ME 104

Sensors and Actuators

Fall 2003

Laboratory 7

Open Loop Digital Control

Of a DC Motor

Department of Mechanical and Environmental Engineering

University of California Santa Barbara

Fall 2003 Revision

Introduction

In Laboratory #4, you learned how to drive a DC Motor using an analog voltage signal and also how to measure and view both (analog) angular velocity and (analog) angular position feedback signals from the motor. In this laboratory, you will learn how to obtain and view digital feedback signals from the motor. The digital feedback signals will be obtained from two separate sources: a **Slotted Disc** and a 4-bit **Gray-Code Disc**. You will also learn how to drive the motor using a digital **Pulse Width Modulated** (P.W.M.) signal.

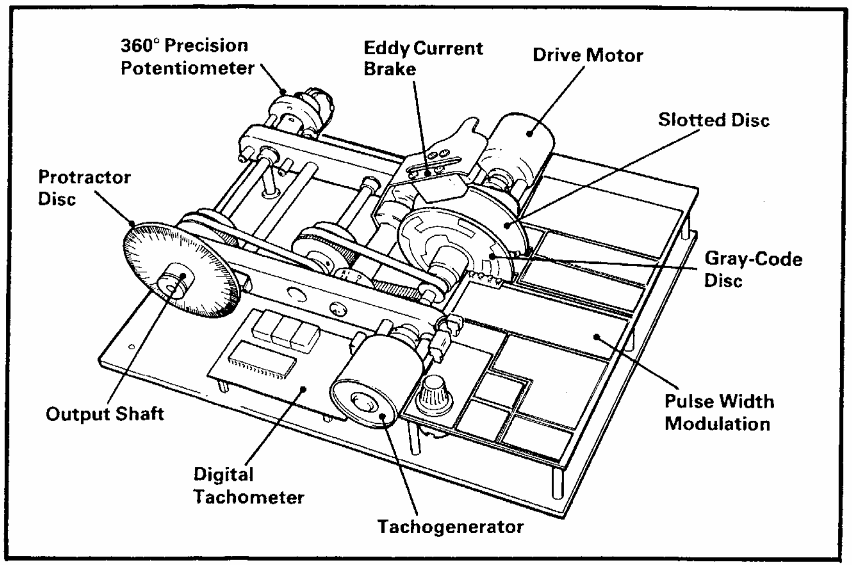

Figure 1: MS15 DC Motor Control Module

All digital outputs from the DC motor module are **Transistor-Transistor Logic** or **TTL** by nature. This means that **logic low** is defined as a value less than 0.7 V, while **logic high** is defined as a value greater than 2.5 V. Typically, logic low is close to 0 V and logic high is close to 5 V. The digital input/output lines on the DAQ Board* are configured to accept TTL signals.

Background Reading

Please read the following material prior to this lab:

1. Histand and Alciatore, **Introduction to Mechatronics**, Sections **6.1-6.3** and Section **9.2.4**
2. **DC Motor Control Module User Manual**, **Pages 3-7** and **14-16**, LJ Technical Systems Inc.

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* The PCI-6024E DAQ Board has eight digital input/output channels.

3. ***LabVIEW* Data Acquisition Basics Manual**, **Pages 15-1 to 15-2** and **16-2 to 16-3.** Available online at www.ni.com/pdf/manuals/320997c.pdf.

Experiment #1: View Digital Feedback from Slotted Disc Output of DC Motor Module

In this experiment, you will use a *LabVIEW* VI to drive your DC motor using an analog voltage signal, similar to what you did in Laboratory #4. At the same time, you will use your oscilloscope to view both analog velocity feedback from the tachogenerator output and digital feedback from the **Slotted Disc** output.

