Shockingly Fun

ENSC 384

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1 Introduction

The Bidirectional DC Motor Speed Controller Kit controls the speed of the DC motor in this project in both the forward and reverse direction. The direction and speed is controlled using a voltage input signal, initial set with a potentiometer. At a 'center' input voltage, the motor is at rest. For input voltages greater than this value, the voltage applied to the motor increases causing it to spin in one direction. For input voltages less than this 'center' input voltage, the motors direction is reversed.

The motor is controlled by a pulse width modulation (PWM) amplifier and driven by four MOSFET transistors in an H-bridge configuration. This report first will briefly discuss the design of the oscillator for a nominal PWM frequency of 300Hz. The results of a simulation performed in the LTSpice software package are then presented. Secondly, the report will illustrate the input/output characterization of the circuit for a series of input voltages based on data gathered during simulation and testing. Furthermore, the power dissipated by the MOSFETs in the power amplifier will be estimated and the heat sink design will be selected. Finally, the verification and testing will be examined on both the physical circuit and the simulated design.

2 Circuit Design and Operation

This section examines the amplifier control circuit, specifically the PWM oscillator.

2.1 Selection of Component Values

The desired PWM oscillation frequency for the circuit is 300 Hz. A diagram for the oscillator, taken from the instruction manual for the motor control kit, may be seen in figure 1; component numbers used henceforth refer to this diagram. As presented during lecture, equations 1 and 2 show the two time components of the oscillator output, rise time and fall time. Given the 300 Hz desired frequency, component values must be found to satisfy equation 3.

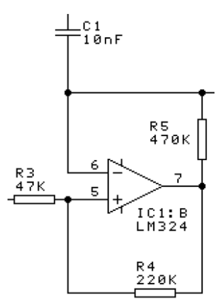

Figure 1: Circuit Oscillator Circuit - From Manual

$$T_1 = R_5\, C \ln\left(\frac{R_3\ V^+}{R_4\ (V^+ - V_{in})} + 1\right) \tag{1}$$

$$T_2 = R_5\, C \ln\left(\frac{R_3\ V^+}{R_4\ V_{in}} + 1\right) \tag{2}$$

$$300 = \frac{1}{T_1 + T_2} \tag{3}$$

There is a single constraint equation (the frequency) and four component values appearing in the equation which must be chosen. As such, three component values must be fixed, arbitrarily or based on external constraints, to solve for the last component value which gives a 300 Hz frequency. Resistor R_3 acts to scale the input voltage and therefore only impacts frequency to the extent that the input voltage does. Similarly, resistor R_4 simply determines the gain of the op-amp, and offsets the output voltage. The values for R_3 and R_4 were set as those of the actual circuit, $47k\Omega$ and $220k\Omega$ respectively. The capacitors value was also fixed at $10nF$ and V^+ was set to 8 V, the same value used when testing the circuit. Given these constraints, the desired value of R_5 for a 300 Hz frequency is shown in equation 4.

$$R_5 = \frac{1000000}{3} \left(\ln \left(\frac{1}{55} \frac{-534 + 55\, V_{in}}{-8 + V_{in}} \right) + \ln \left(\frac{1}{55} \frac{94 + 55\, V_{in}}{V_{in}} \right) \right)^{-1} \tag{4}$$

It can be seen from equation 4 that the value of R_5 which produces a 300 Hz output frequency depends on the input voltage which is variable. The relationship between input voltage and the desired value for R_5 is shown in figure 2. A single V_{in} must be chosen to determine the value of R_5. Using a 'center' input voltage ($V_{in} = 2.28V$ from figure 5), or the voltage for which the motor is disabled, the desired value for R_5 is $406.1k\Omega$. This value is quite close to the value used on the board $470k\Omega$.

