

## **Hands on Remote Learning using a DC Motor Controller**

**Robert Barsanti, Ronald Hayne, Johnston Peeples**

*The Citadel*

### **Abstract**

An Electrical and Computer Engineering Laboratory exercise has been included in the junior year fall term to partially bridge the theory to practice gap for multiple basic electrical and computer engineering topics. The laboratory investigates facets of power electronics and computer control for students who have recently been introduced to the theory of transistor bridge circuits for voltage polarity control in their electronics class, and digital pulse width modulation for DC motor speed control in their first computer logic class. After brief study of its specification, students follow a lab sequence to set up and instrument a commercial H-bridge to first record polarity and magnitude of output voltages under specified input conditions, and subsequently to observe DC motor response to same inputs. DC power polarity, and averaging through Pulse Width Modulation (PWM), as well as the collateral realities of brushed DC motor noise and logic versus power supply levels become clear to most student for the very first time. This particular laboratory, consuming only two hours in residence and similar time for report generation, has resulted at least two unexpected positive outcomes. First, students who have taken this lab display a better understanding of DC motors topics taught in an electrical machines course the following spring semester, and second, when appropriate they understand and properly use H-bridge motor control in their senior design. This lab is perfect for remote learning since it uses the analog discovery measurement system, and a low cost commercially available motor, and motor controller circuit. This exercise can also be used as a precursor to a more sophisticated related laboratory activity, in which the students make use of a microcontroller to generate the pulse width modulation signal.

### **Keywords**

Lab Exercise, Motor Controllers, H-Bridge, Pulse Width Modulation, Remote Learning,

### **Introduction**

It is well documented that many students are motivated to learn more when a hands-on activity is added to the topic [1, 2]. Additionally, many electrical engineering programs are looking for remote laboratory exercises in the pandemic environment. To achieve these goals the faculty has put together a laboratory exercise to demonstrate the operation of a motor controller that can be accomplished by second or third year students with an Analog Discovery kit [3, 4, 5, 6, and 7] and an inexpensive motor controller [8, 9, and 10].

For the assessment minded among us, at least three ABET student learning outcomes are addressed in the performance of the lab exercise. Outcome 1: identify, formulate, and solve

complex engineering problems by applying principles of engineering, science, and mathematics. Outcome 6: develop and conduct appropriate experimentation, analyze and interpret data, and use engineering judgment to draw conclusions. Outcome 7: acquire and apply new knowledge as needed, using appropriate learning strategies [11].

## The H-Bridge Controller

The students begin the exercise by downloading the data sheet for L298 Dual H-Bridge Motor Driver shown in figure 1. [9]

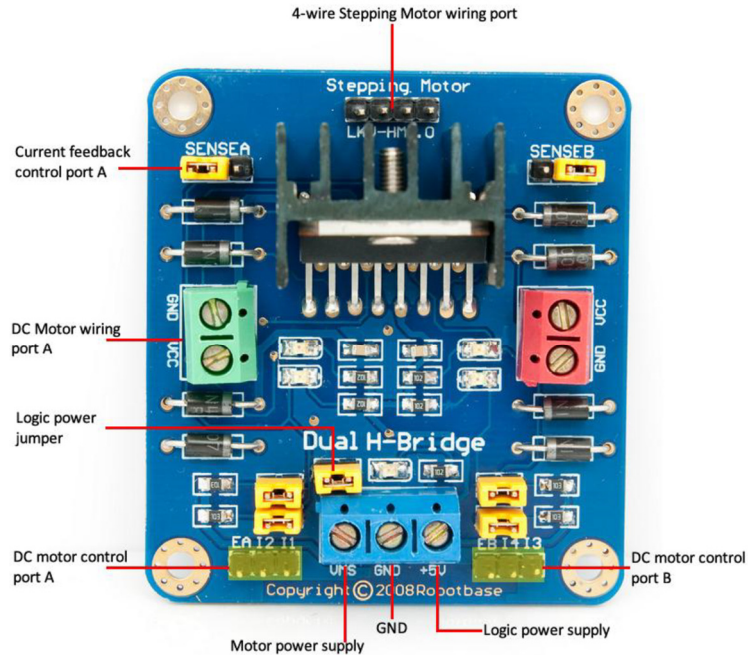


Figure 1. L298 Motor Driver [9]

The L298 Motor Driver is a dual H-bridge that can provide up to 46 volts and 4 amps to drive a variety of inductive loads including DC and stepping motors. Motor power and Logic power inputs for both motors are connected to the VMS and +5V terminals of the blue connector at bottom center of Figure 1. The small dark green connectors at bottom right and left accept digital inputs for direction control (I1, I2) and for speed control (EA). Modulated power is output to each motor from the green and red terminals midway along each side of Figure 1.