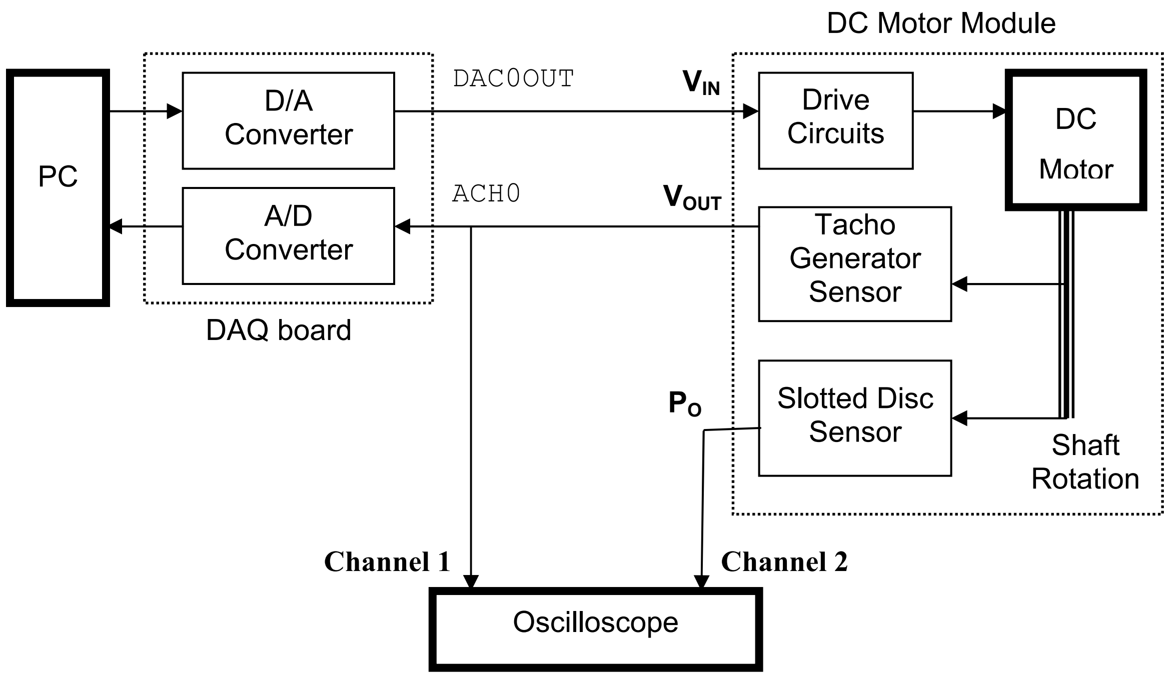

Figure 2. System diagram for obtaining digital feedback from the slotted disc sensor and displaying it on an oscilloscope.

1. Open **`yourname_lab4_ex5.vi`** and save this as **`yourname_lab7_ex1.vi`**. This VI is shown in **Error! Reference source not found.**.

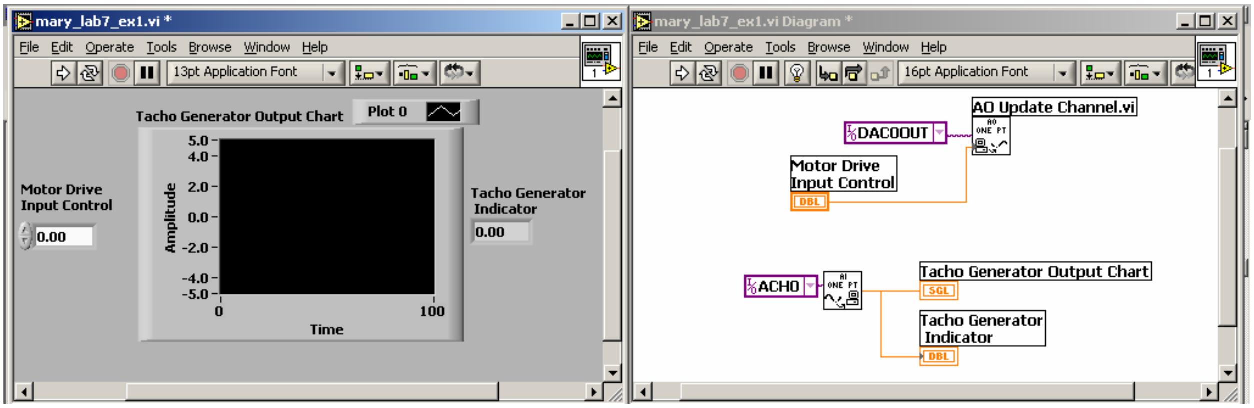

Figure 3. Front panel and block diagram for `yourname_lab7_ex1.vi`.

2. Prepare (set the appropriate switches on) your DC motor control module so that you can drive the motor with analog voltage input and also obtain analog velocity feedback from the tachogenerator output.
   - **MOTOR DRIVE** switch: **V_{IN}** position – selects analog motor drive input
   - **TACHOGENERATOR** switch: **V_{OUT}** position – enables analog velocity feedback output

3. To drive the motor using the analog voltage output from the DAQ board, connect your motor control module to the CB-68LP connector block as shown in Table 1.

Table 1. CB-68LP connector block pin assignments for open loop analog control of DC motor velocity.

DC Motor Control Module	Connect to:
V_{IN} socket (Analog voltage) on **MOTOR DRIVE INPUT** panel	Pin 22 (DAC0OUT)
V_{OUT} socket (Analog voltage) on **TACHOGENERATOR OUTPUT** panel	Pin 68 (ACH0)

4. Ground Pin 55 (AOGND) and Pin 67 (AIGND) on the connector block to common ground on the DC power supply or to the **0V** socket (Analog ground) on the DC Motor Control Module.
5. Connect your DC motor control module to your oscilloscope such that the tachogenerator output **V_{OUT}** is viewed on **Channel 1** and the slotted disc output **P_0** is viewed on **Channel 2**. For best viewing, set your vertical scales to 2 volts/division and your horizontal scale to 200 ms/division.
6. Make sure the **Eddy Current Brake** is disengaged. That is, make sure it is in the `0` position.
7. Make sure that no wires or cables interfere with the moving parts of your motor.