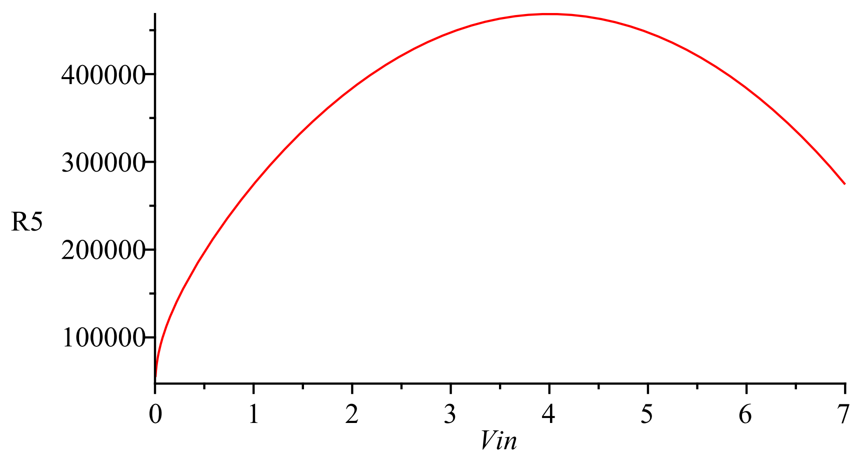

Figure 2: Input Voltage Vs Desired Value for R_5 for 300 Hz Frequency

A circuit simulation confirms a nominal frequency very close to 300 Hz. To verify the frequency, a Fourier transform of the oscillator output for $V_{in} = 2.28V$ and $R_5 = 406.1k\Omega$ is shown in figure 3. It can be seen that the dominant frequency is approximately 300 Hz. A theoretical plot of duty cycle over a range of input voltages may be seen in figure 4.

2.2 Input Output Characterization

The input-output characteristics of the amplifier were examined for the simulated circuit and the actual circuit. The result may be seen in figure 5. It should be noted that the simulated circuit had no load whereas the actual circuit was driving the motor, with no load. Sample values are given in table 1. Refer to section 3.1 for an overview of the process used to obtain experimental values.

3 Verification and Testing

This section details lab activities to test and verify the circuit. After the provided circuit components were soldered to the PCB, two tests were performed. The first found the experimental transfer function between

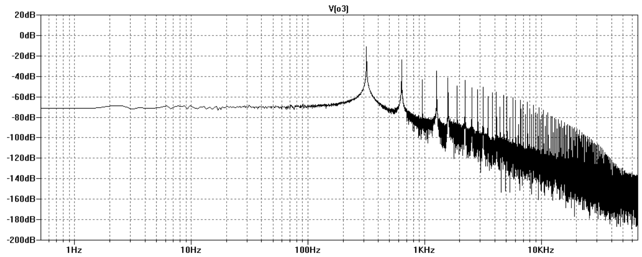

Figure 3: Fast Fourier Transform of Simulated Oscillator Output

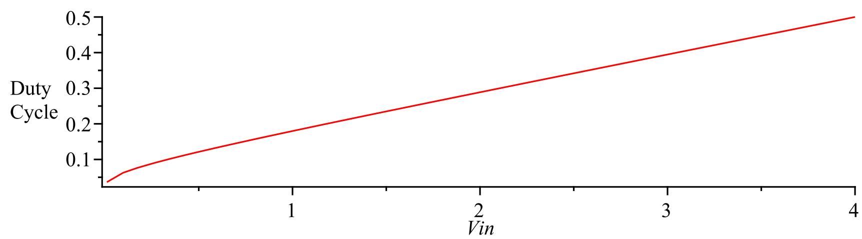

Figure 4: Oscillator Duty Cycle for $V_{in} = 0$ to $V_{in} = \frac{V^+}{2}$

amplifer input voltage and voltage output to the motors. The second test estimated the power dissipated by the MOSFET transistors.

3.1 Amplifier Transfer Function

To obtain the response of the motor to an applied input, the input voltage to the amplifier was adjusted using a potentiometer, Multimeters were used to capture to between the potentiometer output and ground (the amplifier input voltage input) and the associated voltage drop across the motor (output voltage). During testing, an unloaded motor was connected to the amplifier. By taking roughly thirty measurements for input voltages in the range of 0 to 4V, it was possible to establish the experimental relationship seen in figure 5, for a given circuit input voltage of 8V.

