DC MOTOR AMPLIFIERS

Topics Covered

- Actuator dead-band measurement and compensation.
- Linearity of an amplifier.

Prerequisites

- The QNET Mechatronic Actuators has been setup and tested. See the QNET Mechatronic Actuators Quick Start Guide for details.
- You have access to the QNET Mechatronic Actuators User Manual.
- You are familiar with the basics of LabVIEW™.
- You are familiar with basic circuit theory.

1 Background

Amplifiers are essentially an electrical network that have a single input and a single output. The voltage gain of the amplifier is defined as the ratio of the output and input voltages when each is measured relative to earth ground. The *operational amplifier* (op-amp) forms the basis of many approaches to signal conditioning. An op-amp is a high-gain DC amplifier that has two inputs known as the inverting input (-), and the non-inverting input (+).

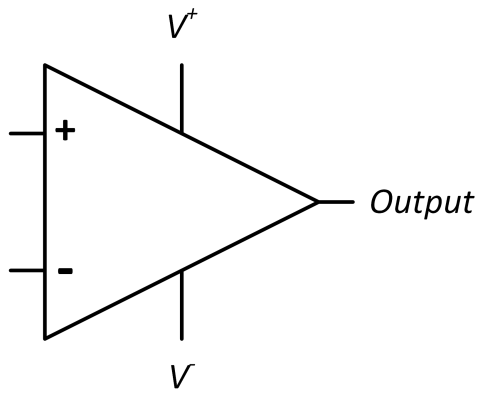


Figure 1.1: Operational amplifier (op-amp) symbol

The output from the amplifier depends on the way in which the inputs and outputs are interconnected. Typically, op-amps are supplied on a silicon chip and have the four inputs shown in Figure 1.1, and a voltage offset.

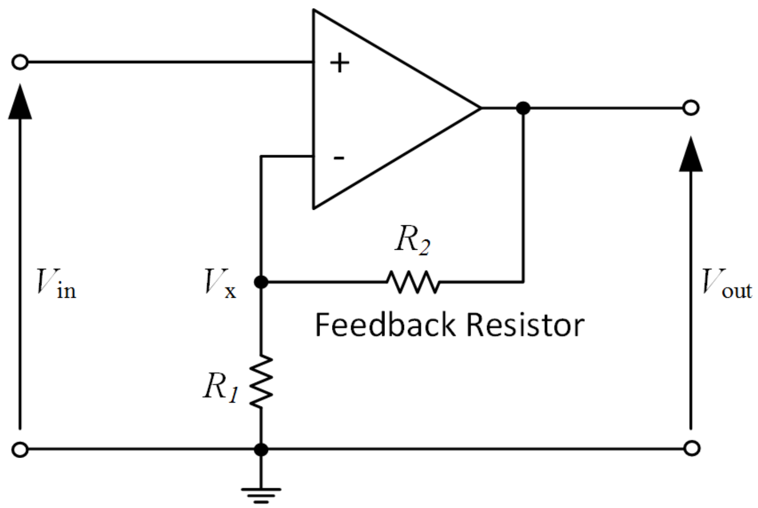
1.1 Linear Amplifier

The first of the two brushed DC motors on the QNET Mechatronic Actuators uses a *linear* amplifier circuit to scale the voltage and current supplied by the NI ELVIS II. The linear amplifier circuit uses two op-amps configured as non-inverting amplifiers, shown in Figure 1.2a. In the case of an op-amp connected as a non-inverting amplifier, the output can be interpreted as being taken across a potential divider circuit consisting of R_1 in series with R_2. Therefore, the voltage, V_x, can be expressed as