8. Turn ON your Tektronix PS280 DC Power Supply. This will provide power to the motor control module.
9. Run **`yourname_lab7_ex1.vi`** by clicking the **Run Continuously** button. For nonzero values of V_{IN}, Channel 2 should show a periodic low-pulse train. If the pulse train is not clearly visible or if it appears faded, adjust the **WAVEFORM INTENSITY** knob on your oscilloscope until you can clearly see the low pulses.
10. Increment your `Motor Drive Input Control` by 1V for every integer value between (and including) `-5.00` and `5.00` and observe the voltage signals on Channels 1 and 2 of your oscilloscope. Make a sketch of your oscilloscope display and write down the steady state* values of V_{IN} and V_{OUT} (as displayed by the digital indicators on your VI front panel). Also estimate and write down the (time) periods T between low pulses.
11. Set your `Motor Drive Input Control` to `0.00` and stop running the VI by clicking the **Abort Execution** (stop) button.

Experiment #2: View and Obtain Digital Feedback from Slotted Disc Output of DC Motor Module

In this experiment, you will repeat what you did in Experiment #1, but also use a *LabVIEW* VI to acquire and view the digital signal from the **Slotted Disc** output. **Digital I/O Channel 0** (DIO0) on the DAQ board has already been configured to read (acquire) TTL voltage signals.

1. Open **`yourname_lab7_ex1.vi.`** Modify it as shown in **Error! Reference source not found.** and save it as **`yourname_lab7_ex2.vi`**.

* "Steady state" means that you have waited long enough that transient motion has ceased.

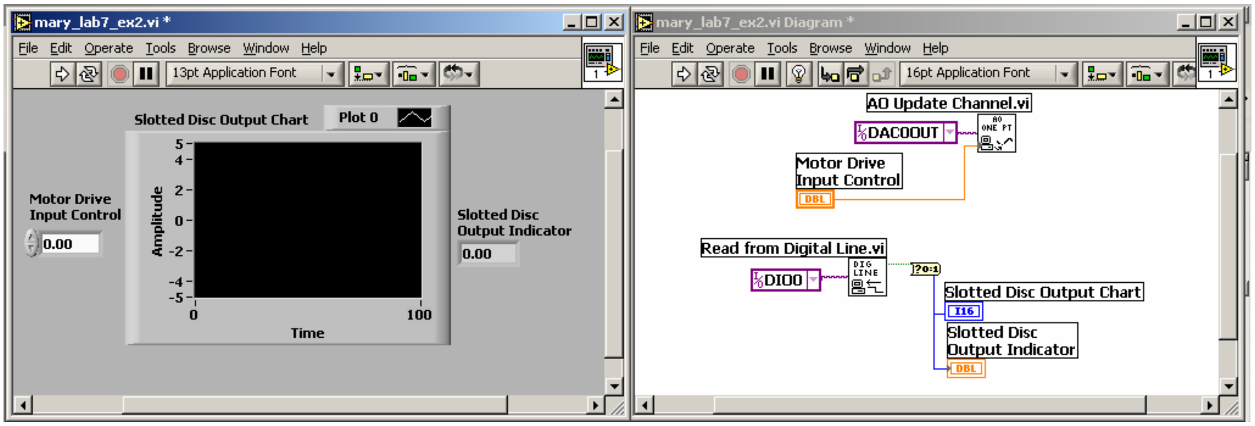

Figure 4. Front panel and block diagram for `yourname_lab7_ex2.vi`.

2. To read (acquire) the digital slotted disc signal, connect the Slotted Disc Output from your motor control module to the CB-68LP connector block as shown in Table 2. Do not remove the connections you made during Experiment #1. Also retain the oscilloscope connections for viewing purposes.

Table 2. CB-68LP connector block pin assignment for reading a TTL voltage signal using Digital I/O Channel 0.

External Signal	Connect to:
Slotted Disc Output (**P_0**)	Pin 52 (DIO0)
Ground (**0V**)	Pin XX (DGND)*

*Digital ground should be provided using the DGND pin that is closest to the Digital I/O line being used. In this case, ground the DGND pin that is closest to DIO0 (Pin 52).

3. Run your VI by clicking the **Run Continuously** button.

Even though your oscilloscope will display the low pulses from your slotted disc output, you will not see all of them on the `Slotted Disc Output Chart` on your front panel. This is because the low pulses are of such a short duration that the probability of one of them being sampled by the **Read from Digital Line VI** is very low. By turning the slotted disc at a very slow angular velocity, however, you can observe the low pulses from the slotted disc output.

4. Set your `Motor Drive Input Control` to `0.00` (**V_{IN}** = 0)
5. Turn the **Slotted Disc** with your hand until the slot is very close to the slot detector diode. Now slowly turn the Slotted Disc back and forth so that the slot passes near the slot detector. Verify that

the `Slotted Disc Output Chart` shows low whenever the slot is aligned with the slot detector.

