Aero Engine Controls Fluid Delivery System

Torque Motor Subsystem

Project Design Review

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1.0 Terms & Keywords

- DMM: Digital Multi-Meter
- FDS: Fluid Delivery System
- PIC: Peripheral Interface Controller
- POT: Potentiometer
- PWM: Pulse Width Modulation (Pulse Width Modulated)
- RVIT: Rotary Variable Inductance Transducer

2.0 Introduction

2.1 Motivation

This project was selected because it was in the group members' field of concentration. Additionally, this project is intriguing since it requires interfacing with engineers who currently work in the field and in meeting performance specifications given by the company. This is a great opportunity to experience practical engineering work prior to joining the workplace.

This project is going to contribute as a part of a vehicular fluid delivery system. It will be a continuation of the work done by a previous group last year. The purpose of this project is to simulate the torque motor that is used by the fluid delivery system in industry. This motor will have an equivalent load of torque that gives an amount of torque analogous to the fluid being delivered.

2.2 Objective

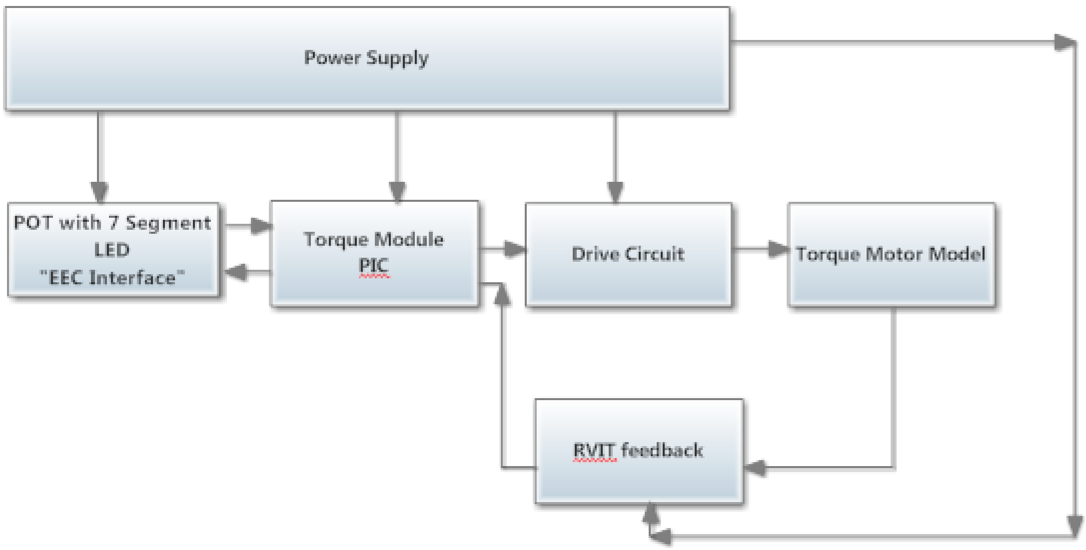
The goal is to design a system that will receive positioning command from a POT knob which is analogous to the EEC controller (a fuel % flow rate controller) and input a variable current though a drive circuitry to drive the motor into desired position. A spring and lever arm will be mounted onto the motor in an effort to simulate fluid resistance. The DC motor used in the project will be equipped with a RVIT sensor, which will provide the positioning information of the motor. This information will be fed back through to the PIC controller for feedback. The PIC will take this RVIT sensor information to adjust the motor controls (by varying the driving current). The RVIT sensor will provide important information which will be used to maximize the efficiency and reliability of the system.

2.3 Benefits & Features

- Insure the reliability of the fluid delivery system
- Provide an accurate estimate of the amount of fluid being delivered
- Improved control over the amount of fluid delivered
- Insure the efficiency of the fluid delivery system
- Provide motor status to a higher level controller
- Dynamic positioning response for motor through use of the RVIT sensor
- Motor with input dependent torque response
- Efficient driving circuitry
- Programmable PIC controller for position and torque modulation

3.0 Design

3.1 Block Diagram



3.2 Block Diagram Descriptions

I. Power Supply: the power supply will be the primary voltage source and will simulate the 28V supply rails used in the industry counterpart of this project. The supply will simply be two over charged 12V batteries connected in series. The 28V rail will be split into 2 sets of voltages; a 13V rail for the H bridge driver chip and 5.1V rail for the PIC.

II. PC "EEC Interface": this is a controller on the vehicle that constantly sends and receives requests to and from the torque module PIC. This component will be simulated by 4 LEDs and a POT in order to interface with the user.

III. Torque Module PIC: this is a programmable PIC controller which will interpret actuation signals from the node controller and send low level actuation signals with which to drive the torque motor model.

IV. Drive Circuit: this is the actuation hardware required to interpret control signals from the PIC board into usable analog signals that will manipulate the motor position. For this project, the drive circuitry will produce a current to drive the motor. (Since we will be implementing this circuit, no additional special circuit is needed)

V. Torque Motor Model: this is a current driven brushed DC torque motor which will act against a compressing spring force to simulate fluid resistance within the delivery system. The motor will operate at 14.5V maximum and 6A maximum (87 Watts).

VI. RVIT feedback: this is the RVIT sensor which will feed positional and torque information back into the PIC controller for dynamic positioning response and efficiency.

3.3 Fluid Resistance Simulation on Torque Motor

The fluid resistance on the valve in the fluid delivery system will be represented by a spring. The motor will have a mounted shaft lever attached to its rotor. This will pull a mounted spring which will act as a torque load analogue to the fluid resistance. The torque delivered can be calculated given spring constant, angle of the lever, and length of the lever. See calculation in testing section.

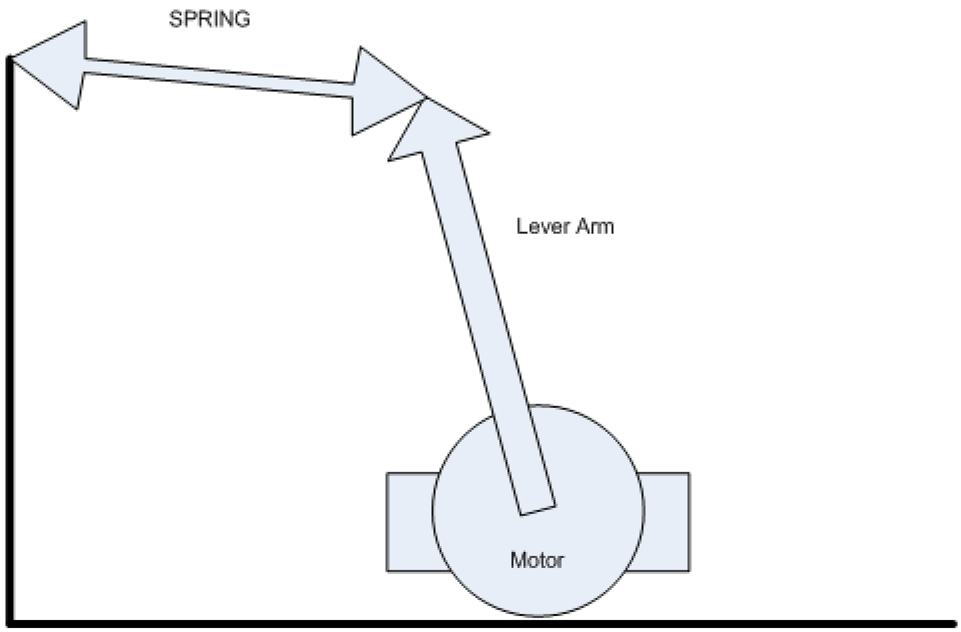
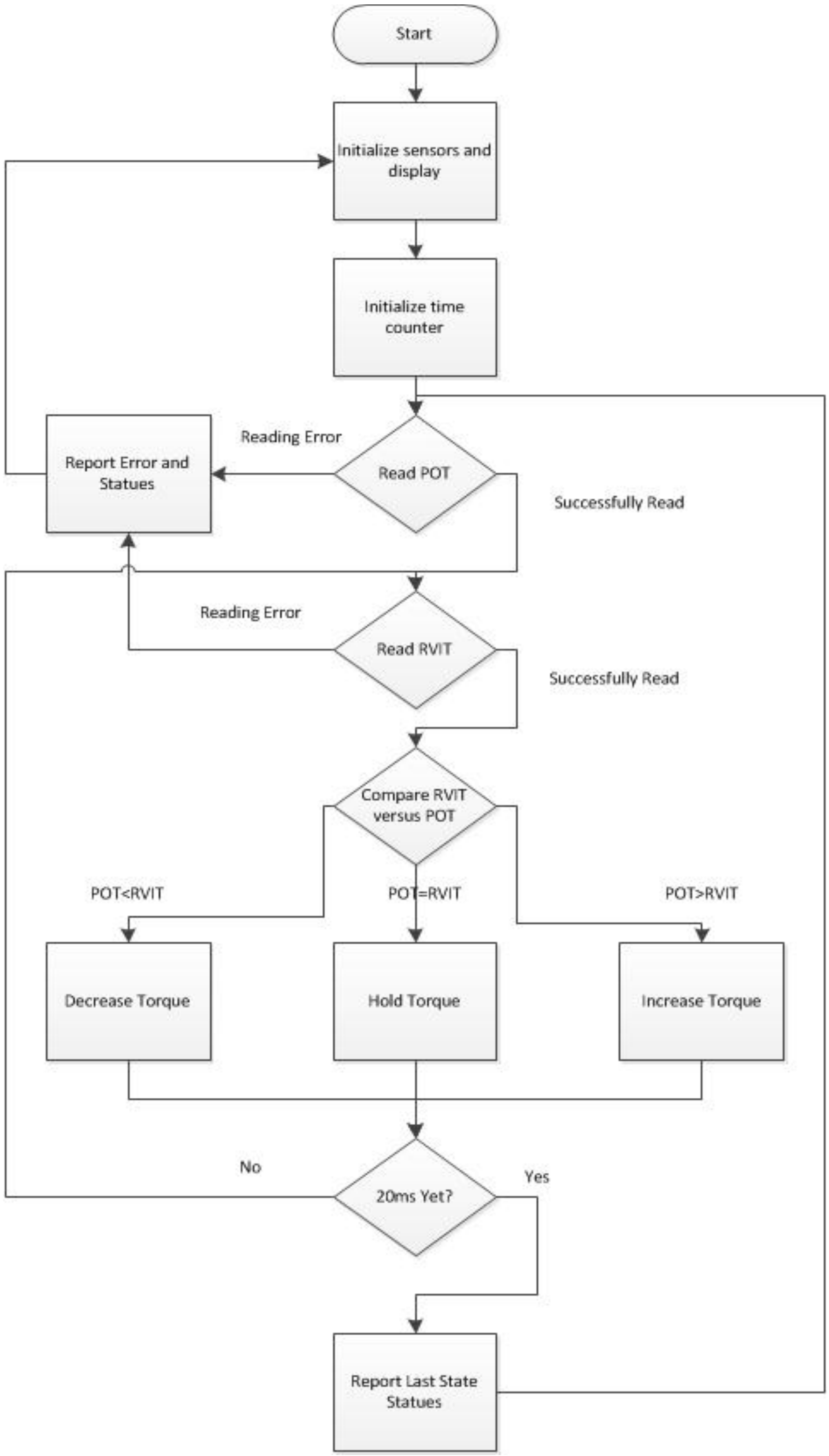