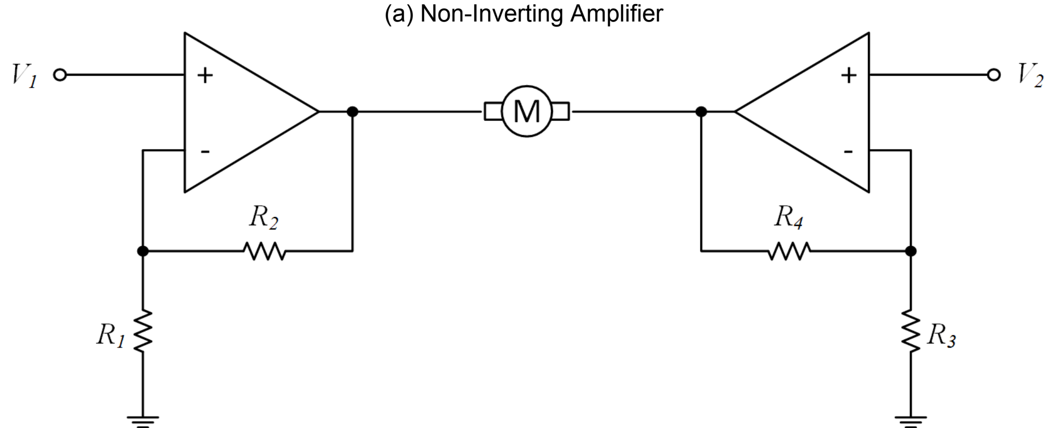
$$V_x = \frac{R_1}{R_1 + R_2} V_{\text{out}} \tag{1.1}$$

Given that there is virtually no current through the op-amp between the two inputs, there is virtually no potential difference between them. Viewing the op-amp as ideal, we can let $V_x = V_{\text{in}}$ which yields

$$\text{Voltage Gain} = \frac{V_{\text{out}}}{V_{\text{in}}} = \frac{R_1 + R_2}{R_1} = 1 + \frac{R_2}{R_1} \tag{1.2}$$



(a) Non-Inverting Amplifier



(b) Bi-Directional Motor Control

Figure 1.2: QNET Mechatronic Actuators Linear amplifier configuration

The two non-inverting amplifiers are combined in a bi-directional configuration, shown in Figure 1.2b, to allow the motor to turn in either direction. This configuration was used because the brushed DC motors on the NI ELVIS II are rated for 24V. Using the ideal non-inverting configuration shown in Figure 1.2a, we would ideally connect one side of the motor to the amplifier, and the other to ground. We would then be able to drive the motor using ±24V. However, as is often the case when working with specific system configurations in mechatronics, the QNET Mechatronic Actuators does not have a -24V supply. To overcome this limitation, the system was configured as shown in Figure 1.2b in order to provide a complete 48V operating range. In the configuration shown, the two amplifiers work together to supply the commanded voltage across the motor. For example, when a command of +6V is sent to the motor, one amplifier supplies 12 - (6/2) = +9V, while the other supplies 12 + (6/2) = +15V. For a command in the opposite direction, such as -10V, the first amplifier supplies 12 + (10/2) = +17V, and the second 12 - (10/2) = +7V.

1.2 PWM Amplifier

In mechatronic systems, brushed DC motors are often controlled using the output from a microprocessor. The most common technique to allow a microprocessor to drive and control a DC motor is using a technique known as pulse width modulation (PWM). This technique generally involves rapidly chopping a DC supply voltage such that the commanded voltage is represented by the average value of the signal. The commanded voltage can thus be varied by modulating the width of the pulse supplied.

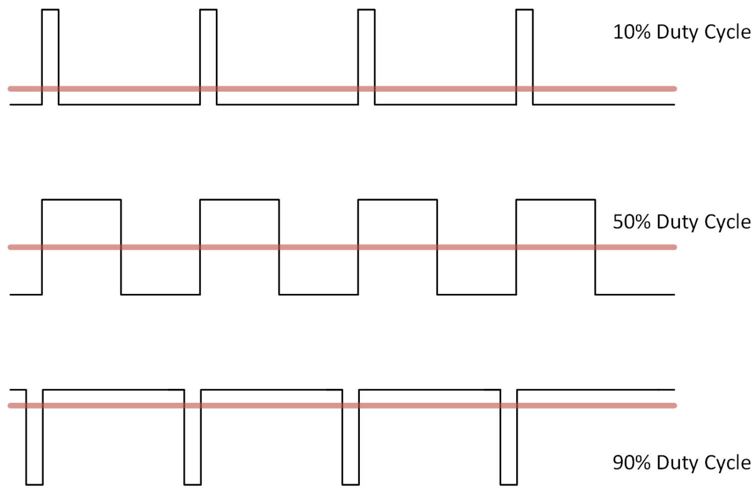


Figure 1.3: PWM Signal

To create a PWM signal that is appropriate for driving a DC motor, a basic transistor circuit known as an H-circuit or H-bridge is used. Figure 1.4 shows a typical full H-bridge configuration for bi-directional DC motor control as it is most commonly configured using transistors. Using the PWM signal to turn the transistors on and off at different rates, we can control the average voltage that the motor sees as a function of the duty cycle and source voltage. For example, with a 24V source, a duty cycle of 25% is equivalent to an applied voltage of $0.25 \times 24 = 6$V, whereas a duty cycle of 50% results in a voltage of $0.5 \times 24 = 12$V.