6. Stop running the VI by clicking the **Abort Execution** (stop) button.

Experiment #3: Build a VI that uses the Slotted Disc Output to Calculate Motor Velocity

In this experiment, you will use a *LabVIEW* VI to drive your DC motor using an analog voltage signal, similar to what you did in Experiment #1. At the same time, you will read (acquire) the digital feedback from the slotted disc output and use that information to calculate the angular velocity of your motor in real-time.

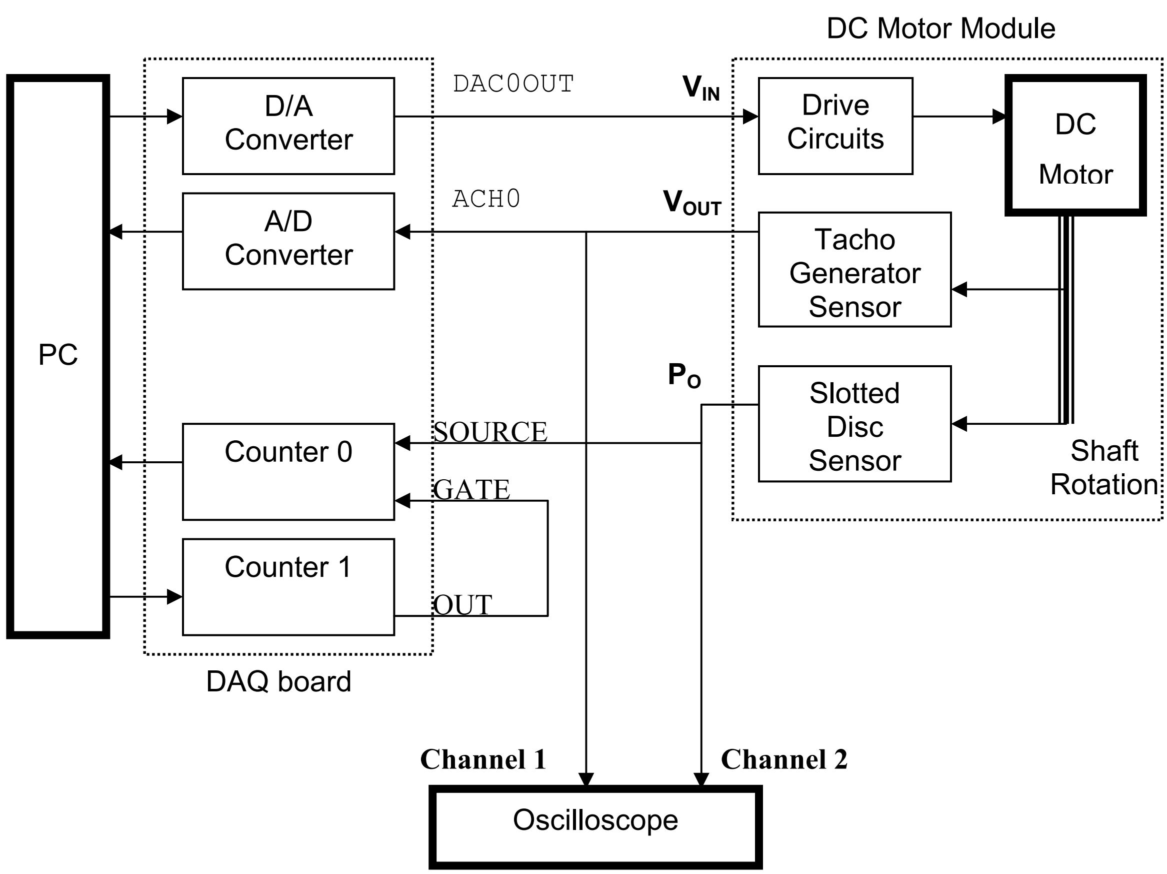

Figure 5. System diagram for obtaining digital feedback from the slotted disc sensor and using a *LabVIEW* VI to convert it to the angular velocity of the motor.