Figure 1: A visual representation of the torque motor module

3.4 Microcontroller Flow Diagram



In a realistic situation, the fluid delivery system, FDS, will be interfacing the EEC controller with the CAN bus. The EEC will send out a request for the FDS status and current fluid flow percentage out of the maximum fluid flow percentage. After the request is sent out from EEC, 20ms is given to the FDS to report back to the EEC. The FDS should send out two status messages. The first will contain the state of the FDS, these statues are: OFF, HOLDING, TRANSITION, MAX, and DRIVE SAFE. State OFF means the FDS is not responding. State holding means the valve or lever has achieved its requested position and is holding the position. State transition means the valve or lever is still in transition to achieve the requested position. MAX means the valve or lever is at its peak position or 100% fluid flow rate. Finally, drive safe state means the FDS lost communication with the EEC.

In this project, the EEC will be represented by a POT. Every 20ms, the POT value will be sampled as a percentage of the max voltage that can be measured by the analog input. The FDS will then process the requested value and RVIT value and then adjust the motor in to the correct position. Since the FDS does not have an EEC to interface back at, it will report its state by LEDs. In this project the off state and drive safe will be included. Since these states are based on the CAN communication status, it is unlikely the POT will be malfunctioning. The FDS will be put into a safe drive state if the POT is indeed malfunctioning. The FDS will be constantly updating its states and position, but will not report the state unless the 20ms interval is up. This will ensure that the EEC will not be flooded by the FDS's status report messages.

In the TRANSITION state, the motor will either go forward or backward depending on the RVIT reference angle to the POT. From the flow chart above in the Increase Torque sub-state, the controller will step up the Torque by .0012 Nm based on the torque resolution calculated based on the RVIT angle resolution. In the Decrease Torque sub-state, the controller will step down the Torque by .0012 Nm based on the torque resolution calculated based on the RVIT angle resolution.

RVIT sensor has an angle resolution .25% of full scale of 120 degrees.

$$120° * .0025 = .3° \, Resolution \qquad (1)$$

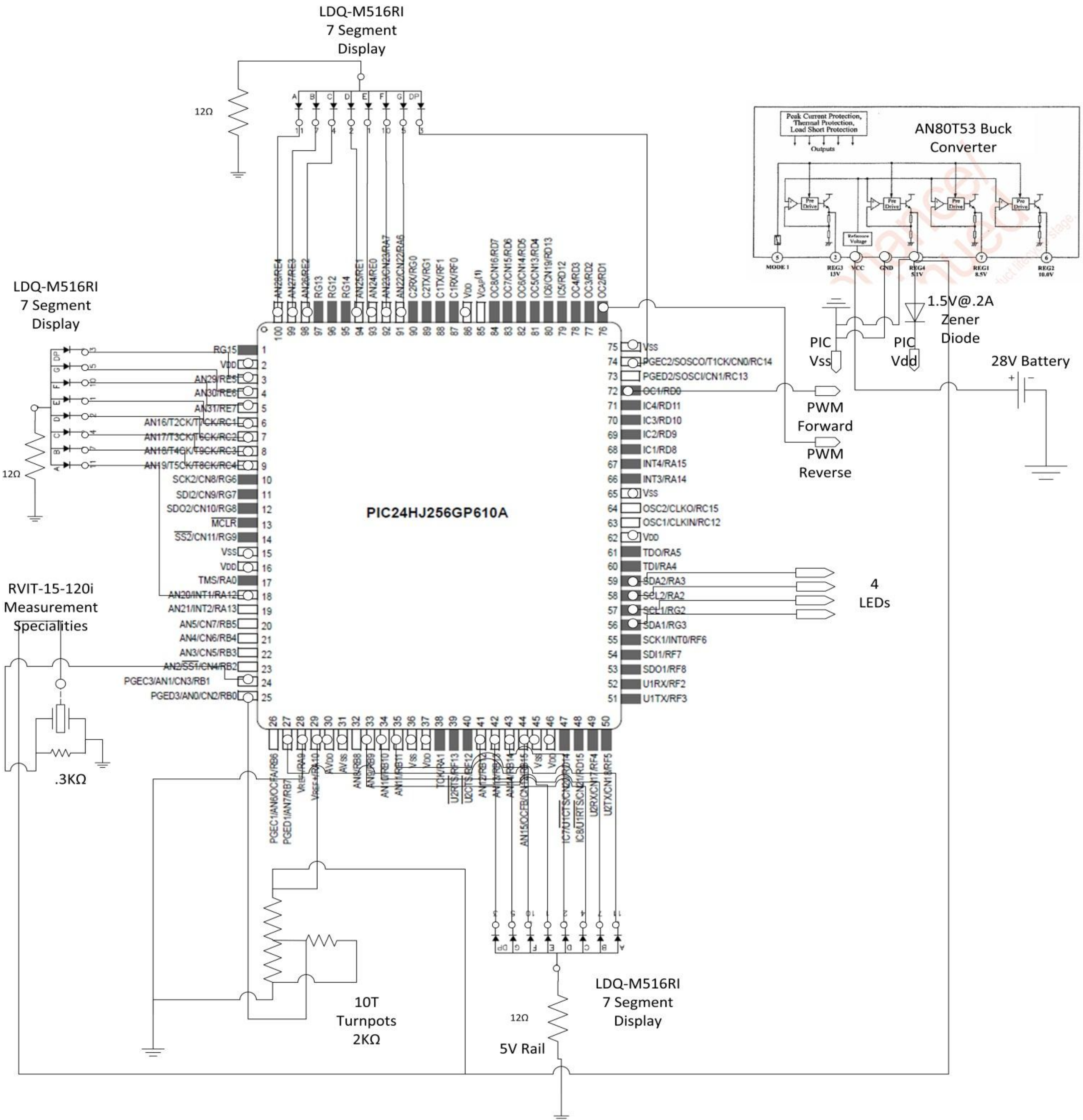
Assume the spring will be in steady state position at 75 degree at .3Nm of torque.

$$\frac{75°}{0.3°} = 250 \, steps \qquad (2)$$

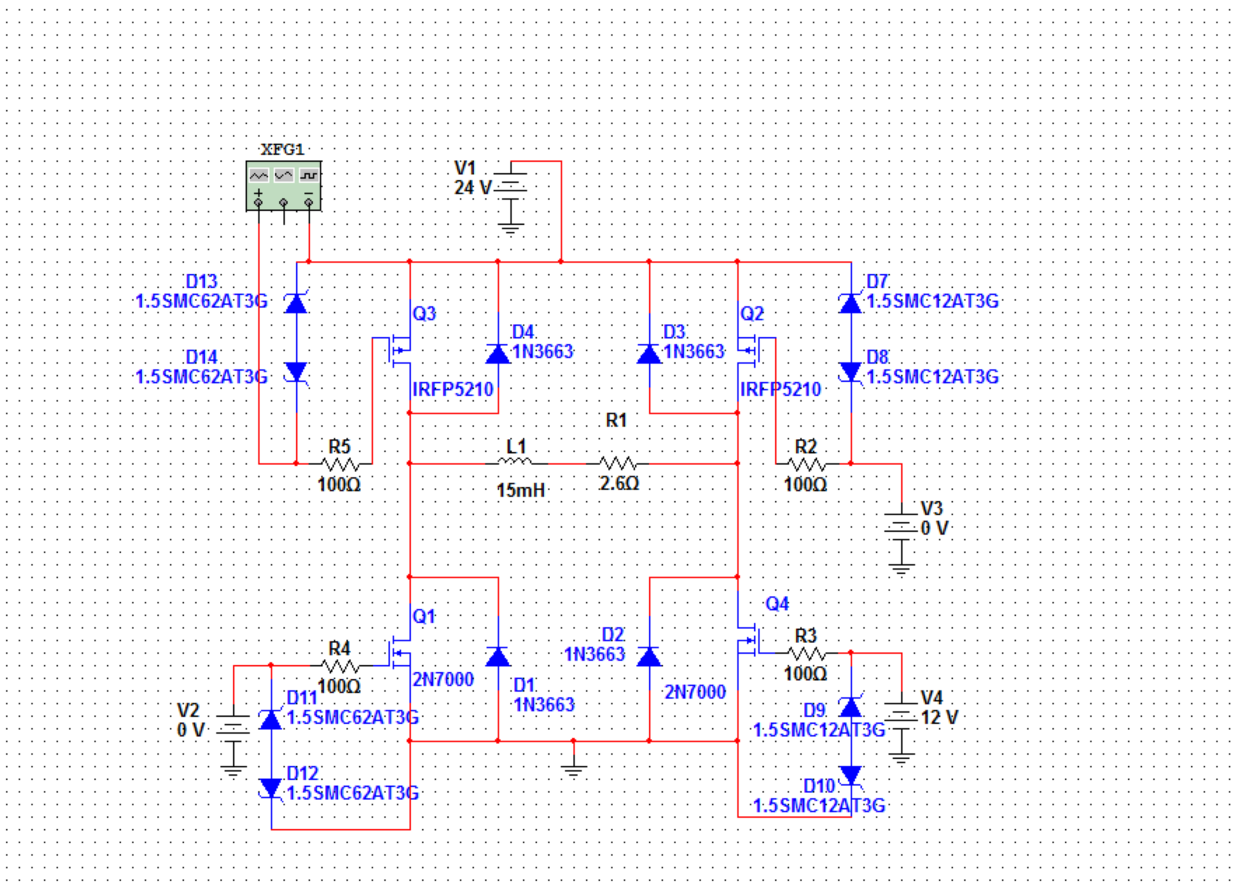
There are about 250 steps that the RVIT sensor can see. The practical solution to controlling the torque steps is to match the 250 steps.