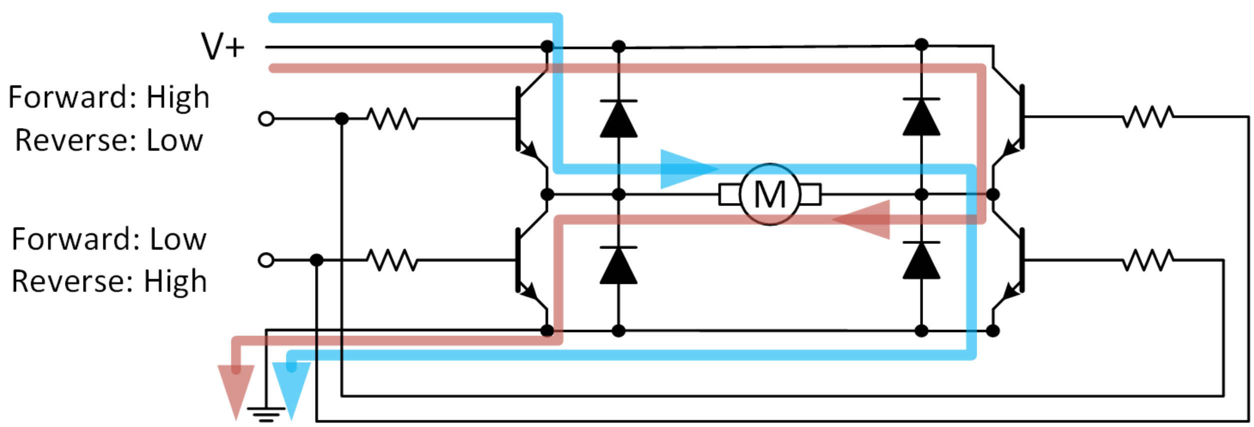


Figure 1.4: H-bridge

The QNET Mechatronic Actuators uses a full H-bridge driver in an integrated circuit. This reduces the required components and provides additional protection, including over-current protection, thermal protection, and shoot-through protection. *Shoot-through* occurs when two of the adjacent transistor switches are open at the same time, shorting the voltage supply to ground. The H-bridge driver used in the QNET Mechatronic Actuators contains MOSFET transistors, as shown in Figure 1.5, which is taken from the block diagram in the data sheet.

