**Stepper Motor Drive**

# EE332: Digital System Design

# Lab4 – A practice for peripheral modules of Nexys4 DDR

## Objectives

The objectives of this lab are following:

- To understand the peripheral modules (Pmod) of Nexys4 DDR
- To understand the working principle of the step motor
- To design a drive circuit for the step motor
- To implement a drive circuit on the Nexys4 DDR FPGA board

## Materials

This lab requires the following materials, which will be provided:

- The Nexys4 DDR FPGA
- A drive board (level shifter)
- A 4-phase unipolar step motor 28BYJ-48
- Some wires

## Introduction of Pmod and Pmod connector

Nexys4 DDR board equips with 4 peripheral module (Pmod) connectors. Pmod™ devices are Digilent's line of small I/O interface boards that offer an ideal way to extend the capabilities of programmable logic and embedded control boards. They allow sensitive signal conditioning circuits and high-power drive circuits to be placed where they are most effective - near sensors and actuators.

Pmod modules communicate with system boards using 6, 8, or 12-pin connectors that can carry multiple digital control signals, including SPI and other serial protocols.

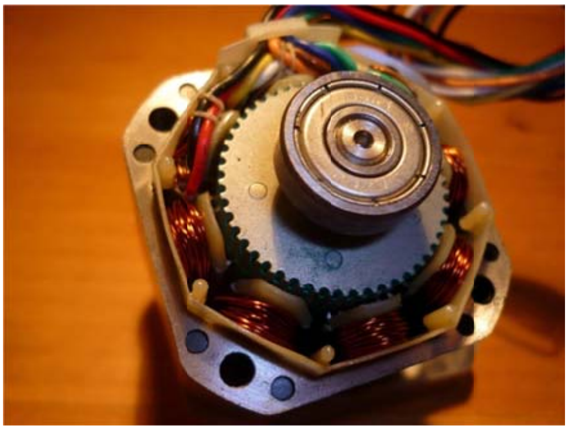
The Pmod connectors are arranged in a 2x6 right-angle, and are 100-mil female connectors that mate with standard 2x6 pin headers. Each 12-pin Pmod connector provides two 3.3V VCC signals (pins 6 and 12), two Ground signals (pins 5 and 11), and eight logic signals, as shown in Figure 1. The VCC and Ground pins can deliver up to 1A of current.


Figure 1 PMOD connectors; front view, as loaded on PCB.

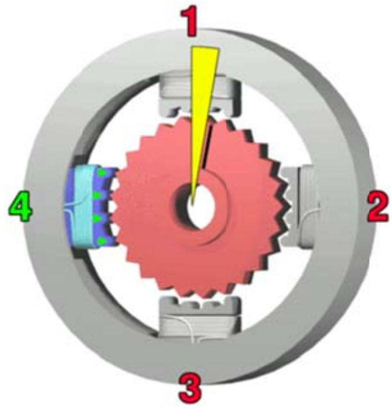
In this lab, a circuit is designed to drive a stepper motor connected to Pmod connector through a drive board.

## Stepper Motor

Stepper motors, an example shown in Figure 2(a), are electromagnetic incremental devices that convert electric pulses to shaft motion (rotation). These motors rotate a specific number of degrees as a respond to each input electric pulse. Typical types of stepper motors can rotate 2°, 2.5°, 5°, 7.5°, and 15° per input electrical pulse, thus dividing a full rotation into a number of equal steps. The motor's position can then be commanded to move and hold at one of these steps without any feedback sensor (an open-loop controller), as long as the motor is carefully sized to the application in respect to torque and speed. Speed of a stepper motor can be controlled in a broad range of values by altering the frequency of input impulses.



(a)




(b)

Figure 2 (a) A stepper motor, and (b) an illustration of a 4-phase unipolar stepper motor

There are two basic winding arrangements for the electromagnetic coils in a stepper motor: bipolar and unipolar.

A 4-phase unipolar stepper motor is adopted in this lab due to its simpler principles. An illustration of the motor operation is shown in Figure 2(b), where 4 electromagnets (1, 2, 3, 4) are turned on in turn, attracting the nearest teeth of the gear-shaped iron rotor. When the top electromagnet (1) is on, with the teeth aligned to electromagnet 1, they will be slightly offset from the right electromagnets (2). Then, the top electromagnet (1) is turned off, and the right electromagnet (2) is energized, pulling the teeth into alignment with it. This results in a rotation of 3.6° in the example shown in Figure 2(b). The 4 electromagnets are turned on in sequence, each contributing a 3.6° rotation. When the top electromagnet is on again, the rotor will have rotated by one tooth position; since there are 25 teeth, it will take 100 steps to make a full rotation in this example.