$$\frac{.3\mathrm{Nm}}{250} = .0012\mathrm{Nm} \qquad (3)$$

3.5 Torque Motor Controller I/O Schematic



3.6 Drive Circuit



The driver circuit is made up from two components, the H bridge driver chip and the H Bridge. The HIP4081A H bridge driver chip is used in the drive circuitry. The H Bridge is made up of two PMOS on the high side and two NMOS on the low side. The PMOS is used in order to secure a constant source voltage from the battery. No boot strapping is required. The PIC will output two PWM signals, one for driving forwards and the other for driving backwards. The two waveforms from the PIC are inverted in order to feed the lower two bridges the flipped waveform to ensure no shoot through occurs. The inverters are connected to 5 volts for operation. When PWM wave 1 is high on the right, high side of the H-bridge, it is low on the right, low side of the H-Bridge. The same is true for PWM wave 2 on the left side of the H-bridge. These PWM will be smoothed out into a constant DC current based on the PWM duty ratio. This is done by converting the H bridge into a buck converter by adding diodes parallel to the low side NMOS. The motor can be modeled as an inductor in series with the resistor. One can clearly see from figure above that the H Bridge is now two buck converters. There are also two delay resistors going into pins 8 and 9 on the driver chip. These resistors were configured according to the delay on the NMOS and PMOS chips in order to avoid shoot-through current when the MOSFETs switch on and off. The PMOS turn off delay must be shorter than the chip set delay in order to stop the current going through PMOS before NMOS turns on. The turn off delay for the PMOS from the data sheets is 12ns. According to the data sheet for the driver chip, a resistance of 10 kΩ corresponds to a 60 ns delay for the chip. Therefore, this amount of resistance should be adequate to compensate for the delay the MOSFETs will produce. The zener diodes (MAZ41500MFTB-ND) must be placed between the source and gate to prevent the gate voltage from going outside -10 to 10 volts. Diodes with a 10 volt breakdown voltage were selected to fit the circuit. Diodes parallel to the PMOSs are also needed to protect each MOSFET by allowing current to flow to the source if the voltage on the motor becomes too high. Standard 0.7 volt diodes (1N3663) were connected from the drain to source of each PMOS. Lastly, in order to stop current from going back into the driver chip, resistors were placed on the gate of each MOSFET. In order to find the resistance needed for each MOSFET, the input capacitance and charge on each MOSFET were used to calculate the voltage, as shown in Equation A.

$$V = \frac{q}{C} = \frac{35nC}{1880\,pF} = 18.62V \tag{4}$$

The input capacitance C_{iss} was 1880 pF, and the total gate charge Q_g was 35 nC, and these values were found on the data sheets of the MOSFETs. Using the voltage calculated and a current of about 0.5 A, the amount of resistance needed could be calculated, as shown in Equation B. Therefore, the decision is to use a resistance of 50Ω on each gate.

$$R_{gate} = \frac{V}{I} = \frac{18.62}{0.5} = 37.23\Omega \tag{5}$$

In order to power the driver chip, 12 volts that come from the output of the buck converter (LM2825N-12-ND) go into pin 15 and 16 on the driver chip.

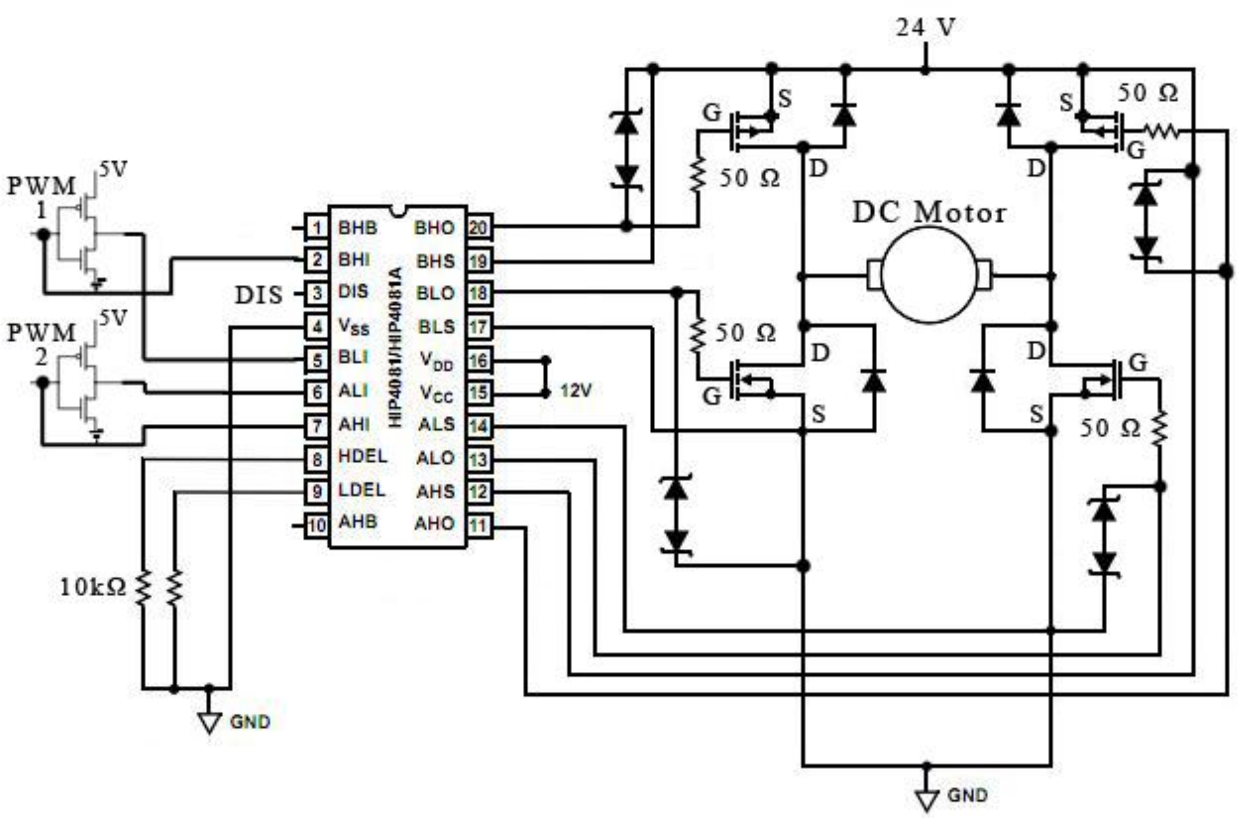
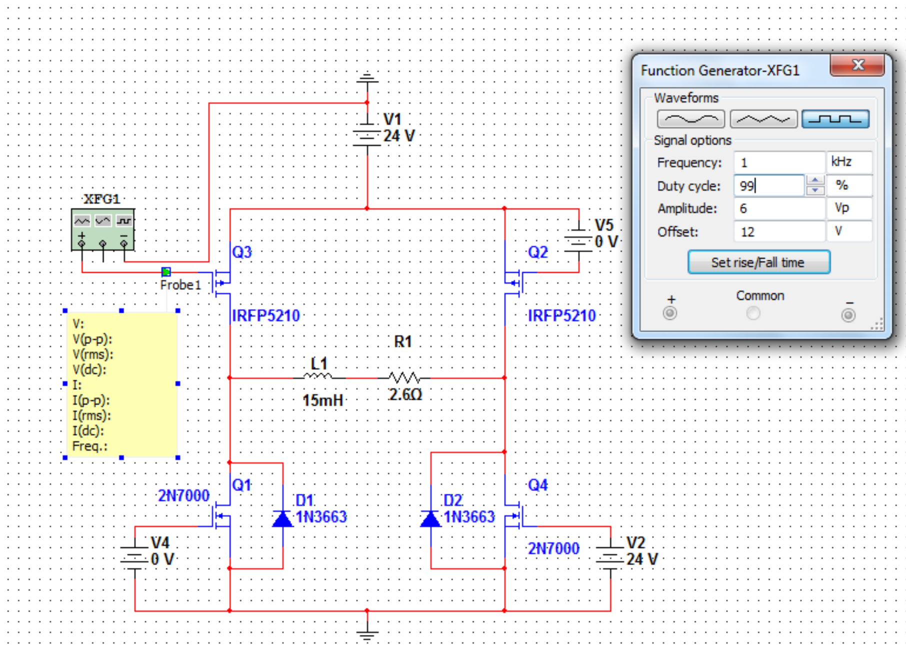


Figure 2: Schematic for the drive circuitry system

4.0 Simulations & Specifications

4.1 Current Control Simulation



The circuit above is a basic H bridge circuit with two diodes in parallel with the low side mosfets. The motor is modeled with an inductor and a resistor; the values are taken from the specification sheet. Since ω is approximately zero in this case, from the equation below one can conclude the voltage drop on the motor is approximately zero also. As one can see by adding the diodes, the circuit is effectively a buck converter. The simulation is done without protection elements to show the concept of controlling current by using a buck converter. In this simulation, mosfet Q1 and Q2 will be set to be off to simulate forward direction driving. Mosfet Q4 is turned on because effectively when Q3 is on Q4 is always on also since the PIC program will be pulsing both Q3 and Q4.

$$v_b = k_v \omega \tag{6}$$

The first set of tests will set the driver, in this case a square wave function generator to 50% duty and vary the frequency of the wave from 1kHz to 10kHz and then comparing the ripple of the current passing through the motor, the resistor and inductor.

