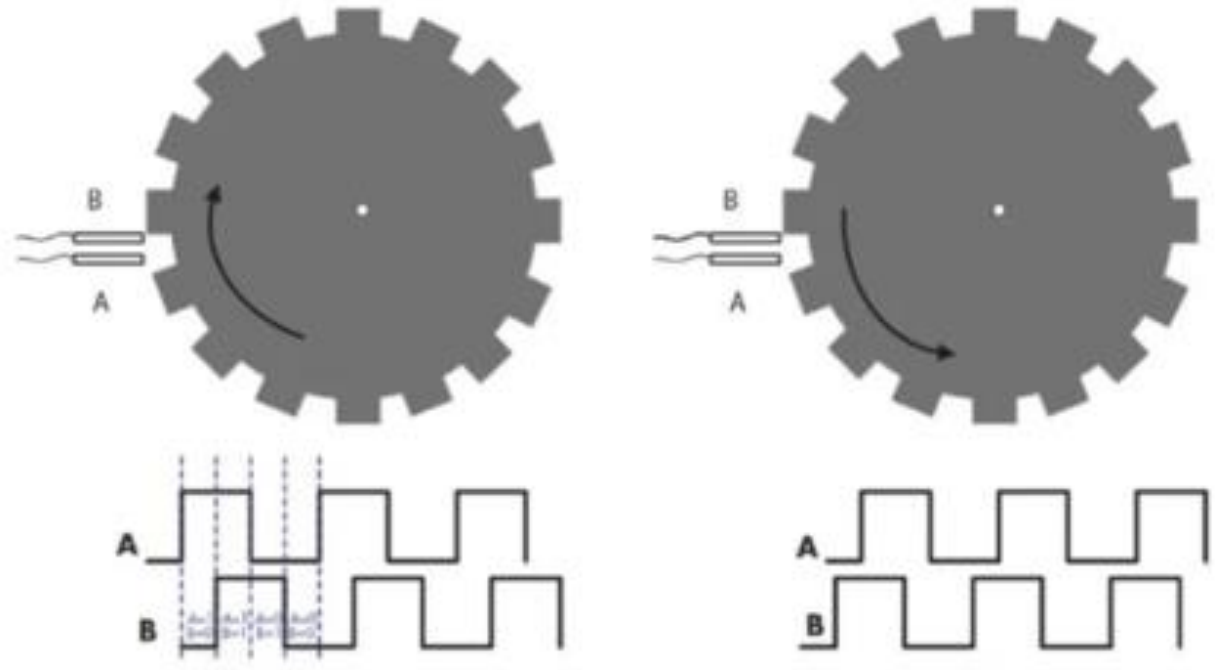

Figure 2: Rotary Encoder theory of operation

The operation of a mechanical rotary encoder is achieved with two contacts placed in above a rotating conductive wheel such that signals A and B produce 90 degree offset square waves. Signal A leads or lags B based on the direction of rotation. By designing a finite state machine (FSM) we can generate signals count enable, rotation direction, and a third on/off signal when the button is pressed. We will use this FSM to generate master clock 50MHz divided frequencies for control of the Knight Rider light sequencer. Rotary encoders are available from a variety of manufacturers and number of teeth which indicate the number of clicks to complete 1 revolution.