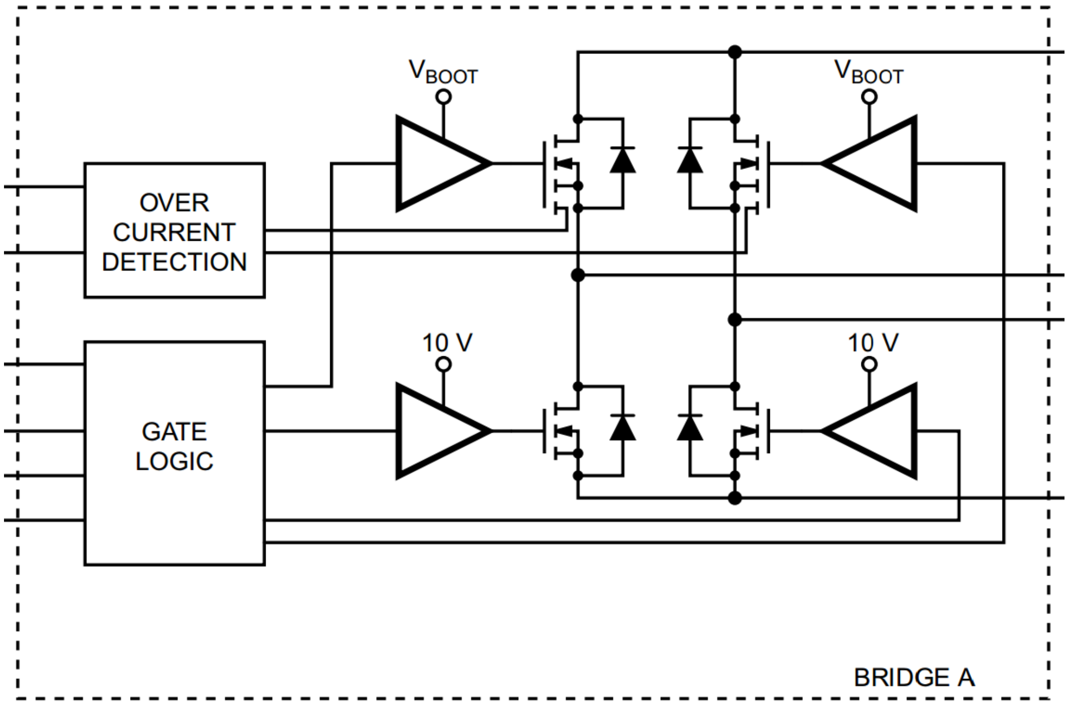


Figure 1.5: MOSFET-based full H-bridge configuration

1.3 Deadband

Deadband is a common non-linear phenomenon that is characterized by a momentary delay in the response of a system. In the case of a DC motor, this behaviour is usually observed as the system transitions from one direction to another, or is close to stationary. Deadband is undesirable because it introduces non-linearity into the response of the motor which can cause the actuator to respond poorly to control signals. The deadband performance of DC motor amplifiers varies significantly depending on the approach taken. Linear amplifiers often exhibit smaller deadbands because their response to commands is immediate, and directly proportional to the input command. PWM amplifiers on the other hand can introduce significant deadband into an actuator system because at lower duty cycles the delay between pulses can cause the motor to lose momentum and stall due to static friction, or stiction. PWM amplifiers can also introduce further delays when transitioning from one direction to another as the shoot-through protection prevents the two switch sets from being simultaneously powered. Custom logic can be introduced into PWM amplifier circuits to compensate for their deadband, and to make the response of an actuator more linear.

2 In-Lab Exercise

1. Open QNET Actuators - DC Motors and Solendoid.vi. **Make sure the correct Device is chosen.**
2. Ensure that the Power Solenoid button is off.
3. Run the VI, and gradually increase the voltage applied by the linear amplifier until the DC motor starts to move. Record the voltage. Repeat the process to find the negative dead-band by gradually decreasing the voltage. Record the voltage.
4. What do the two voltages recorded represent? Comment on their values, and how they might effect the performance of the DC motor.
5. Reset the voltage applied to 0V, then increase the voltage once again to the value found in Question 3 that causes the motor to begin to turn.
6. Slowly decrease the applied voltage until the motor stops moving. Comment on this phenomenon, and what might be the cause.
7. Design and implement a procedure to test the linearity of the amplifier. Record your results, and discuss the performance of the amplifier.

   Note: If the motor is stalled for more than a couple seconds, the current applied to the motor will be halted to protect the motor and amplifier from overheating. If you would like to reset the status of the stall detection monitor, press the Linear PWM Stall Ack button.

8. Using the theoretical torque constant of the DC motor, k_t = 0.0253, what is the torque that corresponds to the static friction of the motor?
9. Repeat the tests performed in Question 3 and Question 7 using the PWM amplifier driven DC motor to analyze the dead-band and linearity of the PWM-driven system. Record and discuss your results.
10. Compare your results from the linear amplifier testing to the PWM amplifier tests. What do the results indicate about the mutual performance of the two types of amplifiers?
11. How might a compensation algorithm be added to the PWM amplifier logic in order to reduce the effects of the dead-band on the response of the system?
12. Given that PWM amplifiers generally have a smaller form factor, generate less heat, and are cheaper than linear amplifiers, give some examples of when you would use one technology over the other.

Quanser Inc.
119 Spy Court
Markham, Ontario
L3R 5H6
Canada
info@quanser.com
Phone: 1-905-940-3575
Fax: 1-905-940-3576

Printed in Markham, Ontario.

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