Section	
Bench No.	

ECE110 Introduction to Electronics

Experiment 8 : PWM Motor Wheel Balance

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This part is reserved for your instructor

Score	
Instructor Signature	
Date	

Experiment 8: PWM Motor Wheel Balance

Laboratory Outline:

In the prelab, you constructed a square wave signal with an adjustable duty cycle typically called a Pulse-Width-Modulated (PWM) signal. In an earlier lab, you used different resistances to attempt to balance the speed of your two wheels. While this method was effective, it also had a very low power efficiency ($\eta = P_{useful}/ P_{input}$) and was prone to motor stalls if attempting to significantly reduce the speed.

Today, we will implement a method of wheel balance that utilized the MOSFET-based motor drives for high efficiency and PWM control for high-motor torque and lower risk of motor stalling. A single potentiometer allows for a simple method of adjustment to make the car run a straight path.

Learning Objectives

- Use the running-motor model you determined prior, estimate the RMS current drawn by the motor at a known RMS voltage.
- Adjust your PWM signal to different duty cycles, make observations on the oscilloscope, save your data.

In the pre-lab you have already built the PWM-based circuit. Connect the oscillator to the motors as in Figure 1.

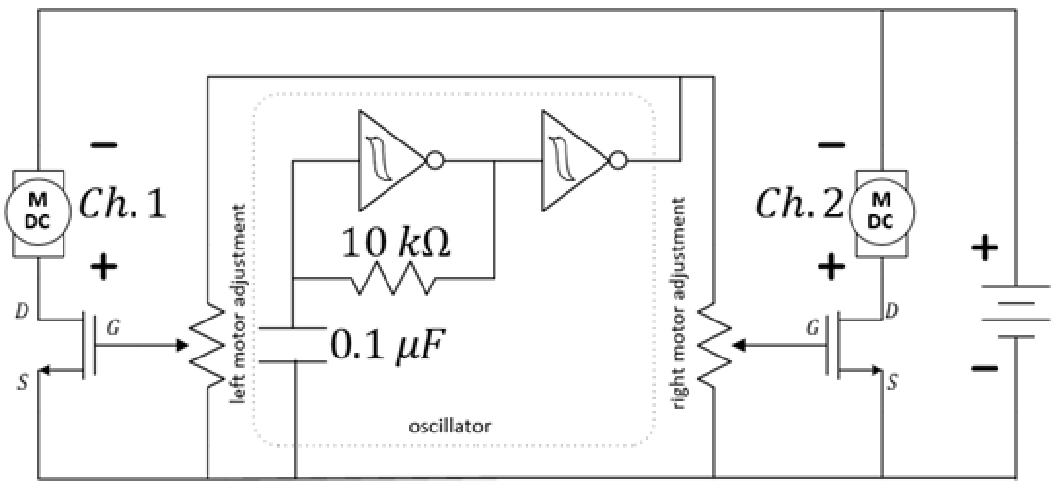


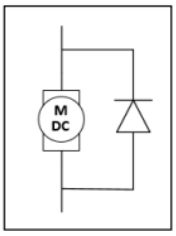
Figure 1*: *Using the oscilloscope to measure across the motors.

Note these two inverters on the same chip

Note that the voltage across the motor is not a perfect square wave. In fact, there is a significant voltage spike when the MOSFET is suddenly turned off. This is referred to as counter-electromotive force (counter-EMF) or sometimes simply “back EMF”. This is a direct result of the windings of the motor acting as an inductor which stores energy in a magnetic field as current flows through it. When the current drive is suddenly suppressed, that stored field energy will resist such a sudden change causing the high spike in voltage.

Question 1: Sketch (or capture using Oscilloscope and plot in MATLAB) the voltage across one motor, careful to show the spike in voltage.

This large spike in the voltage can lead to motor damage. We can protect each motor by placing a signal diode across each motor. We will learn more about diodes later which will help us understand how they work in this application. Place the diodes across the motor's leads as shown in the image on the right. Use your Oscilloscope verify the spike has been suppressed.



