EE 316 - Electronic Design Project

Project: P2

DC Motor Speed Controller

Second Project Report

15 April 2019

Objective

This project can be examined in the three parts.

First part is controlling dc motor accurately. The important point is driving motor with changing PWM signal with respect to the duty cycle. Duty cycle is changing according to the error signal. The error signal is determined by taking the difference of obtained voltage from monostable multi-vibrator and adjusted input voltage.

In the second part, according to this error signal oscillator circuit generates pulses which have different duty cycles. To drive the motor, the signal sends to the half-bridge driver then the motor starts to turn. The speed of the motor depends on the duty cycle. A perforated disc attached to the motor's shaft. A led and phototransistor placed near the disk. While the disk is turning, phototransistor generates a signal. The frequency of this signal depends on the speed of the motor. Then the signal transmitted to the monostable multivibrator.

The aim of the last part is monitoring rps on the BCD screen. Briefly, duty is driving the motor with a specific duty cycle and generate the error signal to control its accuracy.

Group Members

Common efforts: Controlling motor with using PWM, Generating Signal and Error Detection, Using 3-Digit Display

Candost Yıldırım

Serkan Demirer

Hasan Harman

1. Design Overview

To drive the motor first time an initial output voltage of the PWM generator must have almost 100%duty cycles which can be adjusted with a potentiometer. For this situation, the potentiometer output voltage must be equal to 4.38V. Since there will be no output voltage from the monostable multivibrator, that voltage directly transmits into the PWM generator unit. Pulses are generated in this unit and their duty cycles depend on the input voltage. This PWM signal turned DC voltage with respect to the duty cycle in the Half-bridge driver so that the motor starts up at set rps.

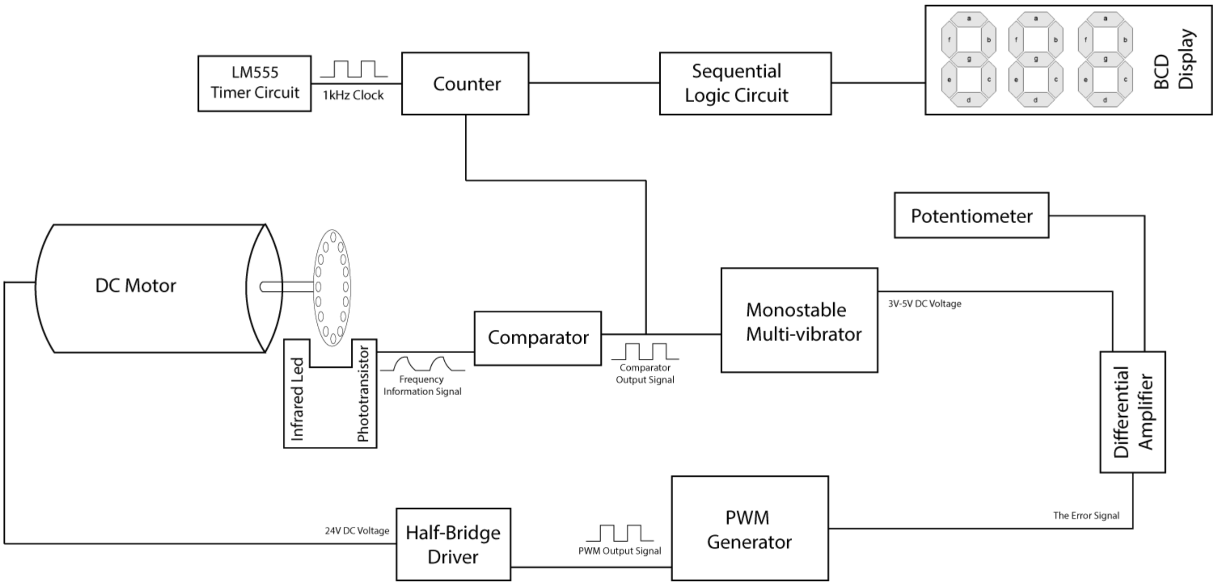

Figure 1. Block diagram of the DC Motor Speed Control Project

Perforated disc (16 holes) starts to turn with the motor. An Infrared led and phototransistor placed near the disc. Phototransistor detects 16 led lights in one tour of the motor and generates the frequency information signal. This signal is converted to a pulse by using a comparator. The monostable multivibrator is used as a frequency to voltage converter in this circuit. It converts the pulse signal to a DC voltage. Potentiometer’s output voltage and the output voltage of monostable multivibrator compared at the differential amplifier. Depending on the result, an error signal is generated. Then the motor is automatically accelerated or decelerated to reach the desired rps.