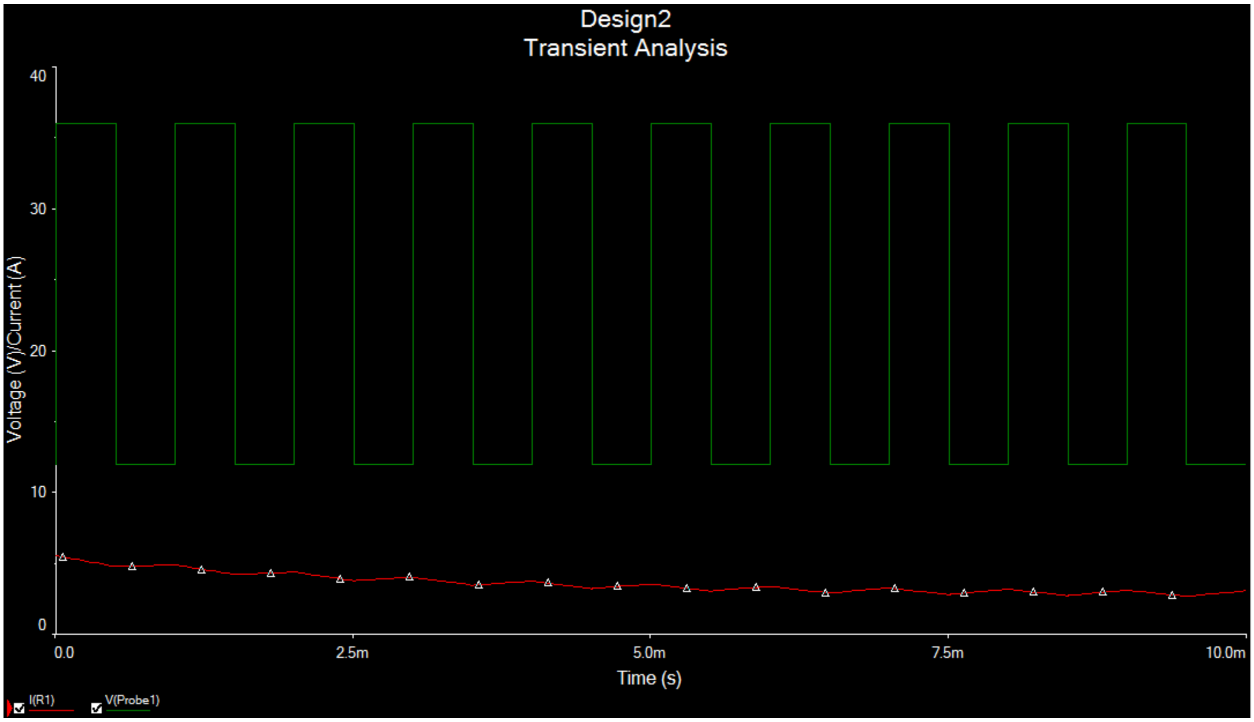


Figure 3: Voltage and current transient analysis at 1kHz

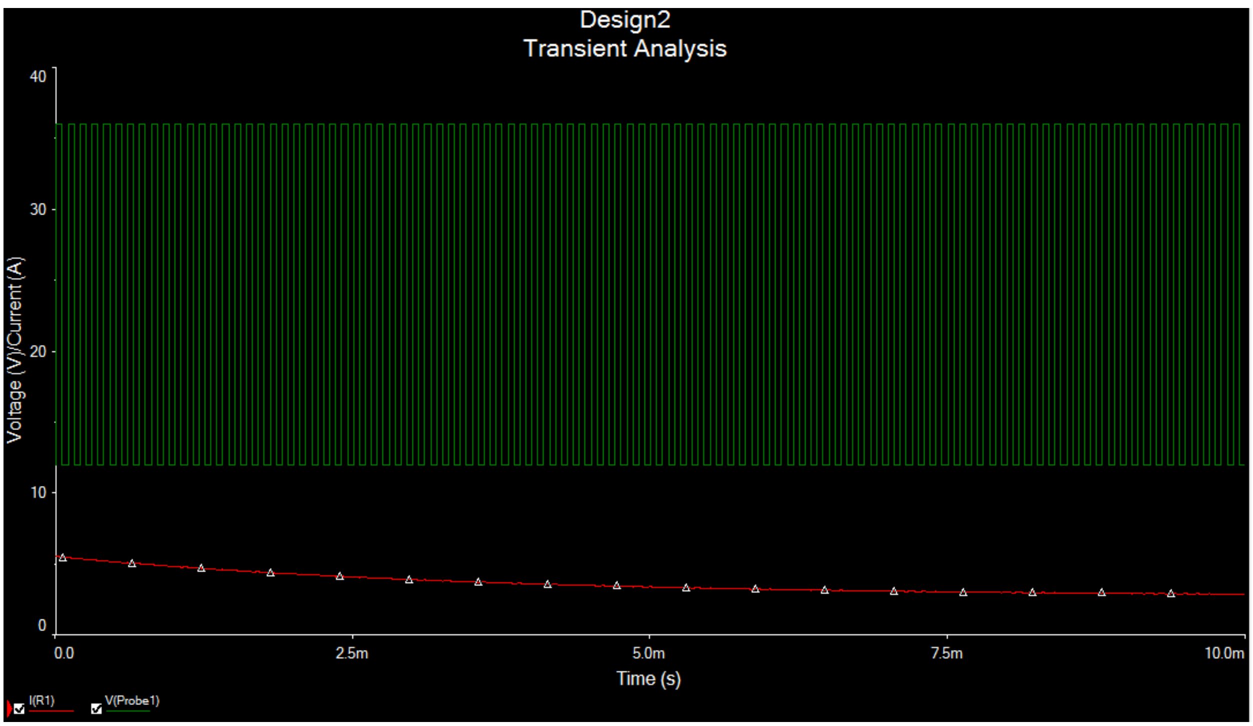


Figure 4: Voltage and current transient analysis at 10kHz

As one can see, there is little to no ripple looking at a 10ms time frame in the 10kHz. In contrast, clearly there are ripples in the 1kHz current. The current in the 1kHz wave fluctuate from .5A to 1A. Higher frequency is clearly the winner when it comes to current control.

4.2 Calculations

From the equation below one can see the duty ratio in a buck converter is directly proportional to its output current over input current. This relationship is tested by running the H bridge at 5kHz and varying the PWM duty ratio from 1% to 99% with a step size of 25%.

$$\frac{Iout}{Iin} = D \tag{7}$$

$$\frac{Vs*D}{R} = Iout \tag{8}$$

In the circuit tested, the function generator is floating on the high side source and is driving the pmos. The function generator gave an error when the polarity is flipped with the source and gate. Since the pmos simulated have a Vgs threshold of about -4V, the duty ratio used on the function generator has to be subtracted out of one to get an equivalent duty ratio.

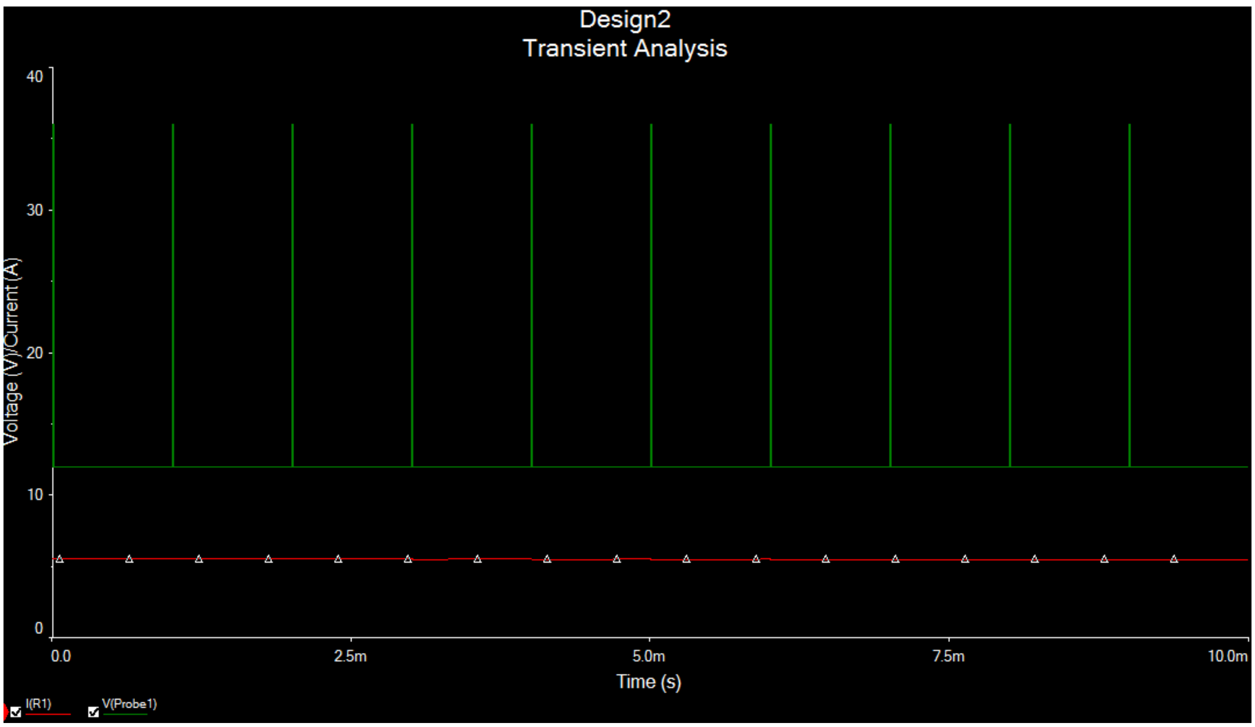


Figure 5: Current analysis for a voltage with 1% Duty Ratio (99% Duty Ratio Equivalent)