Only one motor is required for this exercise.

## H-Bridge Theory

The direction of motion of a DC motor depends on the polarity of the applied voltage. Consider figure 2. If switches S1 and S4 are closed, the VCC supply voltage is connected to the left side of the motor. Conversely, if switches S2 and S3 are closed VCC is connected to the right side, and the motor will turn in the opposite direction.

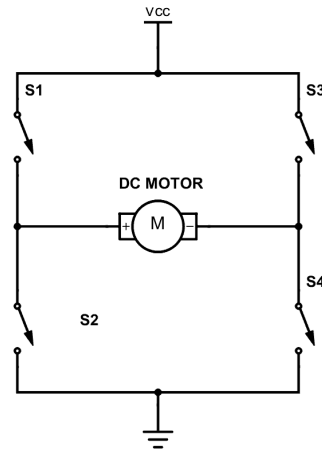


Figure 2. H-Bridge Concept Circuit [12]

The simple principle described in figure 2, can be extended to the circuit diagram for the L 298 N dual H-bridge shown in figure 3. Note that it contains two H-bridge circuits A and B. Third year ECE students with experience using transistors and digital logic gates should be able to describe the operation of this circuit. In particular, how the transistors act as switches and how the logic AND gates control the inputs I1, I2, and EA.

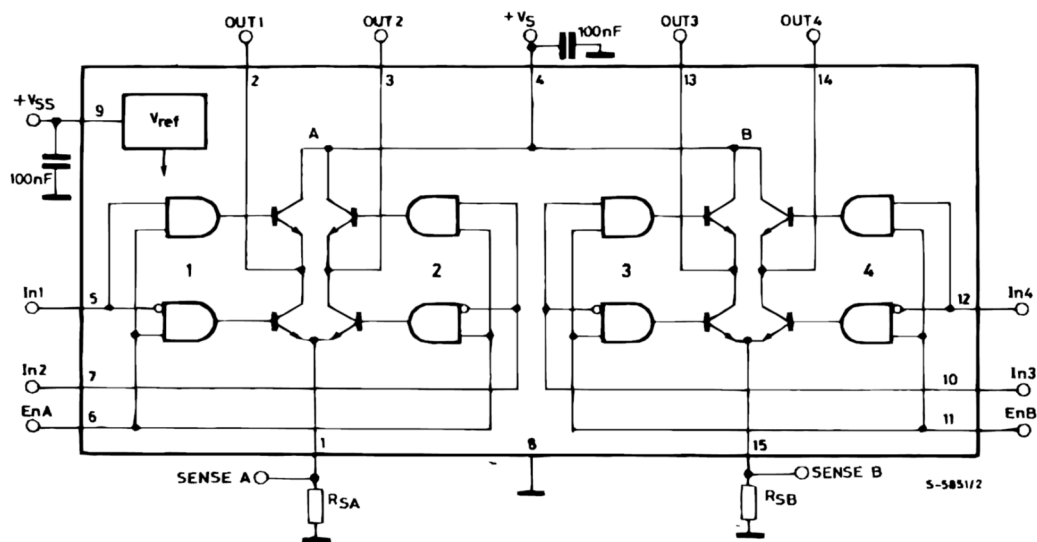


Figure 3. L298N Circuit Diagram [9]

### Laboratory Set Up

Students connect the L298, a 6 V DC motor, a 220 ohm resistor, and measuring equipment as shown in figure 4. The 220 ohm resistor is used as a surrogate for the motor when measuring voltages and observing waveforms to eliminate the noise caused by the inexpensive, brushed motor. Analog Discovery kits are used to supply the logic power, and measure  $V_{out}$ . Data

collection is designed to illustrate both the operation of the L298 (its  $V_{out}$  and LED indicators) and the reaction of the motor (speed and direction). The voltage  $V_{out}$  and the LED indicators are observed using the resistor surrogate, which is then replaced by the motor to observe the effects of the voltages and polarity on motor speed and direction.