The output of the comparator signal is also transmitted to a counter. LM555 works as a timer and counter count the numbers of turn in one second. In the sequential logic part store the number of turns in one second then it displayed in the BCD screen.

2. Design Description

2.1. Error Signal Generation

The output of the differential amplifier is called the error signal. The error signal is represented as given below. Error signal generation can be examined in four parts.

$$Error\ Signal\ = V_{outPot} - V_{outMMV}$$

LED – Phototransistor Circuit

An Infrared Led and Phototransistor are positioned face to face with a 5mm gap. A perforated disc placed in that gap. When the disc is rotating and the LED is always on, the phototransistor detects the light passing through the holes of a disc. When a phototransistor detects light, it generates current depends on the intensity. In our LED-phototransistor pair component amplify the current and turned to voltage. The output of this component is a fractured pulse wave. Peak voltage (v_p) of this signal is nearly 5V.

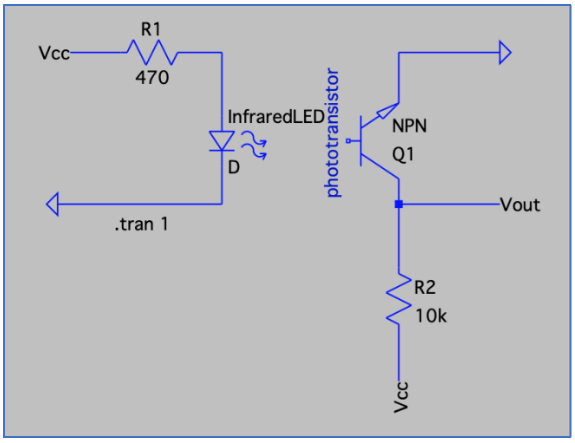

Fig.2: LED-Phototransistor Circuit

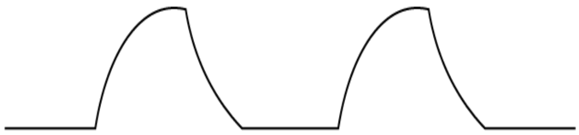

Fig.3: Output of the phototransistor

LED-Phototransistor Circuit Design Targets			
Description of the design target	**Min.**	**Max.**	**Unit**
Input voltage v_{cc}	**4.7**	**10**	**V**
Diode Current	**10m**	**25m**	**A**
Output voltage v_p	**4.8**	**5.2**	**V**

Comparator

The output of the phototransistor is a fractured pulse wave as shown in Fig3. The input voltage of MMV is modeled as a square wave while simulating. The output signal of LED is modeled as a sinusoidal wave in the simulation so, a comparator is used to get sharper rising edges and falling edges. The aim of the comparator is reducing the error while circuit installation.