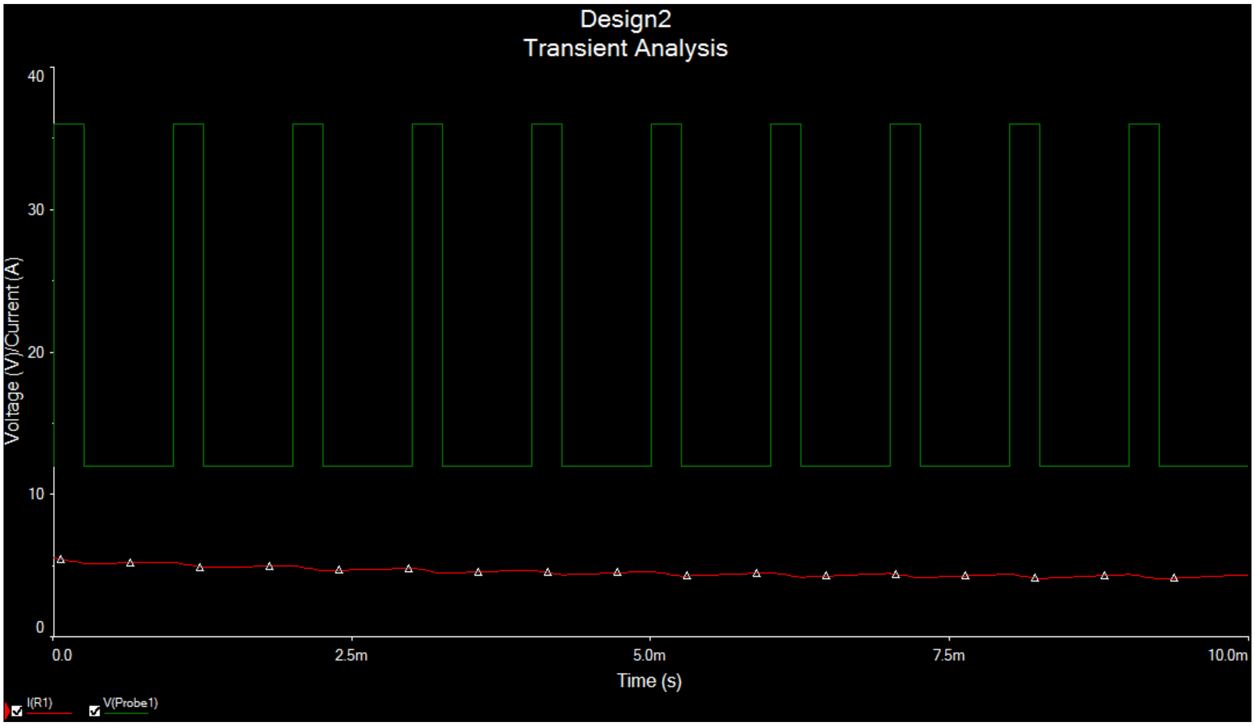


Figure 6: Current analysis for a voltage with 25% Duty Ratio (75% Duty Ratio Equivalent)

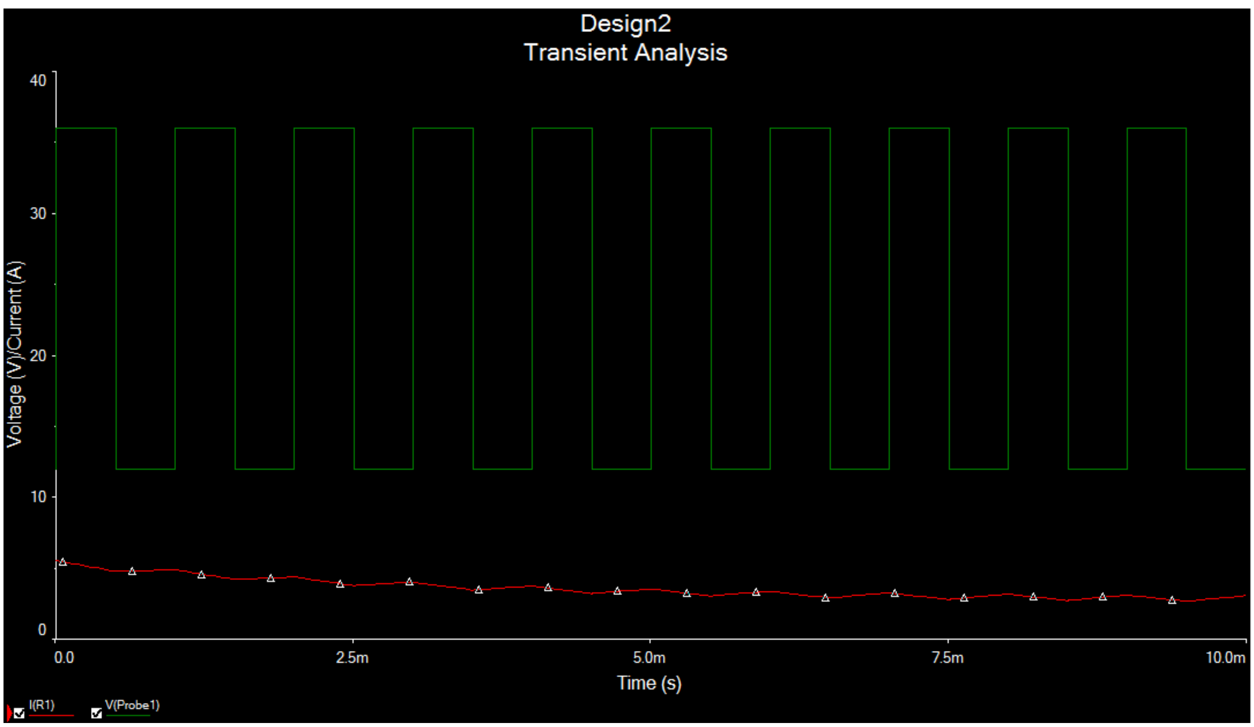


Figure 7: Current analysis for a voltage with 50% Duty Ratio (50% Duty Ratio Equivalent)

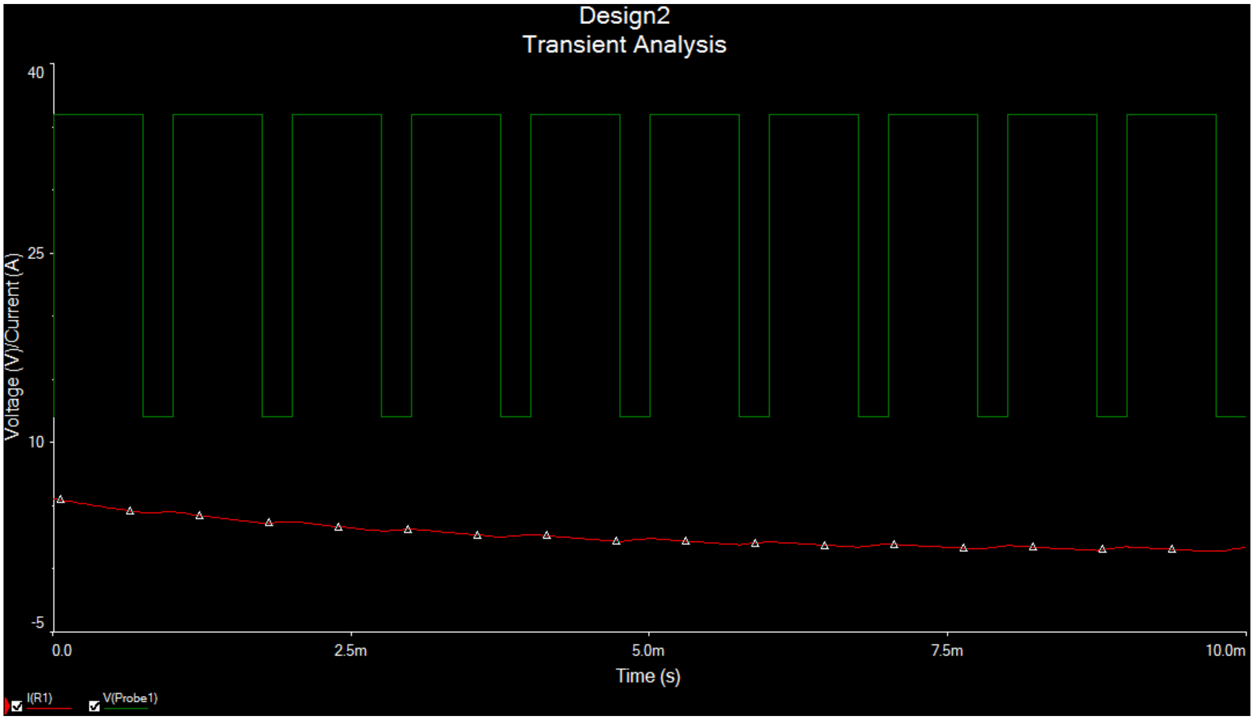


Figure 8: Current analysis for a voltage with 75% Duty Ratio (25% Duty Ratio Equivalent)