3.2 Heat Sink Design

Given the high-power nature of the MOSFET drive transistors, it is important to ensure they do not exceed their maximum operating temperature. To this end, the maximum thermal resistance factor, θ_{JA} for which the MOSFETs may operate safely was calculated. The thermal resistance factor is given by equation 5.

$$\theta_{JA} = \frac{T_J - T_A}{P_D} \tag{5}$$

In this equation T_A represents the ambient temperature, for which $25°C$ was used. The T_J value, or maximum silicon junction temperature, is supplied by the manufacturer and was seen to be $175°C$ for both types of transistors. The P_D value is the power dissipated and is calculated by subtracting the power measured at the load from the power measured at the supply. To determine the load power, two multimeters were used to measure voltage drop across the motor and current through the motor. During the test, the motor was loaded by attempting to hold the shaft. The supply power was similarly calculated by measuring input voltage and current to the entire circuit. It was assumed that that the power dissipation for components

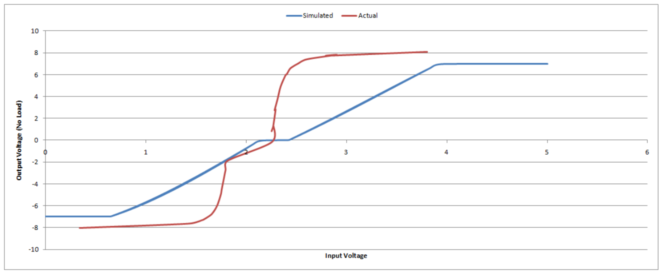

Figure 5: Input-Output Characterization for Simulated (Unloaded) and Actual (Loaded with Motor) Circuit

other than the MOSFETs was negligible. For a loaded motor, it was seen that, Input: 10v @ 0.65 A, Output: 8.25v @ 0.70 A, producing the P_D value in equation 6 .

$$P_D = P_S - P_L = (10V \times .65A) - (8.25V \times .70A) = 0.725W \tag{6}$$

Based on the experimentally observed power dissipation, the maximum thermal junction resistance may be calculated. This is shown in equation 7, assuming all power is dissipated by a single MOSFET. It should be noted that due to the H-bridge design, power dissipation is actually split across two different transistors. The Junction-to-Ambient thermal resistance for both MOSFET transistors is less than $63°C/W$. As such, it is clear that based on experimentally observed power dissipation, there is no need for a heat sink.

$$\theta_{JA_{MAX}} = (175 - 25)\, 0.725 = 206°C/W \tag{7}$$

4 Conclusion

In this part of the project, the bidirectional DC Motor Speed Controller Kit circuit was analyzed and built. Based on the provided circuit diagram, component parameters for an oscillator with a 300 Hz frequency were selected for use in a pulse width modulation amplifier. Using LTSpice, a simulation to verify calculations was performed. The amplifier transfer function was found experimentally and from simulation data, illustrated by an average PWM output vs. input voltage graph.. Finally, an experimental estimate for the power dissipated by the circuits MOSFET transistors was found and used to determine no heat sink is needed.

Table 1: Input-Output Characterization

V_{in}	V_{out} (Actual)	V_{out} (Simulated)
3.8	8.06	6.4819629
2.90	7.8	2.1355862
2.799	7.71	1.6661552
2.6	7.38	0.7739846
2.515	7.0	0.394138
2.459	6.70	0.1553944
2.43	6.48	0.0338252
2.4	6.0	0.0016906
2.39	5.95	0.0012864
2.34	4.89	0.0002554
2.31	3.77	-0.0002944
2.29	2.8	-0.0008018
2.28	2.72	-0.001161
2.27	1.23	-0.001596
2.265	1.2	-0.0018552
2.261	1.1	0.8382106
2.25	0.81	-0.0029108
1.81	-1.9	-1.7913446
1.791	-2.75	-1.8549068
1.752	-4.56	-2.1259024
1.746	-4.92	-2.0894574
1.709	-5.96	-2.2841442
1.665	-6.64	- 2.5689882
1.630	-6.94	-2.748412
1.572	-7.27	-3.0502118
1.555	-7.33	-3.1671898
1.425	-7.64	-3.82
0.338	-8.04	-7.00