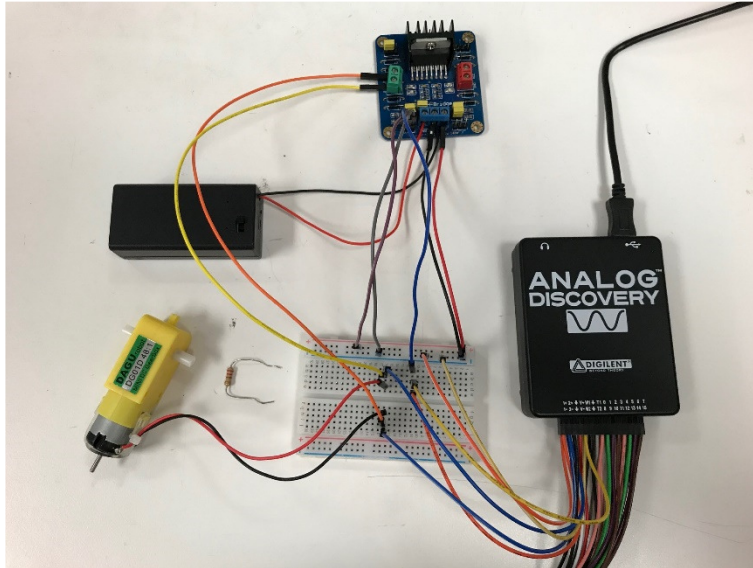


Figure 4: Lab set up for motor controller

Measuring the voltage across the 220 ohm resistor and observing the LED lights on the L298 controller the students complete the truth table shown as table 1.

EA	I2	I1	$V_{out}$	LED	Motor Direction
L	L	L	0.00 V	BOTH	Brake
L	L	H	0.00 V	RED	Brake
L	H	L	0.00 V	GREEN	Brake
L	H	H	0.00 V	NONE	Brake
H	L	L	-6.4 mV	BOTH	Brake
H	L	H	7.57 V	RED	Clockwise
H	H	L	-7.57 V	GREEN	Counter-CW
H	H	H	0.8 mV	NONE	Brake

Table 1: Logic Table for DC Motor Control.

The truth table indicates that no output voltage is provided to the motor unless the controller is enabled (EA high). Further, positive or negative voltage results when either I1 or I2 is high, therefore controlling the direction of rotation of the DC motor.

## PWM Theory

Pulse width modulation or duty-cycle variation methods are commonly used to control the speed of DC motors. Controlling the on time and off time (duty cycle) of a pulse signal changes the average voltage supplied to the motor without changing the magnitude of the supply.

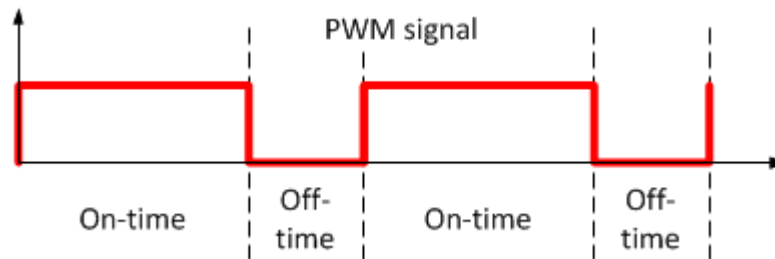


Figure 5. PWM Signal [13]

The students' next procedural step is to set up the circuit for pulse width modulation by connecting the EA input to the waveform generator output of the Analog Discovery. Figure 5 displays the PWM waveform captured by the Waveforms software.