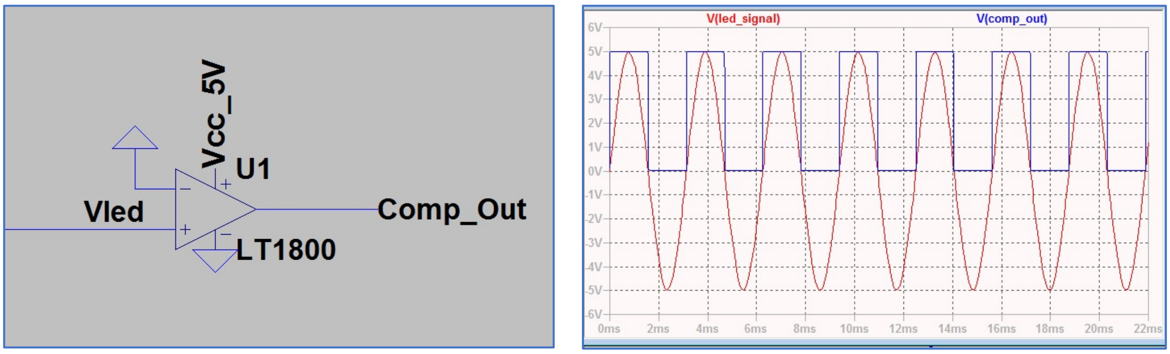

Fig.4: Comparator Circuit and Output Signal

Comparator Design Targets			
Description of the design target	**Min.**	**Max.**	**Unit**
Input voltage	**4.8**	**5.2**	**V**
Output low voltage	**0**	**-**	**V**
Output high voltage	**-**	**5.1**	**V**
Output slew rate	**5**	**10**	**V/ms**

Monostable Multivibrator

Monostable multivibrator converts the frequency of comparator's output to a voltage value by integrating over one period. Since the output of MMV should not contain high frequency, low pass filter placed at the output of the multivibrator to eliminate high frequencies. Low pass filter cut off frequency calculation shown in figure 6. Expected f_c is 150Hz. With using a resistor (R2) as a 100kΩ and 1μF capacitor (C2) f_c is obtained 159Hz.

$$V_{out} = \frac{X_c}{X_c + R} \times V_{in}$$

$$\frac{V_{out}}{V_{in}} = \frac{X_c}{\sqrt{R^2 + {X_c}^2}}$$

$$\frac{1}{\sqrt{2}} = \frac{\frac{1}{\omega c}}{\sqrt{\frac{1}{\omega c}^2 + R^2}}$$

$$\omega = \frac{1}{R.C} \text{ and } f_c = \frac{1}{2\pi RC}$$

Low pass filter cut off frequency calculation

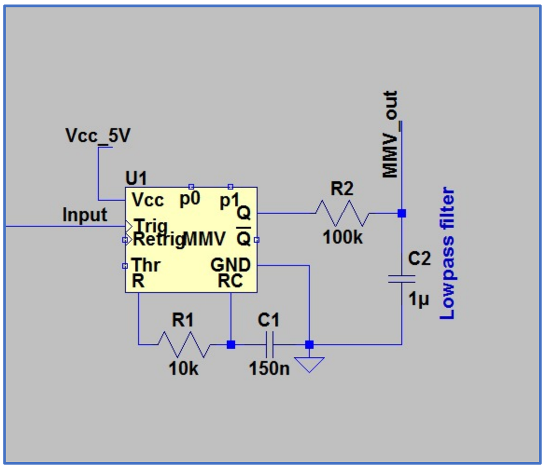

Fig.5: MMV Circuit

Monostable Multivibrator Design Targets			
Description of the design target	**Min.**	**Max.**	**Unit**
Cut-off frequency f_c	**150**	**160**	**Hz**
Supply voltage	**5**	**10**	**V**
Output Ripple Voltage v_{rip}	**0**	**30**	**mV**

Differential Amplifier Circuit

Differential amplifier subtracts the voltage value of the output of MMW (V_{MMV}) from the voltage set by the potentiometer (V_{pot}). The output of this circuit part is called the error signal. If the error signal is positive that means motor's speed must increase. Otherwise, the error signal is negative then the speed of the motor must decrease. If the error signal is equal to zero, the motor is turning at the speed we want.