1. Build the VI shown in Figure 6 and save it as **`yourname_lab7_ex3.vi`**.

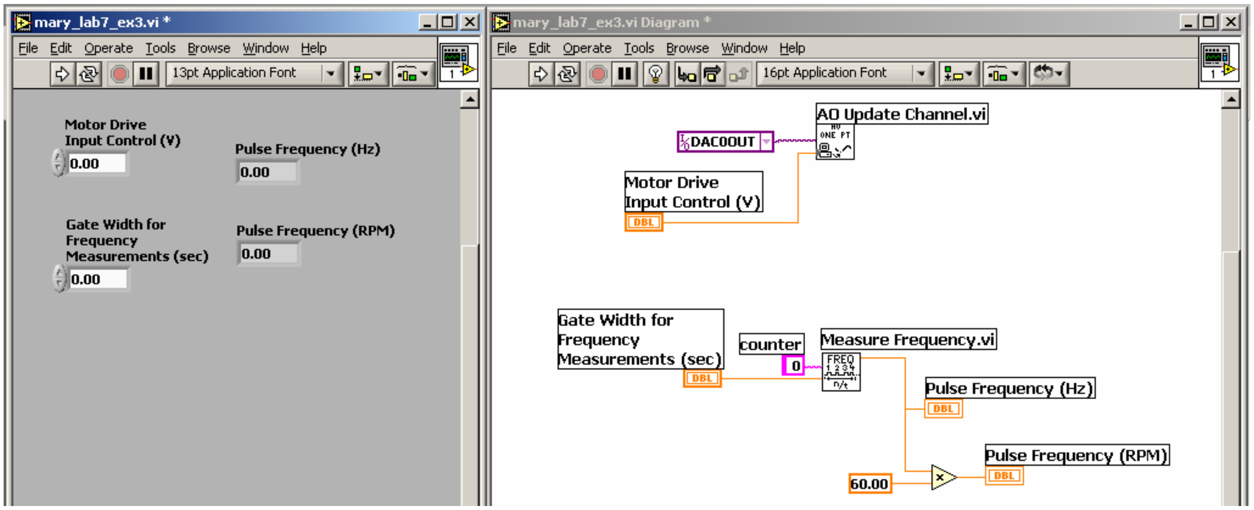

Figure 6. `yourname_lab7_ex3.vi`: VI for acquiring digital feedback from the slotted disc sensor and converting it to angular velocity.

The **Measure Frequency VI** measures the frequency of a TTL signal on the specified counter's (**Counter 0**) SOURCE pin (see step 3 below) by counting the number of positive edges of the signal during a period of time specified by `the Gate Width for Frequency Measurements` control. In addition to this connection, you must wire **Counter 0**'s GATE pin to the OUT pin of **Counter 1** (see step 2 below). When this is done, **Counter 1** supplies a known pulse to the GATE of **Counter 0**, which allows **Counter 0** to count the number of cycles of the unknown pulse during the known GATE pulse.

2. Connect CB-68LP Pin 40 (`GPCTR1_OUT`) to Pin 3 (`GPCTR0_GATE`).
3. To read (acquire) the digital slotted disc signal, connect the Slotted Disc Output from your motor control module to the CB-68LP connector block as shown in Table 3. Of the connections you made during Experiment #2, the only one you should remove is the connection between $\mathbf{P_0}$ and `DIO0` (CB-68LP Pin 52). Retain the oscilloscope connections for viewing purposes.

Table 3. CB-68LP connector block pin assignment for reading a TTL voltage signal using Counter 0 Source.

External Signal	Connect to:
Slotted Disc Output ($\mathbf{P_0}$)	Pin 37 (GPCTR0_SOURCE)

Ground (**OV**)	Pin XX (DGND)*

*Digital ground should be provided using the DGND pin that is closest to the Digital I/O line being used. In this case, ground the DGND pin that is closest to Pin 37.

4. Set the `Gate Width for Frequency Measurements` control to `2.00` seconds.
5. Run your VI by clicking the **Run Continuously** button. Your DC motor will show a delayed response to your `Motor Drive Input` commands due to the online calculations being performed by the **Measure Frequency VI**.
6. Increment your `Motor Drive Input Control` by 1V for every integer value between (and including) `-5.00` and `5.00` and observe the voltage signals on Channels 1 and 2 of your oscilloscope. Write down the steady state values of V_{IN} and motor angular velocity in both Hertz and RPM (as displayed by the digital indicators on your VI front panel).
7. Set your `Motor Drive Input Control` to `0.00` and stop running the VI by clicking the **Abort Execution** (stop) button.
8. Save this VI as **`yourname_lab7_ex3.vi`**.

Experiment #4: Build a VI that displays the Gray Code Disc Output in Decimal Form

In this experiment, you will build a LabVIEW VI that collects the 4-bit digital feedback from the Gray Coded Disc Output and directly converts it to a decimal number. **Digital I/O Port 0** (DIO) on the DAQ board has already been configured to read (acquire) eight lines[*] of TTL voltage signals.

1. Build the VI shown in Figure 7 and save this VI as **`yourname_lab7_ex4.vi`**.

[*] Digital I/O port 0 (`DIO`) consists of the eight digital I/O lines `DIO0` to `DIO7`.