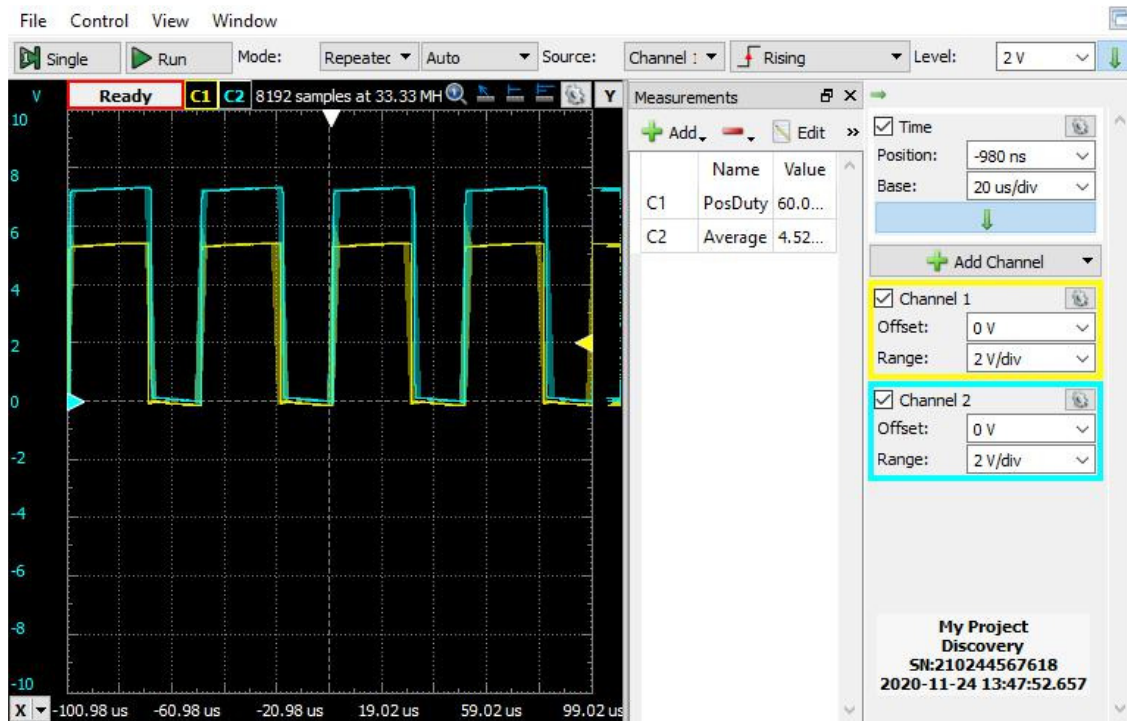


Figure 6. PWM using Analog Discovery Waveforms software

Figure 6 displays a 20 kHz square wave with a 60% duty cycle. Two channels are employed to observe both the input signal provided to EA and the output voltage across the 220 ohm load. The varying duty cycle at the L298N EA input modulates the 9V DC power to control the speed of the motor. The students record the output voltage for each duty cycle in table 2.

$D$ (%)	20	30	40	50	60	70	80
$V_{out,avg}$ (V)	2.21	3.04	3.85	4.67	5.48	6.29	7.10

Table 2: PWM Data

Students observe that increasing the duty cycle increases the output voltage and thus the speed of the motor.

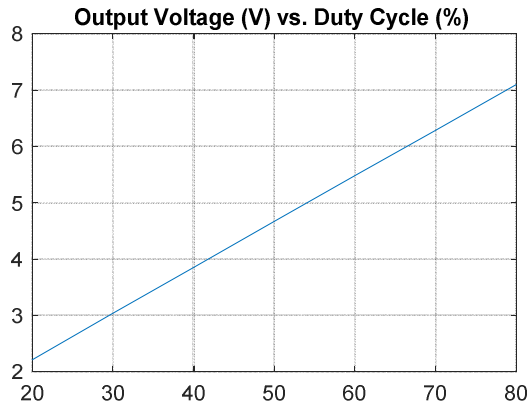


Figure 7: Output Voltage vs Duty Cycle using table 2 data

### Lab Questions

The typical laboratory write-up includes the objectives, equipment, procedure, data, results and conclusion section. Additionally, the following questions can be used to induce further thought.

1. What is pulse width modulation?  
Pulse width modulation achieves a desired range of DC (average) values for a given waveform by adjusting its duty cycle.
2. What is the relationship between threshold voltage  $V_{ON}$  and threshold duty cycle  $D_{ON}$ ?  
 $V_{ON}$  is the input motor voltage that results in a motor output voltage sufficient for the motor to turn.  $D_{ON}$  is the duty cycle of the enable input that modulates the constant input motor voltage to create the average DC motor output voltage sufficient for the motor to turn.
3. Discuss two ways that the L298 can be used to control the speed and the direction of the DC motor.

The *direction* of the DC motor is controlled by applying logic High or Low to the inputs I2 and I1. The *speed* of the DC motor may be controlled by (a) adjusting the voltage of the power supply to the motor driver board or (b) applying a pulse-width-modulation signal to the motor's Enable line.

### Extensions to Microcontrollers

A follow-on lab uses a PIC32 microcontroller to generate the PWM signals to drive the same H-bridge. Figure 8 depicts the hardware set up, extended to include the Digilent chipKit Wi-Fire

microcontroller board [14] and the L298. The Wi-FIRE is compatible with the advanced Microchip MPLAB®X IDE and works with all MPLAB ®X programmer/debuggers, such as the Microchip PICKit™3 or the Digilent® chipKIT PGM.