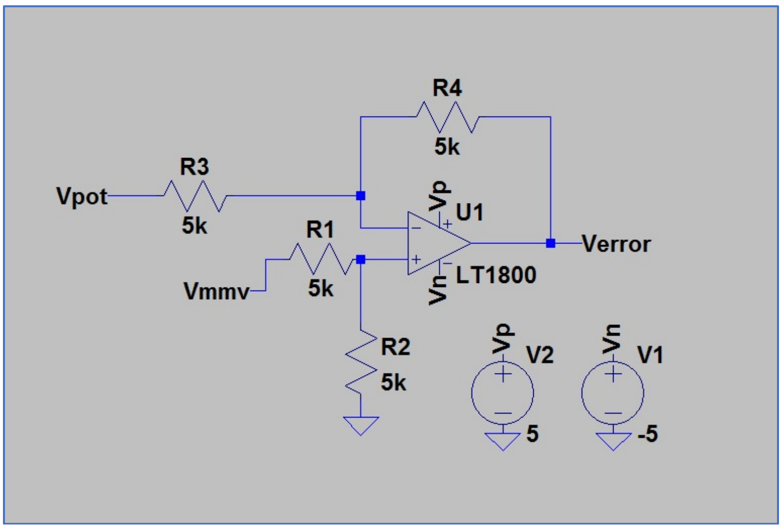

Fig.6: Differential Amplifier Circuit

Differential Amplifier Design Targets			
Description of design target	**Min.**	**Max.**	**Unit**
The output voltage of MMV V_{MMV}	1.64	4.4	V
The output voltage of Potentiometer V_{pot}	1.6	4.4	V

2.2. PWM Unit

The PWM unit is composed of an oscillator and comparator.

Upper op-amp circuit used as an oscillator. The oscillator creates triangular pulses. Their peak to peak voltage is 2.8V. Their calculations are given below. The output of the oscillator is fixed. The output of this op-amp connected to the second op amp's positive input. This op-amp used as a comparator to compare triangular pulse and error signal. The output of comparator gives pulses. The duty cycle of pulses depends on the value of the error signal. At the output of the comparator circuit, negative pulses are observed when the motor is rotating faster than wanted and their amplitudes are -5V. To obtain positive error value for all potentiometer levels, a 5V offset is applied to generated pulses. This process is called Pulse Width Modulation. This pulse signal is used to drive the motor and it is transmitted to Half-Bridge driver.

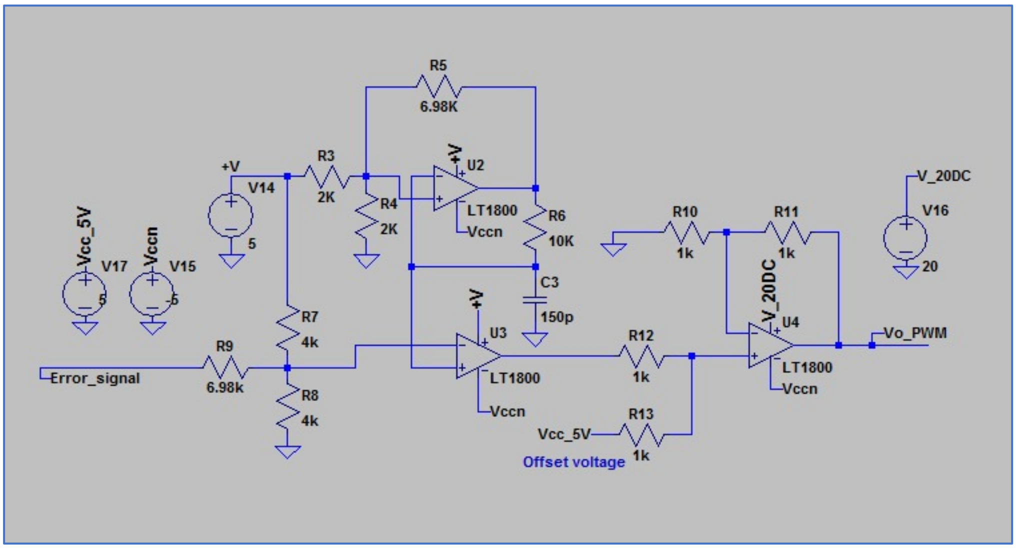

Fig.7: PWM Unit Circuit Design

PWM Unit Design Targets			
Description of design target	**Min.**	**Max.**	**Unit**
Duty cycle	0	100	%
The output voltage of PWM	0	10	V
The frequency of PWM Signal	-	400k	Hz

2.3 Driving Motor

To drive the motor L298N dual full-bridge driver is used. It contains two full-bridge drivers. The full-bridge driver consists of two haft-bridge drivers. Full bridge driver allows turning the motor in different directions. In this project does not relate to turning direction so only one half-bridge is used. Bridges are composed of transistors. Transistors work as a switch. When they become on the situation, they allow passing supply voltage(V_{cc}) to the motor. They're on/off situation depends on the PWM signal.