Finite State Machine Design

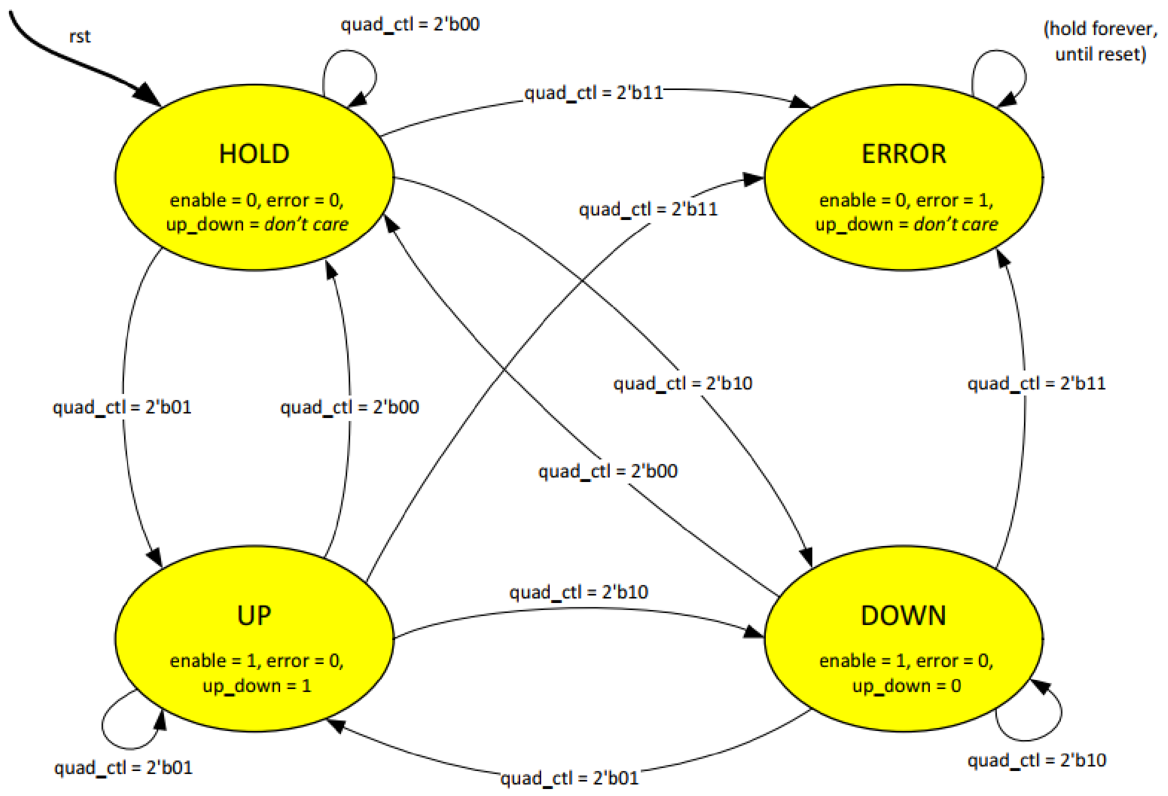

Figure 3: The rotary encoder state machine transitions are controlled by inputs A and B encoded as signal quad_ctl[1:0]

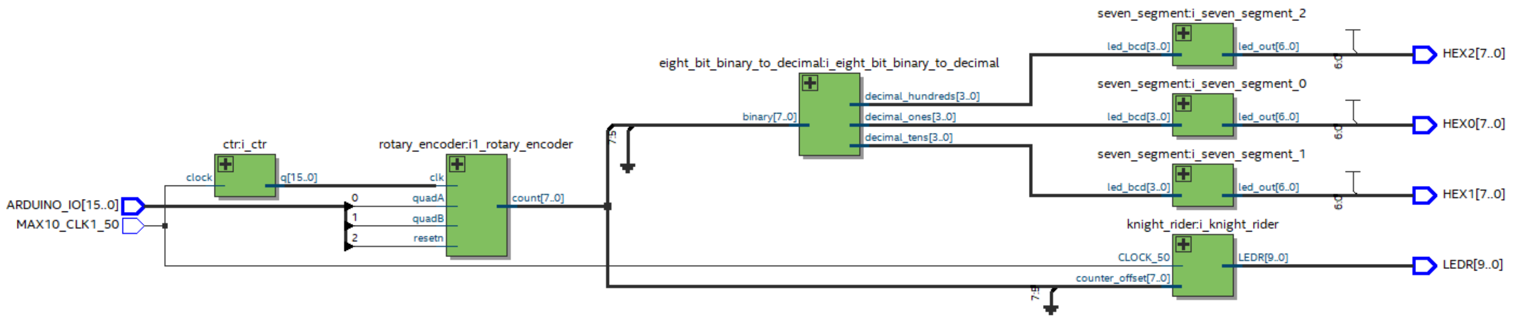

Figure 4: The block diagram depicts the Knight Rider light sequencer with rotary encoder controlling the speed of the LED sequencing