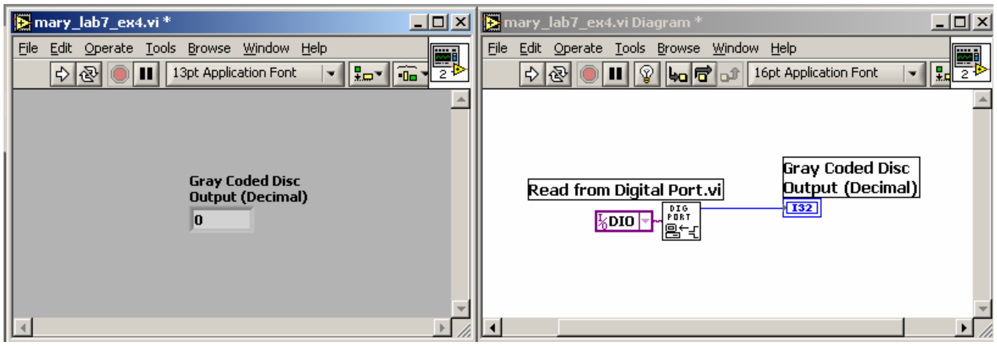

Figure 7. `yourname_lab7_ex4.vi`: VI for acquiring digital feedback from gray coded disc.

2. Make sure that the Analog and Digital control panels on your DC motor control module are not connected to the CB-68LP connector block. In particular, make sure that $\mathbf{V_{IN}}$ is not connected to the CB-68LP.
3. To read (acquire) the 4-bit Gray-Coded Disc signal, connect the Gray-Coded Disc Output from your motor control module to the CB-68LP connector block as shown in Table 4.

Table 4. CB-68LP connector block pin assignment for reading a TTL voltage signal using Digital I/O Port 0 (default).

Output from **GRAY CODED DISC** Panel	Connect to:
Gray-Code Bit 0 ($\mathbf{D_0}$)	Pin 52 (DIO0)
Gray-Code Bit 1 ($\mathbf{D_1}$)	Pin 17 (DIO1)
Gray-Code Bit 2 ($\mathbf{D_2}$)	Pin 49 (DIO2)
Gray-Code Bit 3 ($\mathbf{D_3}$)	Pin 47 (DIO3)
Ground (**OV**)	Pin 19 (DIO4), Pin 51 (DIO5), Pin 16 (DIO6), and Pin 48 (DIO7).

4. Run your VI by clicking the **Run Continuously** button.
5. Turn the **Gray-Code Disc** with your hand until 0° on the **Output Shaft** disc (See Figure 1) is aligned with the marker. Slowly adjust the Output Shaft until the `Gray Coded Disc Output` indicator on your front panel shows `0`.
6. Slowly turn the Output Shaft in the counter-clockwise direction and write down the `Gray Coded Disc Output` values in the order in which they appear. Do so until the `Gray Coded Disc`

Output value returns to 0. Verify that the values repeat (predictably) if you keep turning in the counter-clockwise direction. Also verify that the values appear in the reverse order if the Output Shaft is turned in the clockwise direction.

7. Stop running the VI by clicking the **Abort Execution** (stop) button.

Experiment #5: Build a Virtual Instrument for Generating a Digital Pulse Train

In this experiment, you will build a *LabVIEW* VI that will enable you to output a digital pulse train from your DAQ (data acquisition) board.

1. Build the VI shown in Figure 8. The **Generate Pulse Train VI** can be used to configure the specified counter (**Counter 0**) to generate a continuous pulse train on the counter's OUT pin (See step 2 below).

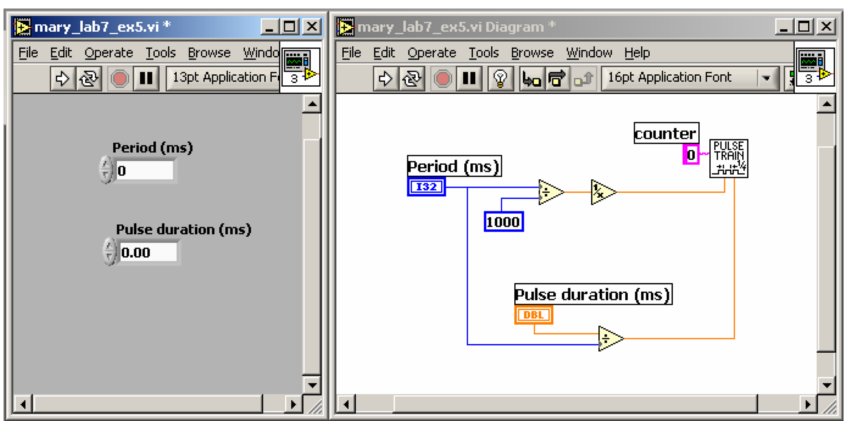

Figure 8. `yourname_lab7_ex5.vi`: VI that generates a digital pulse train.

2. Right click on the `Pulse Duration` control and select **Data Range**. In the Data Range dialog box, enter `1.00` for the **Minimum** and `2.00` for the **Maximum**. Leave all the other settings unchanged. Click the **OK** button to apply these bounds.
3. Connect Pin 2 (`GPCTR0_OUT`) of your CB-68LP connector block to **Channel 2** of your oscilloscope. For best viewing, set your vertical scales to 2 volts/division and your horizontal scale to 10 ms/division.
4. Set the `Period` control to `20` ms and the `Pulse Duration` control to `1.50` ms.