Question 2: Sketch the suppressed waveform on the figure above as well.

Question 3: As shown in the figure 1, If you reverse the polarity of Channel 2 (that is, if you reverse the red and black probes of Channel 2 *only*), the motors will (nearly?) stop. Try this, but ***only for a few seconds at a time*** because the MOSFETs will get ***very hot***. Why do the wheels stop?
Hint: The negative electrodes of all measurement channels of the oscilloscope are internally connected to the ground.

Build the motor-control circuit below that includes an adjustable wheel-speed balance potentiometer. You should see the familiar motor-drive circuits as well as the recently-constructed oscillator. You may be surprised to see three Schmitt-trigger inverters in this design. The first Schmitt-trigger is used in the PWM oscillator design. The second Schmitt trigger buffers the oscillator circuit from the MOSFET of one motor-drive circuit so that that circuit does not cause a significant load on the oscillator that might affect its behavior. The third Schmitt-trigger inverter inverts the previous signal such that the duty cycle of the second wheel is mirrored of that of the first motor. That is, while the first wheel is driven by duty cycles that can be adjusted from 0 to 100%, the second wheel is driven by duty cycles that vary from 100% to 0%, respectively. The two duty cycles will always follow $dc_1\,\% + dc_2\,\% = 100\%$.

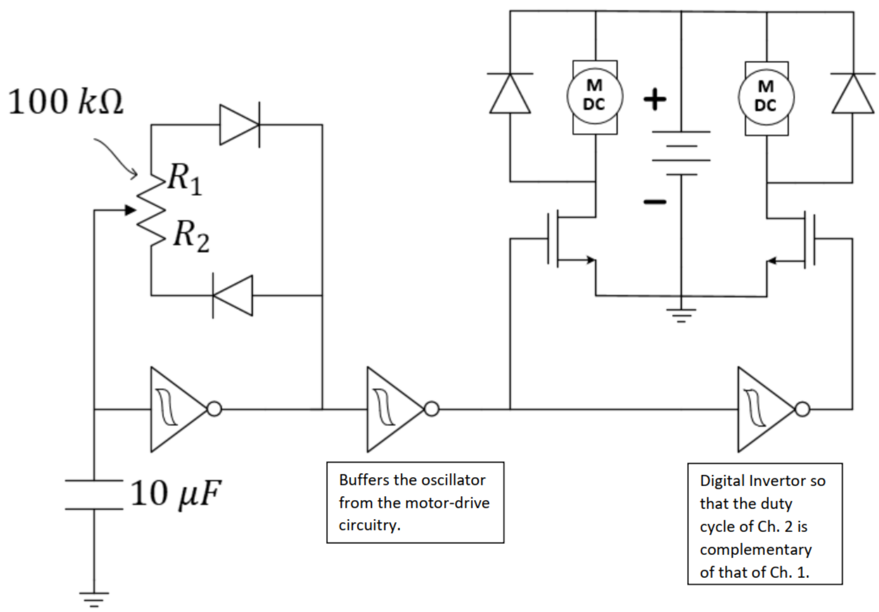


Figure 2: *PWM-based wheel balancer.*

Disconnect the motors from the positive side of the battery to disable them for now. Place the probes of **channel 1 and 2** between the circuit ground and the two outputs of the inverters (MOSFET gates) as shown in the figure below. After pressing the **Default Setup** button on the scope, adjust the scopes **vertical, trigger, and horizontal settings**, respectively, to get a nice view of the two *orthogonal* waveforms. **Use your $100k\Omega$ potentiometer to adjust the duty cycle so that Channel 1 is at 40% and Channel 2 at 60%.** Use the **measure button** to do this accurately.