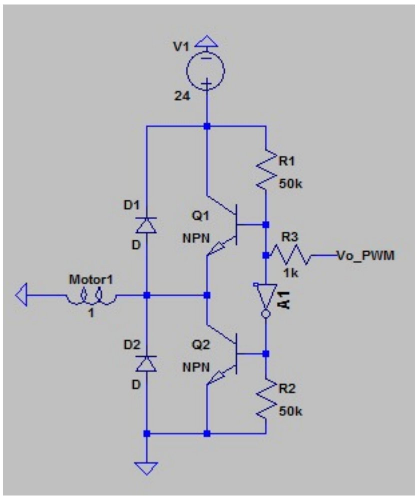

Fig.8: Half-Bridge motor driver

Half-Bridge Driver Design Targets			
Description of design target	**Min.**	**Max.**	**Unit**
Input voltage	**0**	**10**	**V-peak**
Output low voltage	**0**	**1**	**V**
Output high voltage	**23**	**24**	**V**
Output duty cycle	**0**	**99**	**%**

2.4 Displaying RPS

The purpose of this circuit part is displaying the number of turns of the motor in one second. As mentioned, the rotating disc has sixteen holes, so every sixteen peaks of phototransistor signal represent one turn of the motor. The output of the phototransistor signal, which was named as a frequency information signal, transmitted to the 4-bit counter. All output pins of counter connect to the NAND gate to get the clock signal for the second counter. This second counter is used to count rotating times of motor. The motor will turn between 1200rps and 3000rps, while the motor is turning 1200rps, the motor shaft will turn 20 times each second and for 3000rps, this value increases to the 50.

To count the 50, this counter is chosen 6-bit. End of the each second, counted turn number loaded parallel to register. A register is used to keep loaded information until the next second. When next second pulse trig the enable of the register, new information loaded from counter-2 to register. While register keeping the information, this information is displayed on the three digits display screen.

Beside them, to create the clock signal 555 Timer IC is used and this clock signal has 1kHz frequency and 50% duty cycle. Its frequency calculation is given below. To count the seconds, the third counter is used, when this counter must be count at least 1000 so, the third counter is chosen 9-bit. Output pins of this counter connect to AND gate, when it counts 1000, out of AND gate will be High then this signal transmitted to register's enable pin to load new information from counter-2. Also output signal of AND gate used to reset counter to. 1ms delay added to signal then is transmitted to reset of counter-2.