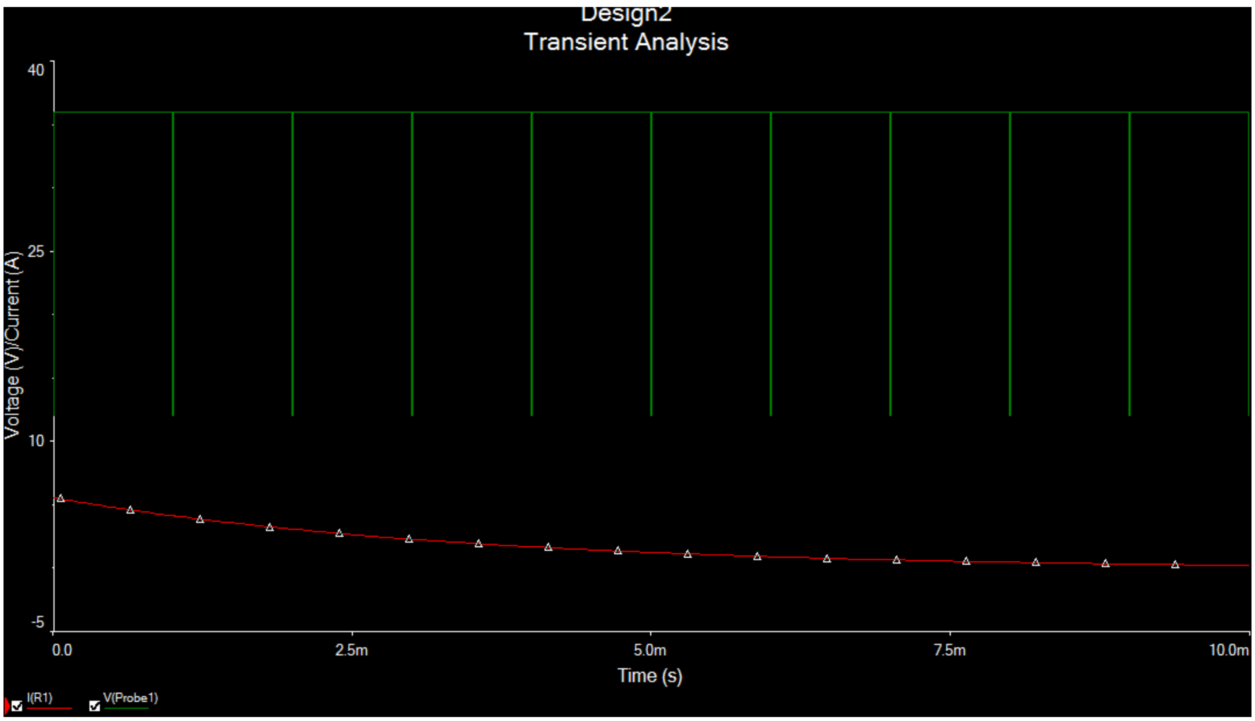


Figure 9: Current analysis for a voltage with 99% Duty Ratio (1% Duty Ratio Equivalent)

From these graphs, one can see that the output current is linearly related to the duty ratio. These two simulations show that one can accurately control current if the PWM is running at a high frequency. Since the duty ratio is linearly related to the output current; to have high resolution in output current, the duty ratio resolution must be high.

Predicting the Torque output is important in the design of this system. Since torque is directly proportional to current into the motor, current prediction is also important. A set of simulation is run and figures are traced for predictions.

At 99% $I_{99\%}$=5.4778A, one can predict at 50% $I_{50\%}$=.5$I_{99\%}$=2.7389A

The simulated result current is 2.7217A

%error=|I simulated – I predicted|/I simulated = 0.63196% (9)

This is very accurate considering the circuit is not running at its potential frequency.

$$Tmech = K_a \phi_d I_a \quad (10)$$

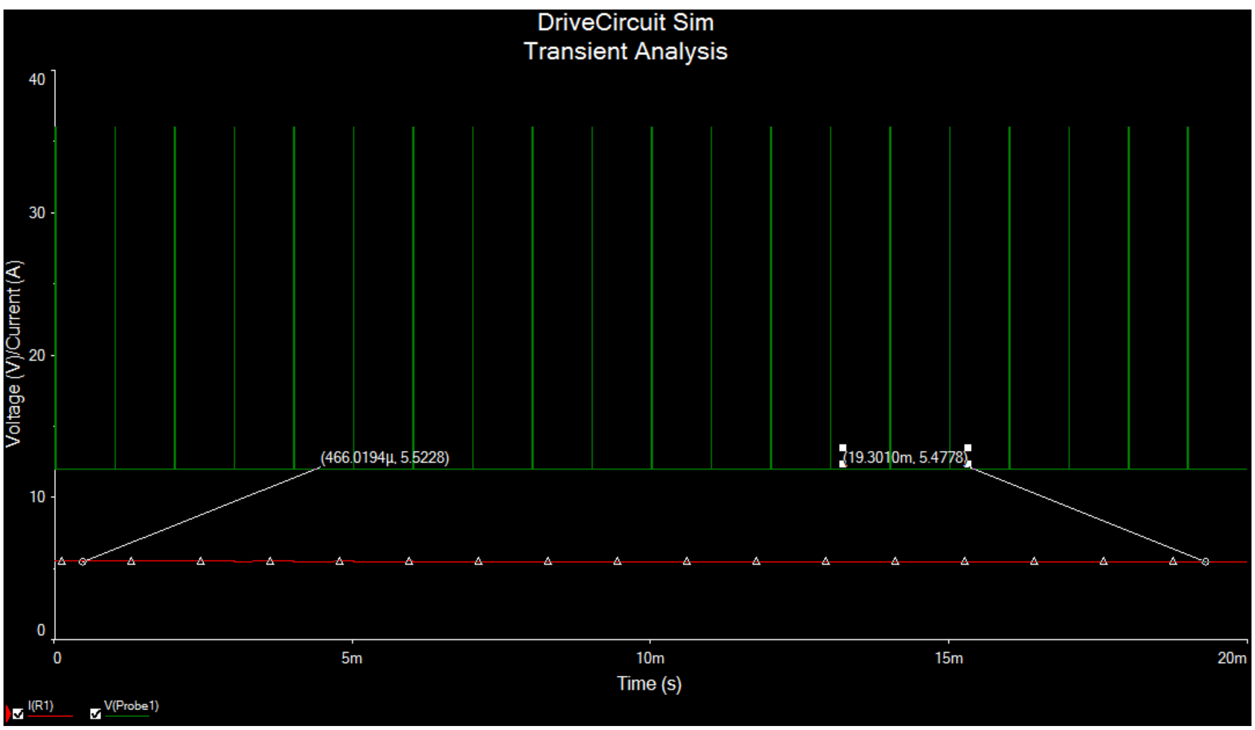


Figure 10: Current analysis for a voltage with 99% equivalent Duty Cycle

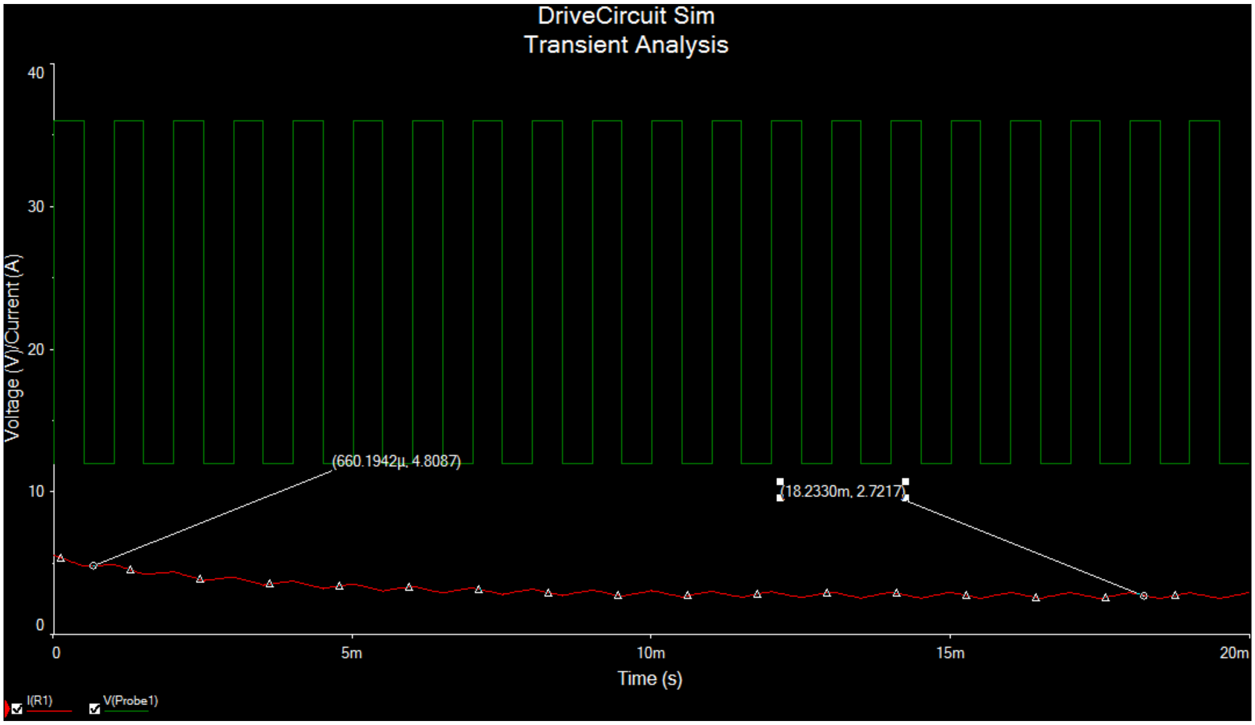


Figure 11: Current analysis for a voltage with 50% equivalent Duty Cycle

4.3 Performance Specifications

1. Motor and drive circuitry must be able to handle sustained maximum power input since the motor control is meant to keep the motor in a stable position between commands
    a. MOSFETs and drive circuitry components must be able to exceed 14.5V and 6A input values without overheating or otherwise becoming useless
    b. Motor must be rated to at least 14.5V and 6A
2. Working angle
    a. The torque motor subsystem must function over a sufficient operating angle which is specified as 60°
3. Angular resolution
    a. The motor drive must be accurate to properly control fluid flow and should not exceed 0.5° of error
    b. If an angular change is small, 0.5° is an insufficient requirement. The percent error of an angle change must also be regulated to within $\pm$10%
4. Maximum Positioning Time
    a. The motor positioning change delay must not exceed 200ms
5. Torque Output/Fluid Resistance Simulation

a. The torque motor must supply at least 0.3N·m of torque at the maximum working angle of 60° to sufficiently simulate a resistive force on the motor
6. Voltage and Current Regulation
    a. Torque output is directly proportional to input current, so the current must be regulated to within $\pm$3% of desired input current magnitude
    b. Voltage seen by the motor must be regulated to avoid saturation constraints during motor operation; $\pm$3% of supply voltage accuracy is desired