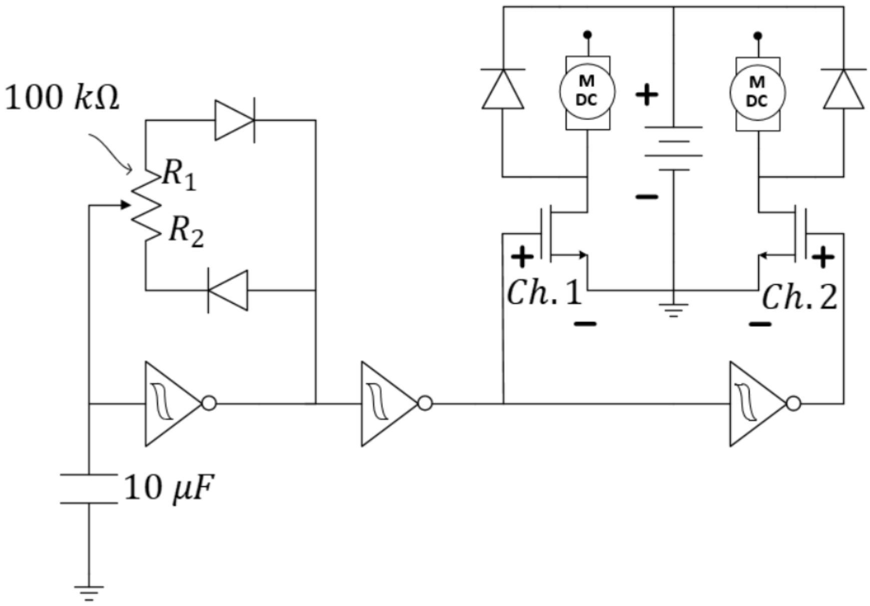


Figure 5: Disable the motors and use the oscilloscope to view and record the orthogonal outputs of the oscillator

Question 4: Use software to collect these waveforms of **channel 1 and 2**. You need to print it out or draw it by hand.

You are now ready to build a self-navigating vehicle. In the process, you have learned to model devices, predict behavior, build circuits, analyze circuit behavior, measure circuit parameters, and troubleshoot using the oscilloscope as a window into your work.

Recall the moving-motor model you determined in lab 6. That model was determined for DC voltages applied to the motor.

$$I = mV + b$$

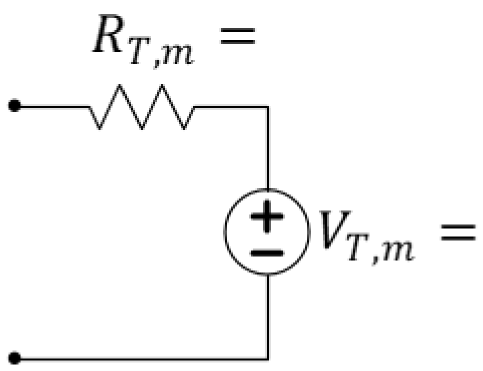


Figure 3: *Recalling the Thevenin model of the moving motor.*

Let's assume that when using PWM signals, we can exchange the model's DC voltage with the RMS voltage of the PWM signal. That is, we will assume

$$I_{rms} = mV_{rms} + b$$

is an accurate model for the motor using the same m and b found in the previous lab. Use this assumption to answer the lab summary questions.

Question 5: What are your values of m and b from lab 6 ?

Question 6: What RMS current would we expect when driving the motor with a PWM signal of 40% duty cycle and a 0-to-peak amplitude of 7 volts?

Question 7: What RMS current would we expect when driving the motor with a PWM signal of 60% duty cycle and a 0-to-peak amplitude of 7 volts?

Question 8: Discuss with the other students alternative ideas for balancing the wheel speeds. Write one or more of those ideas below.

Save this circuit! Store this motor-drive circuit for next week with your car chassis in the locker and take the other breadboard home for Prelab#9.

Explore More! Modules

Explore More! Modules provide students with options to investigate new concepts! As time allows, do one or more of the modules before returning to the laboratory's core procedure.

This week, we highly recommend the following ***Explore More! Modules:***

***Explore More*! 8B The Clipping Circuit**	***Explore More*! Schmitt Trigger IV**	***Explore More*! Voltage-Follower Buffer**