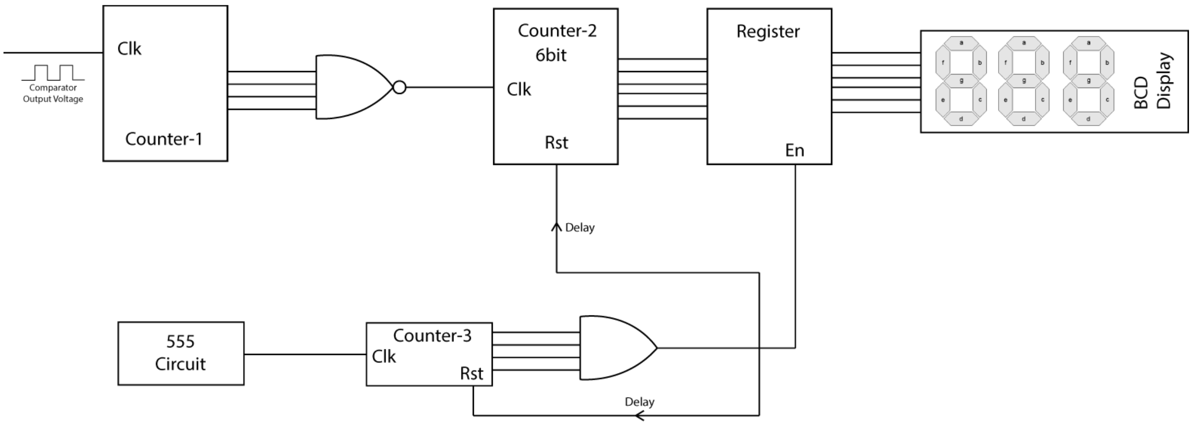

Fig.9: Display Unit Circuit Schematic

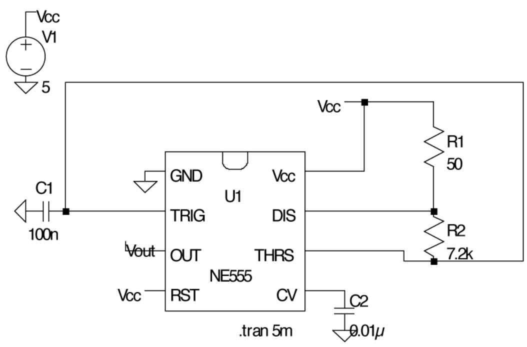

Fig.10: 555 Timer Circuit

Capacitor charging time

Charging equation = $\frac{2}{3}V_{cc} = \frac{1}{3}V_{cc} + \frac{2}{3}V_{cc}(1 - e^{(-T_c/T_a)})$ where T_c = charging time
$T_a = (R_1 + R_2)$.C

To solve for T_c;

$$T_c = T_a \ln(2) = 0{,}693(R_1 + R_2).C$$

When the capacitor's charge reaches the limit $\frac{2}{3}V_{cc}$, it starts to discharge. It is discharging until it's charge reach $\frac{1}{3}V_{cc}$.

$\frac{1}{3}V_{cc} = \frac{2}{3}V_{cc}(1 - e^{(-T_D/T_B)})$ where T_D = discharging time
$T_B = R_2$.C

To solve for T_D;

$$T_D = T_B \ln(2) = 0{,}693(R_2).C$$

3. Component List

Component description	Part Number	Manufacturer	Supplier
DC Motor	**SY28 0752045**	STMicroelectronics	Electronics Lab.
Operational amplifier	**LT1800**	Linear Technology	Electronics Lab.
Npn-BJT	**BC237**	Texas Instruments	Electronics Lab.
H-bridge drier	**L298n**	STMicroelectronics	Electronics Lab.
Monostable Multivibrator	**74HC123**	Texas Instruments	Electronics Lab.
Timer	**LM555**	STMicroelectronics	Direnc.net
**			

** Since we have not started to build displaying rps part in the lab so, the components which will use for this part are not decided completely.

References

1. "Monostable Multi vibrators"
https://www.daenotes.com/electronics/digital-electronics/monostable-multivibrators-working-construction-types

2. "Pulse Circuits - Monostable Multivibrator"
https://www.tutorialspoint.com/pulse_circuits/pulse_circuits_monostable_multivibrator.htm

3. Rockey Choudhary, Monika Bhardwaj, Prof. B. P Singh, Jan. (2012). Design and Analysis of Pulse Width Modulator (PWM) using Current Comparator
https://www.ijser.org/paper/Design-and-Analysis-of-Pulse-width-Modulator-PWM-using-Current-Comparator.html

4. "PWM Motor Speed Controller / DC Light Dimmer"

http://www.solorb.com/elect/solarcirc/pwm1/

7. STMicroelectronics L298 Dual Full-Bridge Driver Datasheet
https://www.st.com/resource/en/datasheet/l298.pdf

8. "How to Design Schmitt Trigger Oscillator"
https://www.allaboutcircuits.com/technical-articles/how-to-design-schmitt-trigger-oscillators/

9. Microelectronics Circuit Analysis and Design, 4th Edition. Neamen Donald A., "The 555 Circuit" p.1100-1107.