5. Run your VI by clicking the **Run** button. The OUT terminal of **Counter 0** will continuously generate the specified pulse train. To apply a new value of the `Pulse Duration`, enter a new value and then hit the **Run** button. Do not change the `Period`. (Leave it as 20 ms).
6. Using your oscilloscope display, verify the duration (width) of your pulses for pulse durations of 1.00 ms, 1.50 ms, and 2.00 ms.
7. To stop running the VI, set the `Pulse Duration` control to `1.50` ms and then click the **Run** button.
8. Save this VI as **`yourname_lab7_ex5.vi`**.

Experiment #6: Drive the DC Motor Using a Digital Pulse Train

In this experiment, you will drive the DC motor using the digital pulse width modulated (P.W.M.) output from your DAQ board. As indicated in the DC Motor Control Module User Manual, a positive going TTL pulse of 1-2 ms duration is required and must be repeated approximately every 20 ms.

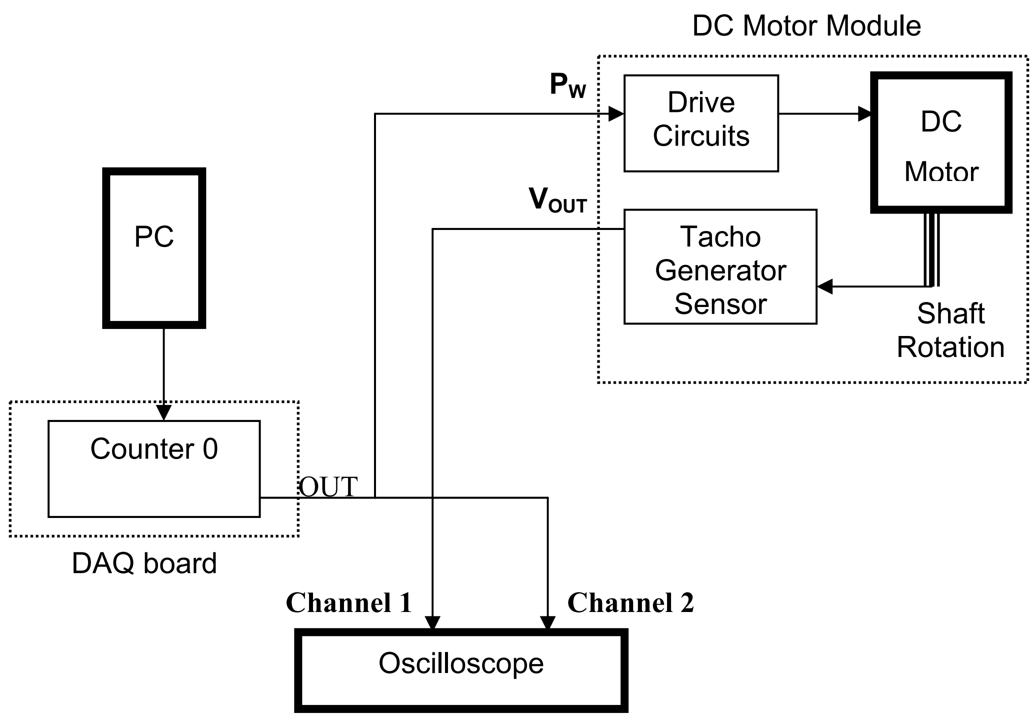

Figure 9. System diagram for driving the DC motor module with a digital pulse train from a VI.

1. Find the **MOTOR DRIVE** switch on your motor control module. To specify that you are using digital pulse width modulated input, select the **P.W.M.** position.
2. Find the **P.W.M. INPUT** panel on your motor control module. To enable the selected input (**P.W.M.**) to drive the motor, use a banana connector to connect the $\overline{\mathbf{E}}$ (**Enable Input)** socket to the **0V** socket.
3. Connect your DC motor control module to your oscilloscope such that the tachogenerator output V_{OUT} is viewed on **Channel 1**. Retain the connection you made to **Channel 2** during Experiment #5.

To use the digital P.W.M. signal from the DAQ board, connect your motor control module to the CB-68LP connector block as shown in

4. Table 5. Do not remove the connections to the oscilloscope.

Table 5. CB-68LP connector block pin assignment for using digital pulse train from Counter 0 Output to drive DC Motor.

P.W.M. INPUT Panel on DC Motor Control Module	Connect to:
P_W socket (P.W.M. digital input)	Pin 2 (GPCTR0_OUT)
OV socket (Ground)	Pin ** (DGND)*

*Digital ground should be provided using the DGND pin that is closest to the Digital I/O line being used. In this case, ground the DGND pin that is closest to Pin 2.

You are now ready to drive your DC Motor.