The motor and drive circuitry must be able to handle sustained maximum power input as the purpose of the motor control is to keep the motor in a stable position until new commands are given. In addition, the torque motor subsystem should be implemented over a sufficient operating angle which is specified here as 60°. As a part of a fluid delivery system, the angular resolution of the motor drive must be accurate to properly control fluid flow and should not exceed 0.5° of error, nor should a positioning change exceed a time delay of 200ms. Since the torque motor should simulate a fluid resistance, it must be able to handle a resistive force. As such, the motor must be able to supply an output torque of at least 0.3N·m at the maximum working angle. It is also important that, given a current driven torque motor, the input current from the drive circuitry to the motor be well controlled as the torque output is proportional to this value; current must be within $\pm$3% of the value desired for any reasonable input. Finally, the voltage seen by the motor must also be regulated so as to avoid saturation effects and function properly within a particular range; supply voltage must be within $\pm$3% of ideal value.

5.0 Verification & Testing Procedures

Requirement	*Verification*
Power Supply	
1. The power supply is used to supply the necessary input voltages to all modules within the project a. Supplies 28V to simulate rail voltage for AEC applications b. Supplies 13V for the H-bridge driver chip input c. Supplies 5.1V for the PIC input as well as for CMOS inverters	1. The power supply will be two over-charged 12V batteries connected in series to form the 28V supply rail. In addition, a four-way buck converter will step down the voltage to 13V and 5.1V for component operation a. Using a digital multi-meter (DMM), measure the battery voltage; the read out must be 28V with a 3% error tolerance b. Measure the voltage at the 5.1V terminal of the buck converter chip with the DMM; the output must be 5.1V with a 3% error tolerance c. Measure the voltage at the 13V terminal of the buck converter chip

	with the DMM; the output must be 13V with a 3% error tolerance
Potentiometer (POT)	
2. The POT is the user control interface that allows for control of the motor a. The POT works properly as a variable voltage divider	2. The POT has a built in load resistance, R_L, which can be variably placed along a resistor to create a voltage divider, separating the one resistor into two, R_1 and R_2 (which is in parallel with R_L). The voltage across the load resistor can be calculated based on: $V_{R_L} = \frac{R_2 R_L}{R_1 R_L + R_2 R_L + R_1 R_2} \cdot (5V)$ a. Measure voltage across load resistor with a DMM when POT is turned off. The voltage should be 0V within 0.5V b. Measure voltages across load resistor and the series resistance with a DMM when POT is turned to maximum. The voltages should be equivalent within a 10% tolerance
PIC	
3. Controller correctly outputs a PWM wave (corresponding to input) and the data for the 4x7 segment display a. PIC reads input from POT/RVIT b. PIC outputs correct PWM wave duty cycle controlled by input c. PIC can output data to be shown on the LED display	3. The PIC is the "brains" of the torque motor subsystem and needs to correctly interpret data or the motor control will fail. It outputs a waveform to the drive circuitry that will ultimately control the current seen by the motor and therefore the torque. a. Connect the PIC output to an oscilloscope. Turn POT 25%, 50%, 75%, and 99%. Compare scope out to simulation waveforms provided for the respective percentage duty. If they are a near match, it works
Drive Circuit	
4. Accepts PWM wave input from PIC and outputs correct current to the motor	4. The drive circuit is responsible for supplying the necessary current with which to torque the motor, since DC motor torque is directly proportional to the input current. a. Measure the gate, source, and drain voltages for each of the MOSFETs using a DMM and compute theoretical value of current using the MOSFET current equation(s): $i_D = 0.5k_p\left(V_{SG} - \lvert V_{tp}\rvert\right)^2(1 + \lambda V_{SD})$; $i_D = 0.5k_n(V_{GS} - \lvert V_{tn}\rvert)^2(1 + \lambda V_{DS})$ b. Measure the current across the transistors/motor using the DMM c. If the two currents are equivalent to within 5% error, then the drive circuitry is functioning properly

RVIT Sensor	
5. The RVIT is a part of a critical feedback loop necessary for dynamic positioning control. As such, it must meet supplier specification requirements. a. The RVIT sensor measures angular displacement correctly	5. Displace the RVIT sensor by 90° and view the angular output displayed on the 4x7 segment display. If the display indicates 90° within a 3% tolerance, then the RVIT works
Torque Motor Module	
6. The motor module must meet the following requirements: a. Working Angle of at least 60° b. Angular Accuracy of 0.5° or 10% c. Torque of 0.3 N·m at the maximum working angle d. Positioning speed of less than 200ms upon new input	6. The torque motor module is the primary aim of this project. As such, it requires the most thorough testing procedures. These tests are explained in more detail in the paragraphs that follow a. Working Angle and Torque test: gradually increase the current supplied to the motor and measure the angular deflection supplied by the RVIT on the 7 segment display. b. Angular Accuracy: supply current to the motor and measure its value with a DMM. Calculate the DC motor torque for this current value according to $T_{DC} = k_M i$. Set this equal to the spring torque and solve for the angular displacement, θ_l: $T_{spg}(\theta_l) = -kL_{arm}(L_s - L_r)\cos(\theta_\tau)$, where $\theta_\tau = \theta_l - \sin^{-1}\left(\frac{L_{arm}(1-\cos\theta_l)}{L_s}\right)$; $L_s = \sqrt{L_r^{\ 2} + 2L_{arm}^{\ \ 2} + 2L_r L_{arm}\sin(\theta_l) - 2L_{arm}^{\ \ 2}\cos(\theta_l)}$ i. Observe the RVIT angle shown on the LED display ii. Calculate the error and difference angle observed: $\varepsilon = \frac{\theta_{calc} - \theta_{RVIT}}{\theta_{calc}} \cdot 100$; $\vartheta = \theta_{calc} - \theta_{RVIT}$ iii. If error is less than 10% and ϑ is less than 0.5°, then the test is passed c. Positioning Speed: count the clock cycles between positioning changes and multiply by the PIC clock period. If the resulting product is less than 200ms, then the positioning delay is minimal enough

5.1 Working Angle & Torque Test

This test will be simple and straightforward; the key result for this test will simply be if the motor torque can overcome the spring and hold its position for an angle change greater than or equal to 60°. The RVIT sensor will provide dynamic feedback to the seven segment display, which will provide the angular change with respect to the resting position. If the system can physically rotate at least 60°, then this test will be passed. Note that this test provides verification of the working angle and torque supplied at the working angle since the spring constant that was calculated (k=19.605 N/m) for the torque motor module took into account a torque of 0.3Nm at an angular displacement of 60°.

- Gradually increase input current to motor

- Display angular change from RVIT sensor on seven segment display

- If motor torque results in angular displacement of 60° or more, then the test will be passed and performance requirement will be satisfied

5.2 Angular Accuracy

The torque motor module is current controlled and the output torque resulting from a current input can be calculated by the following motor torque equation:

$$T_{DC} = k_M i \qquad (11)$$

Here, T_{DC} is the torque of electrical origin supplied by the input current, k_M is the motor constant, and i is the input current. When the motor reaches a desired angle change, it should be in static equilibrium, meaning that the motor torque is equal to the spring torque. Thus, with an equation derived for the spring torque as a function of the angular displacement with respect to resting position, θ_l, the two torque equations can be set to equal each other and a theoretical value of θ_l can be obtained. The following is an equation derived for the spring torque on the lever arm as the motor rotates and stretches the spring:

$$T_{spg}(\theta_l) = -kL_{arm}(L_s - L_r)\cos(\theta_\tau) \qquad (12)$$

Here, T_{spg} is the torque generated by the spring, k is the spring constant, L_{arm} is the length of the lever arm, L_r is the un-stretched spring length, L_s is the stretched spring length, and θ_τ is the angle between the spring force and the orthogonal of the lever arm. The spring constant, lever arm length and resting spring length are all constants and the stretched spring length and spring force angle are both functions of the angular displacement given as follows:

$$L_s = \sqrt{L_r{}^2 + 2L_{arm}{}^2 + 2L_rL_{arm}\sin(\theta_l) - 2L_{arm}{}^2\cos(\theta_l)} \qquad (13)$$

$$\theta_\tau = \theta_l - \sin^{-1}\left(\frac{L_{arm}(1-\cos\theta_l)}{L_s}\right) \qquad (14)$$

Derivations for these formulas and equations are included for reference in the appendix. L_{arm} and L_r were chosen to be 0.1524m (6in) and a reasonable spring constant was calculated to be 19.605N/m (this calculation can also be found in the appendix). As aforementioned, by setting equations (1) and (2) equal to each other, a theoretical value for θ_l can be found. Since the RVIT sensor will provide the real angle change, the percent error can be calculated as:

$$\varepsilon = \frac{\theta_{calc} - \theta_{RVIT}}{\theta_{calc}} \cdot 100 \tag{15}$$

Here, θ_{calc} is the calculated theoretical value for θ_l, θ_{RVIT} is the measured value of θ_l, and ε is the percent error of θ_l. Additionally, the difference between actual resulting angle and the theoretical can be found as follows:

$$\vartheta = \theta_{calc} - \theta_{RVIT} \tag{16}$$

As long as the magnitude of ϑ is less than 0.5°, then this test will be passed.