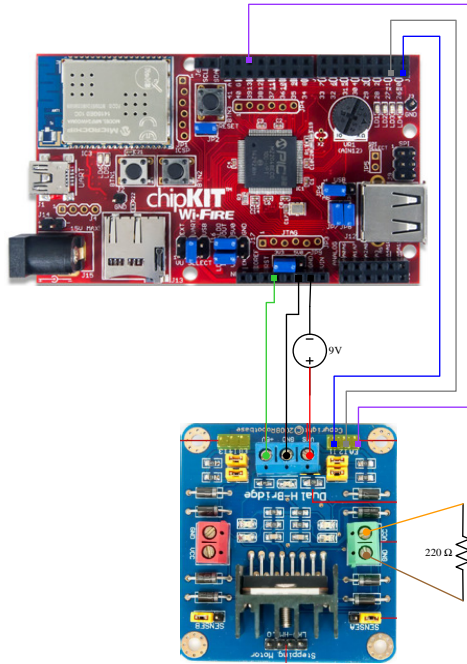


Figure 8. Hardware set-up for using PIC 32 to create the PWM signal

### Remote Learning

This laboratory exercise is an ideal candidate for remote learning. As itemized in Table 3, the hardware costs for the primary lab (DC motor, L298 and 9V battery) is only \$30, and can be extended to include the microcontroller component for an additional \$80. Remote learners also need equipment to generate the PWM signals and to record the necessary voltages, which in this case are the Analog Discovery Kit and corresponding WaveForm software.

Component	Price
L289N H Bridge	23.50
DC Motor	6.00
9Volt battery	2.00
Digilent chipKit Wi-Fire	79.00
Analog Discovery Kit	(Academic) 279.00
Waveforms Software	Free
<b>Total Cost</b>	<b>\$389.50</b>

Table 3. Price Data



The cost of the Analog Discovery Kit is justified since the program uses these kits for multiple experiments from starting with first year introduction to engineering courses, see reference [7]. The program loans these kits to the students for the duration of the semester.

### **Student Outcomes, Assessments and Results**

This laboratory exercise requires one lab period or about two hours in to build and record data. Most students require another two hours to produce a quality laboratory report. Faculty feedback indicates that students who have taken this lab display a better understanding of DC motors topics taught in the required electrical machines course the following spring semester. Faculty also report that students understand and properly use H-bridge motor control in their senior design projects.

Informal student feedback was positive. Students enjoyed the project, and the simplicity of using the Analog Discovery instrument system.

### **Summary**

The paper reports on a low cost, hands-on project that can be added to an undergraduate analog control or digital control lecture class to improve the student interest and understanding DC motor controller concepts. The paper provides project objectives, procedures and hardware implementation details for a controlling a DC motor driven by a commercial H-bridge controller, and thus allowing students to explore the use of PWM for speed control using low cost instrumentation.

### **References**

- [1] Kuh, G. D., "High Impact Educational Practices: What They Are, Who has Access to Them, and Why they matter, AAC&U, 2008.
- [2] Zhan, W., Wang, J., Vanajakumari, M., "High impact activities to improve student learning", 120<sup>th</sup> ASEE Annual conference, June 2013.
- [3] Analog Discovery Technical Reference Manual, Digilent Inc., 2013.
- [4] Waveforms SDK manual, Digilent Inc., 2015.
- [5] <https://reference.digilentinc.com/reference/instrumentation/analog-discovery/start>
- [6] <https://reference.digilentinc.com/reference/instrumentation/analog-discovery-2/specifications>
- [7] Mazzaro, G., Hayne, R., "Instructional Demos, In-Class Projects, and Hands-On Homework: Active Learning for Electrical Engineering using the Analog Discovery," Proceedings of 2016 ASEE annual conference.
- [8] L298 Dual H Bridge Motor Driver <https://www.robotshop.com/en/seedstudio-l298-dual-h-bridge-motor-driver.html>
- [9] <https://www.robotshop.com/media/files/pdf/datasheet-mot103b1m.pdf>
- [10] <https://www.robotshop.com/en/dfrobot-6v-180-rpm-micro-dc-geared-motor-with-back-shaft.html>
- [11] <http://www.abet.org/accreditation>
- [12] <https://www.build-electronic-circuits.com/h-bridge/>



[13] PWM wave, <http://modularcircuits.com/blog/wp-content/uploads/2011/10/image4.png>

[14] Wi-FIRE Reference Manual [Digilent Documentation],  
<https://reference.digilentinc.com/reference/microprocessor/wi-fire/reference-manual>

## **Authors**

### **Robert Barsanti**

Bob Barsanti is a Professor in the Department of Electrical and Computer Engineering at The Citadel, where he teaches a variety of courses and does research in the area of target tracking and signal processing.

### **Ronald Hayne**

Ron Hayne is a Professor in the Department of Electrical and Computer Engineering at The Citadel, where he teaches digital systems design using hardware description languages. He is a retired Army Colonel with experience in academics and Defense laboratories.

### **Johnston Peeples**

John Peeples is a Professor in the Department of Electrical and Computer Engineering at The Citadel, where he teaches solid states electronics and senior design. He does research in the area of electronic cooling.