5. Open **`yourname_lab7_ex5.vi.`**
6. Using the **Operating** tool, click the **Run** button to drive the DC Motor using the digital P.W.M. output from your DAQ board.
7. Verify that a `Pulse Duration` (width) of 1.50 milliseconds results in a stationary motor. Also verify that a pulse duration of 1.00 ms results in maximum speed in one direction, whereas a pulse duration of 2.00 ms results in maximum speed in the opposite direction.
8. Increment your `Pulse Duration` control by `0.10` ms for every (tenth of a millisecond) value between (and including) `1.00` ms and `2.00` ms and observe the voltage signals on Channels 1 and 2 of your oscilloscope. Write down the steady state values of the `Pulse Duration` indicator (on your VI front panel) and also the value of the **OUTPUT SHAFT RPM** indicator shown on your **Digital Tachometer** (Figure 1).
9. To stop running the VI, set the `Pulse Duration` control to `1.50` ms and then click the **Run** button.

10. Turn OFF your Tektronix PS280 DC Power Supply

Saving Files

Before you leave, remember to save all of your files to a **floppy disk** (for later use and backup purposes). For this laboratory, you should save the following files from the `Desktop`:

`yourname_lab7_ex1.vi`

`yourname_lab7_ex2.vi`

`yourname_lab7_ex3.vi`

`yourname_lab7_ex4.vi`

`yourname_lab7_ex5.vi.`

Laboratory Report

1. For the VI's you wrote in this laboratory (listed in the preceding section), provide a printout that shows the front panel and block diagram.
2. Using the data you collected in Experiment #1, plot low pulse frequency (1/**T**) versus $\mathbf{V_{IN}}$. ($\mathbf{V_{IN}}$ is the Motor Drive Input, while **T** is the period between low pulses). Clearly label your axes and units.
3. Using the data you collected in Experiment #3, plot $\mathbf{f_{Hz}}$ versus $\mathbf{V_{IN}}$. Clearly label your axes and units. Compare this plot with your plot from Question 2 above. Explain any differences.
4. Using the data you collected in experiment #3, plot $\mathbf{f_{RPM}}$ versus $\mathbf{V_{IN}}$. Clearly label your axes and units. Compare this plot with your plot from Question 5 from Lab report #4. Explain any differences.
5. Starting from 0, list, in order, the decimal values you observed during Experiment #4 when you turned the Output Shaft in the counter-clockwise direction. Do your values agree with the **Gray code** shown on page 7 of the DC Motor Control Module User Manual?
6. In Experiment #4, what would happen to the values on the `Gray Coded Disc Output` indicator if you connected **Digital I/O Channel 6** (`DIO6`) to 5V (high) instead of 0V (low)? Explain.
7. Using the data you collected in Experiment #6, plot **OUTPUT SHAFT RPM** versus pulse duration $\mathbf{P_W}$. Does your plot agree with the figure on page 6 of the DC Motor Control Module User Manual? Explain.
8. Specify the CB-68LP pin numbers of the **Digital Ground** (DGND) connections you used in Experiment #2, 3, and 6. Also list the pin numbers of all the other DGND connections that are available on your CB-68LP connector block.

Your Lab Report should clearly state your name, Lab Report number, Lab date, and your laboratory partner's name (if any). Your lab report should be thorough, but concise. You will be graded on quality, not quantity. **Lab Report #7 is due at the beginning of Laboratory #8.**

Additional Reading

Feel free to read the following material to learn more about *LabVIEW*'s digital I/O and related features.

1. ***LabVIEW* Data Acquisition Basics Manual**, **Chapter 16** *(When You Need It Now—Immediate Digital I/O*), **Chapter 24** *(Generating a Square Pulse or Pulse Train*) and **Chapter 26** *(Measuring Frequency and Period*). Available online at www.ni.com/pdf/manuals/320997c.pdf.

Extra Credit Exercise: Build a VI that Converts and Displays the Gray Code Disc Output from Gray Code to Natural Decimal Code.

In Experiment #4, you built a VI that directly converted the Gray Code Disc output to decimal form. In this extra credit exercise, you will modify that VI such that the Gray Code Disc output is converted to natural (counting) decimal code. That is, the Gray code should be first converted to natural (counting) binary code and that natural binary code should be directly converted to decimal form.* When you turn the motor Output Shaft in the counter-clockwise direction, the natural decimal code output should count from 0 to 15 and repeat every 40°.

1. Open **`yourname_lab7_ex4.vi`** and modify it so that your front panel shows two indicators. One should be the `Gray Coded Disc Output` in decimal form (as in Experiment #4), while the other indicator should show the Gray Code output after it has been converted to natural (counting) decimal form.
2. **<u>Lab Report Question 9</u>**: For the VI you wrote in this extra credit exercise, provide a printout that clearly shows the front panel and block diagram. Explain how you implemented the conversion from Gray Code to natural decimal code.

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* See Mechatronics textbook, Section 9.2.4.