## Drive modes of stepper motor

In view of the operation principle of the 4-phase unipolar stepper motor, to drive the stepper drive, we have to generate 4 signals to control the 4 electromagnets. According to the different accuracy and torque, there are three modes we could adopt, shown in Figure 3.

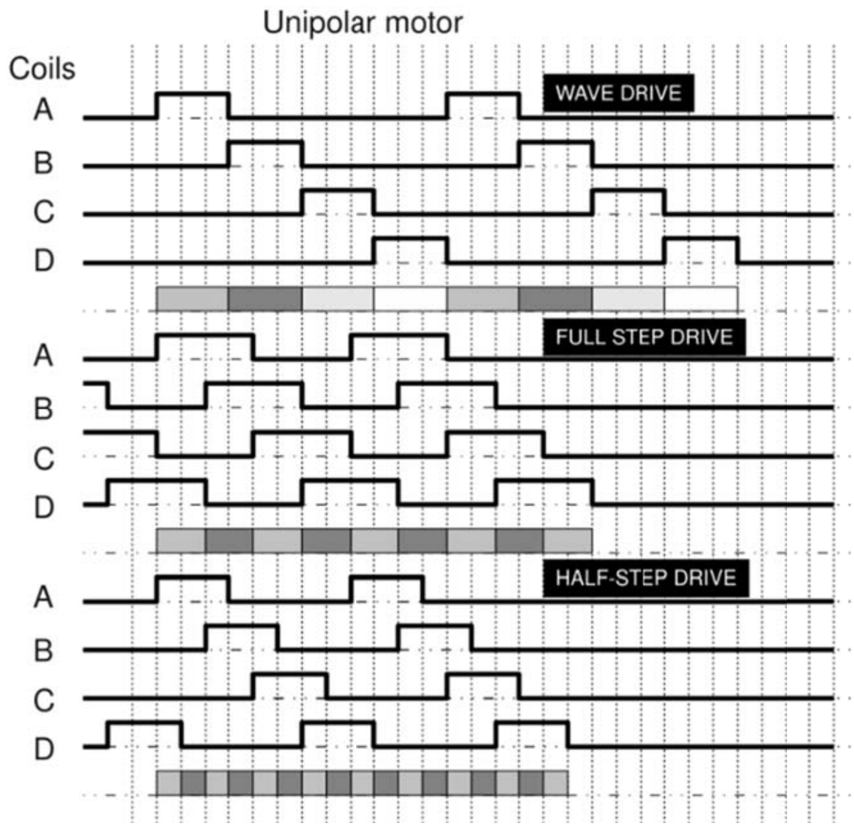



Figure 3 Waveforms on the 4-phase unipolar stepper motor under different stepper mode

**Wave drive**

In this drive method only a single phase is activated at a time. It has the same number of steps as the full-step drive, but the motor will have significantly less than rated torque. It is rarely used. In the earlier example, the rotor has 25 teeth and it takes 4 steps to rotate by one tooth position. So there will be 25×4 = 100 steps per full rotation and each step will be 360/100 = 3.6 degrees.

**Full-step drive**

This is the usual method for full-step driving the motor. Two phases are always on so the motor will provide its maximum rated torque. As soon as one phase is turned off, another one is turned on. Wave drive and single phase full-step drive have the same number of steps to make a full rotation but difference in torque.

**Half-stepping**

When half-stepping, the drive alternates between two phases on and a single phase on. This increases the angular resolution. The motor also has less torque at the full-step position (where only a single phase is on). This may be mitigated by increasing the current in the active winding to compensate. The advantage of half stepping is that the drive electronics need not change to support it. If we change it to half-stepping, then it will take 8 steps to rotate by 1 teeth position. So there will be 25×8 = 200 steps per full rotation and each step will be 360/200 = 1.8°. Its angle per step is half of the full step.

## Rotation Speed and Direction

In generating the impulse signal controlling the 4 electromagnets, we have to define proper frequency of the impulse, to control the speed of the rotation. 28BYJ-48 stepper motor used in this lab has a step angle 5.625°/64, i.e., every impulse rotates the rotor by 5.625°/64. Thus, 360/(5.625/64)=4096 steps (i.e., impulses) are required to make a full rotation. By adjusting the duration of the impulses in Figure 3 therefore you can adjust the rotation speed.

Change the sequence of the impulses for the 4 electromagnets change the direction of the rotation.

## Stepper motor Drive Board

The I/O standard used in Nexys4 DDR is 3.3V, i.e., the voltage of impulses generated by the FPGA board is 3.3V, while the step motor requires a supply voltage larger than 5V. Therefore, a drive board (shown in fig.4) is used to convert the 3.3V voltage to 5V.