5.3 Positioning Speed

This test is also fairly straightforward. Since the PIC is clock controlled, the number of clock cycles until the motor comes to rest as indicated by the RVIT can simply be counted. If the sum of these clock pulses is less than 200ms, then this test will be passed.

- PIC is clock controlled; count number of clock cycles between initial resting position and new resting position when a current is applied and multiply by the period of each clock cycle

- If the product calculated is less than 200ms, then this test will be passed

5.4 Tolerance Analysis

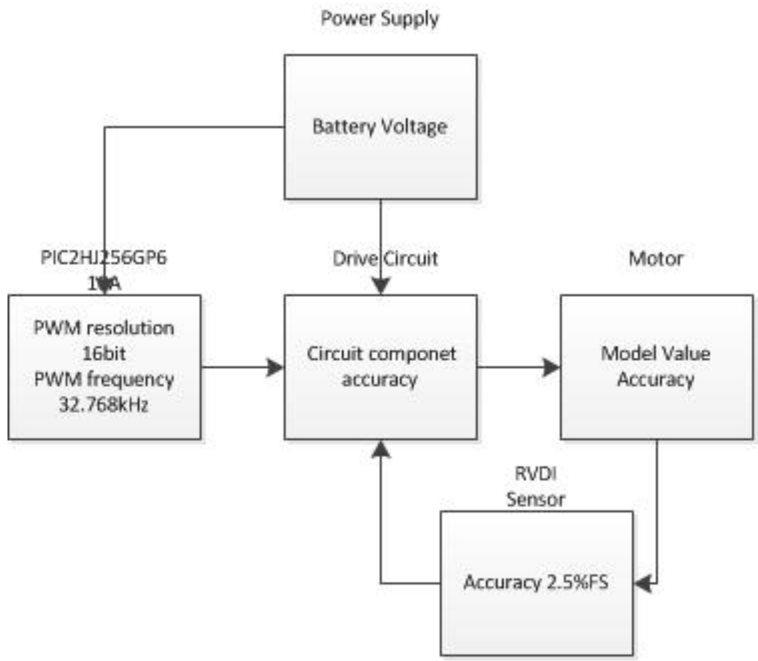


Figure 12: Block Diagram for Error Tolerance Analysis

The most critical parameter for tolerance analysis is the motor drive current generated by the drive circuitry. If the current is controlled well within performance specifications, then the motor torque for the design will also be sufficiently well controlled. However, small fluctuations of the drive current will result in position and output torque errors which will in turn reduce angle accuracy. Since RVIT position and torque information is part of a feedback loop, small errors may propagate into much larger errors and reduce system performance and efficiency. The lab multi-meters are more than accurate enough to display current within the $\pm 3\%$ constraint from the performance specifications, so this measurement method is sufficient.

$$I \propto T^e \tag{17}$$

The first parameter that could cause the current through the DC motor is the frequency of the PWM wave. Since the H bridge circuit is also behaves as a buck converter, the frequency of PWM wave dictates how fast the MOSFET switch opens and shuts. The frequency of the switching is directly related to the ripple of the current. From the simulation circuit used in the previous section, a 32.768kHz test was run having the results below. 32.768kHz is the frequency of the output gates OC1 and OC2 for the PWM.

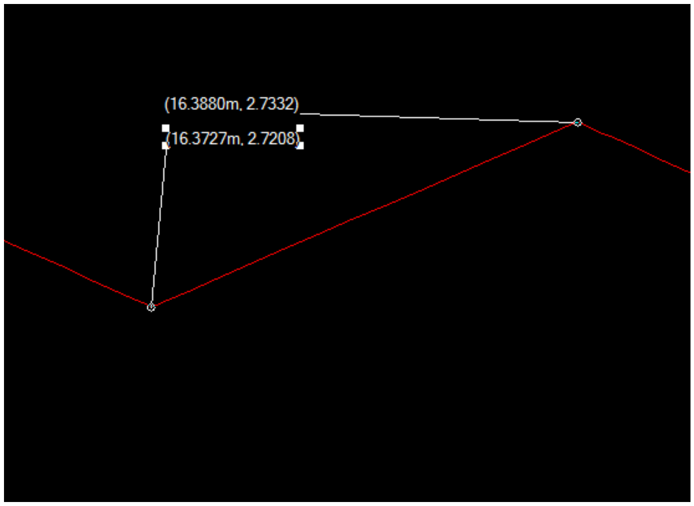


Figure 13: Current ripple simulation run at 32.768kHz

$$\%\text{difference} = \frac{|I_{peak} - I_{bottom}|}{(I_{peak} + I_{bottom})/2} = \frac{|2.7332 - 2.7208|}{(2.7332 + 2.7208)/2} = .4657\% \qquad (18)$$

At this frequency, the fluctuation of torque will be also .4657% which is very low.

The next parameter that could cause the current through the motor to fluctuate is the voltage of the battery. A good estimation of the voltage fluctuation is $\pm .5V$. The resistance on the motor should stay constant.

$$V/R = I = \pm \frac{.5V}{2.6\Omega} = \pm .1923A \qquad (19)$$

$$Current\ Fluctuation\ \% = \frac{Current\ Fluctuation}{Max\ Current} = \pm \frac{.1923A}{6A} = \pm 3.205\% \qquad (20)$$

There is a massive fluctuation of current depending on the change in voltage. However, in this FDS no input torque prediction is needed since the step and check system with steps of torque is applied. The effect of this current fluctuation is alleviated. From previous calculations, the step resolution is .4%. Each step raises .4% of the maximum torque needed to move the lever to 75 degrees. So every .5V difference can only increase each step size by 3.205% which is would not affect the accuracy of the torque output much. The step and check system is also the reason the values for the basic component like resistors and inductors will have little to no effect on the accuracy of torque produced.

The last parameter that may limit the current accuracy is the resolution of the PWM wave. The PWM wave in the PIC has a resolution of 16 bits. $2^{16} = 65536$, which means the duty cycle can be controlled with .0015% precision. This is extremely accurate since the RVIT sensor only has .25%FS precision.

It is clear that the frequency of the PIC will cause the most inaccuracy in the torque response. Through the calculations, one can see a .4657% fluctuation in the torque. The acceptable position difference from POT specified position is .5 degrees difference. The torque is proportional to the position, and the position range maximum is 75 degrees.

$$75° * .4657\% = .349° \qquad (21)$$

There could be 0.349 degrees error which is within the 0.5 degrees threshold position accuracy specified.

6.0 Cost Analysis & Schedule

6.1 Cost Analysis

Item	Cost/unit	Quantity	Item Cost
Microcontroller/PIC Pic24HJ256GP610A	$25.00	1	$25.00
Development Board DM240001	$130.00	1	$130.00
Torque Motor Sonceboyz 4236	$50.00	1	$50.00
Fans/Heat Sink	$15.00	1	$15.00
RVIT-15-120i Sensor	$365.00	1	$365.00
FET Driver FN3659	$7.93	1	$7.93
Power PFET IRF9Z20	$1.71	2	$3.42
Power NFET FDP8447L	$1.13	2	$2.26
Zener Diodes 10V	$0.10	8	$0.80
Diodes	$1.00	4	$4.00
Resistors (100Ω)	$0.20	4	$0.80
7 Segment Display	$7.13	1	$7.13
Buck Converter Chip LM2825	$2.12	1	$2.12
CMOS Inverter CD4069UB	$0.66	1	$0.66
LEDs	$0.77	4	$3.08

Estimated Part Cost:	$617.20

Labor: ($30/hour)(50 days of labor)(3 hours/day)(3 workers) = $13,500 (22)

Total Cost $617.20 + $13,500 = $14,117.20 (23)

6.2 Schedule

Date	Task	Team Member
2/8/2012	Project Proposal Posted to PACE	David
2/10/2012	Part Selection and place order	Zhimin
2/13/2012	Hardware Design Completed	Ross

2/17/2012	Software Design Outlined	Zhimin
2/20/2012	Design Review Sign-up	David
2/23/2012	Drive Circuitry Assembled	Zhimin
2/25/2012	Spring-Motor Contraption to Shop	David
3/16/2012	Software Coding Written	Zhimin
3/26/2012	Begin Preliminary Testing	Ross
3/26/2012	Mock Demo	David
4/2/2012	Mock Presentation	Ross
4/16/2012	Final Demo and Presentation Sign-up	Zhimin
4/23/2012	Final Project Demo	David
4/26/2012	Final Project Presentation	Ross

7.0 Ethical Considerations

In order to ensure that the torque motor module meets ethical standards, a variety of ethical considerations must be made. The torque motor module was designed for an airplane, and therefore it is very important that all parts of the design operate correctly and communicate properly with each other. If one part of the design does not work, then the motor will not work properly causing safety concerns. Redundant safety circuitry must be developed in order to ensure that the design is the safest it can possibly be. Therefore, a safe-drive state is implemented in order to correspond to the situation where the PIC has lost communication with the EEC. The safe-drive state will be defined by the particular vehicle that the torque motor module is designed for. Also, the amount of torque that is actually being delivered to the motor must match the amount that the user is putting in on the potentiometer. If there is a mismatch, then the product will not work as specified and safety concerns may also arise. Additionally, this project was a continuation of a project from previous semesters. Work from previous semesters must be acknowledged and properly credited in order to be ethical.