2 Lab Steps

The following blocks are included in the starting point project:

knight_rider: Light sequencer function. Includes the clock_divider module to determine sequencing rate

rotary_encoder: This System Verilog module is the finite state machine determining the value of the rotary encoder.

ctr: This divides down the clock rate to the rotary_encoder FSM – can be adjusted to determine how various clock rate affect the accuracy of the encoder

eight_bit_binary_to_decimal: converts binary to ones/tens/hundreds digits

seven_segment: Takes ones/tens/hundreds digits and decodes seven segment display values

DE10_LITE_Golden_Top: top level module. The user will assemble the various blocks to construct the entire design

2.1 Extract archive.

Download the Quartus archive file at this link.

Save in a directory with a location you will remember. Double click on the rotary_encoder_project.qar and extract the file in Quartus.

3 Simulate the rotary encoder

It's always a good idea to simulate state machines prior to assembling the top level design. Refer to Figure 2 for the waveforms of inputs A and B. In theory, the clock can be considerably faster than the pulses from the rotary encoder. It is assumed you know how to either use the University Waveform View application within Quartus, or write a testbench to stimulate the rotary encoder with the A and B waveforms offset by 90 degrees. If you need a starting point testbench, refer to the tb.v file included in the archived project.

4 Compile and download the knight_rider module to your DE10-Lite FPGA development board

In Quartus, set the project navigator tab to files if not already in this state. Right click on knight_rider.v and set to top level entity. Compile the design and confirm there are no errors. Open the programmer and select rotary_encoder_project.sof and download to the DE10-Lite FPGA development board. Observe the LEDs sequencing at the appropriate frequency.

5 Assemble the top level design

The top level module is called DE10_LITE_Golden_Top.v . The input and outputs and associated pin locations are defined in the file you unarchived. You will instantiate the various modules shown in Figure 4. Some of the the modules work properly as coded, but first you will need to make some modifications to knight_rider.v to allow a new input port called counter_offset to be routed through knight_rider to the submodule called clock_divider. The counter_offset value is generated by the rotary encoder.

Open up the knight_rider.v file and make the appropriate changes as requested in the comments section. Similarly, open up DE10_LITE_Golden_Top.v and make the necessary changes to connect the various blocks to incorporate the rotary encoder, binary to decimal converter and seven segment decoder to display the value of the rotary encoder values on the DE10 Lite board.

6 Connecting the rotary encoder to the DE10-Lite board

The Rotary Encoder has 5 terminals: Power, ground, A, B and Switch. Each manufacturer might label these slightly differently. For the Tegg 2 PCS KY-040 360 Degree Rotary Encoder Module Brick Sensor clickable Switch with Knob Cap for Arduino that is listed in the link in section 1, the mapping is shown below.

A: DT
B: CLK
Button: SW
Power: +
Ground: GND

To make the appropriate connections to the Arduino header you will need to refer to the schematic of the DE10-Lite. This can be downloaded from this link. Look for the DE10-Lite CD-ROM manual and download that file. Unzip the file and under the Schematic folder, open up the file called de10-lite.pdf. On page 13, you will observe the Arduino connections. Use 5 male to female jumper wires to make the connections. Connect the CLK pin to Arduino_IO0, DT pin to Arduino_IO1, SW pin to Arduino_IO2, Power to an appropriate VCC5 pin and GND to a ground socket on the Arduino header.

7 Compile the project and program the board

Make sure that your top level entity is set to DE10_LITE_Golden_Top and compile your design. Once the jumper wires are connected to the rotary encoder, program the .sof file to the DE10-Lite kit and experiment with the operation. Make sure that the operation shows hex values 1 through 8 and the sequencing rate of the LEDs progressively gets faster with the higher rate. Turning the rotary encoder clockwise should speed up the sequencing rate and counter-clockwise should reduce the sequencing rate. Pushing the button should reset the counter back to 1. Make appropriate changes to your code until you get the appropriate behavior you are seeking.

Document Revision History

Name	Date	Changes
Larry Landis	1/4/2021	Initial Release of lab manual