A sample connection of the FPGA board, the drive board and the motor is shown in Figure 5. **Note that the “+” and “–” pins on the drive board is connected to the 3V3 and GND pins of the selected Pmod connector of the FPGA board.**

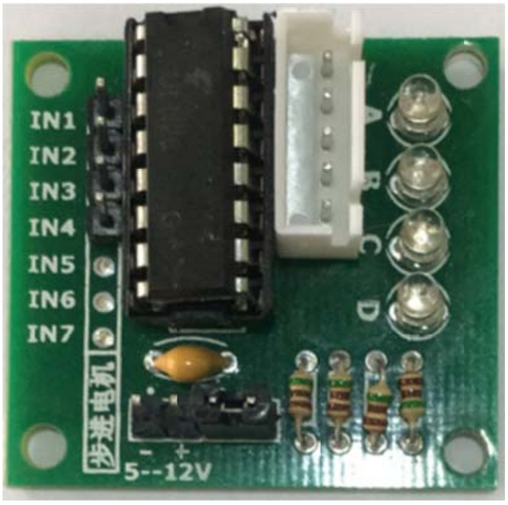



Figure 4 A stepper motor drive board.

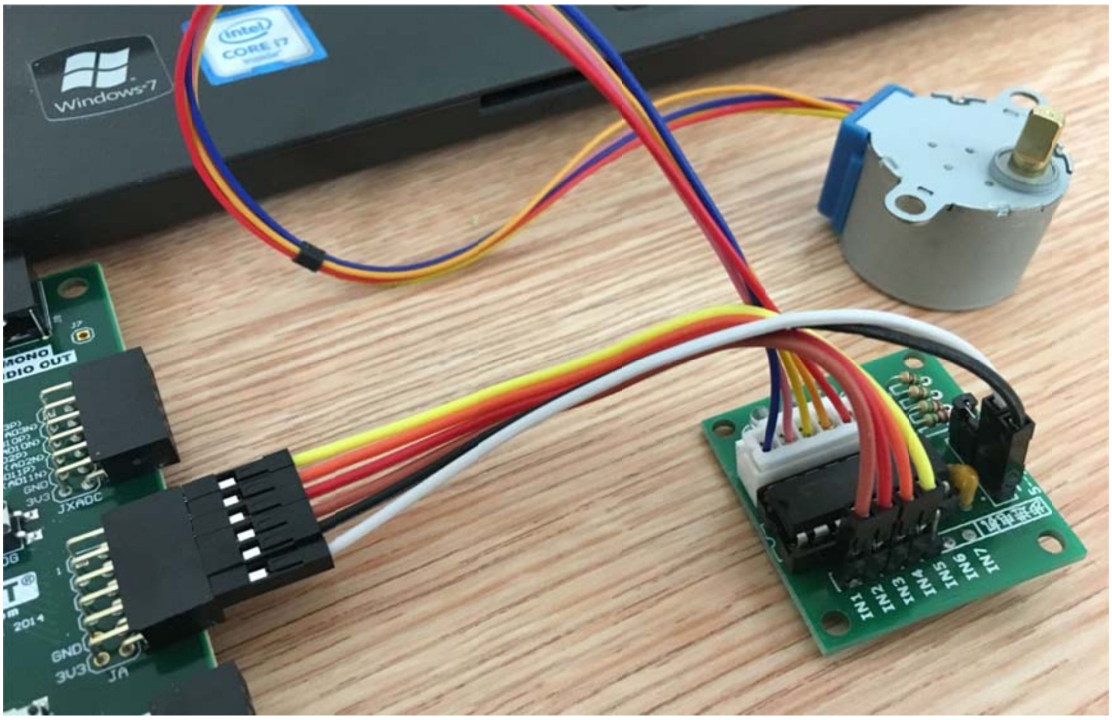



Figure 5 A connection of the FPGA board, the drive board and the motor.

Refer to the data sheet of the 28BYJ-48 stepper motor and its compatible drive board for detailed parameters. Note that the idle in-traction and out-traction frequency in the data sheet are the maximum star-up and normal running frequency, respectively.

## Lab Requirements

Design a circuit with following controls to drive the stepper motor through the drive board:

1. The direct of the rotation may be controlled, for example by a switch.
2. The speed of the motor may be controlled, for example by two push buttons, one to increase the speed, and the other to decrease the speed.
3. The rotation may be stopped and re-started.

## Pre-Lab preparation

**Part 1: Reading**

Read the instruction of this lab, and pages 21 in the Nexys4 DDR Board Reference Manual.

**Part 2: Computation**

1. Compute the duration of the impulses that make a full rotation of the rotor at 1 minute.
2. Find out the rotation speed range of the given motor, and their corresponding impulse durations.

### In-Lab Procedure

Design the circuit to meet the design requirement. Demo your design.

### Post-Lab Report

No report is required.