BCIT SCHOOL OF ENERGY

Mechatronics and Robotics Engineering Technology

ROBT 3351: Automation Equipment

DESIGN PROJECT:

POWER SUPPLY, VOLTAGE REGULATOR, AND MOTOR DRIVER

EDUCATION
FOR A COMPLEX WORLD.

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1 INTRODUCTION

The purpose of this design project is to deepen the theoretical understanding of the concepts taught in the lectures. The design project focuses on two main concepts: linear voltage regulators and h-bridge motor drivers. Upon completion of the project, students are encouraged to drive one of the bench top DC motors and program the required drive signals with a microcontroller.

1.1 OBJECTIVES

The objectives of this design project are to:

- Understand the components of a linear voltage regulator.
- Analyze the behavior of a DC motor under various conditions.
- Design circuits with BJTs.
- Layout a schematic to solder breadboard.
- Develop soldering skills.

1.2 TASKS

Perform the following tasks to obtain complete marks.

1. Circuit Analysis and Wiring Diagram.
    a. Power Supply **[8]** – October 18, 2024
    b. Voltage Regulator **[13] –** November 1, 2024
    c. Motor Driver **[19] –** November 15, 2024
2. Demonstrations – December 6, 2024
    a. Power Supply
        i. Fuse and Switch **[4]**
        ii. Unregulated Voltage **[4]**
        iii. 5 V and 12 V Regulated Voltage **[4]**
    b. Voltage Regulator
        i. Adjustable Voltage **[4]**
        ii. Adjustable Current **[4]**
        iii. No Regulation **[4]**
    c. Motor Driver
        i. Speed **[5]**
        ii. Brake **[5]**
        iii. Direction **[6]**
    d. Data and Photos **[20]** – December 6, 2024

2 LINEAR POWER SUPPLY

A linear power supply converts AC voltage into a steady DC voltage source. The supply will accept an step-down AC voltage that is at an appropriate level. The fuse adds protection against high currents and a Zener diode will discharge high voltages. This design provides 5V, 12V, as well as a unregulated voltage.

2.1 SCHEMATIC

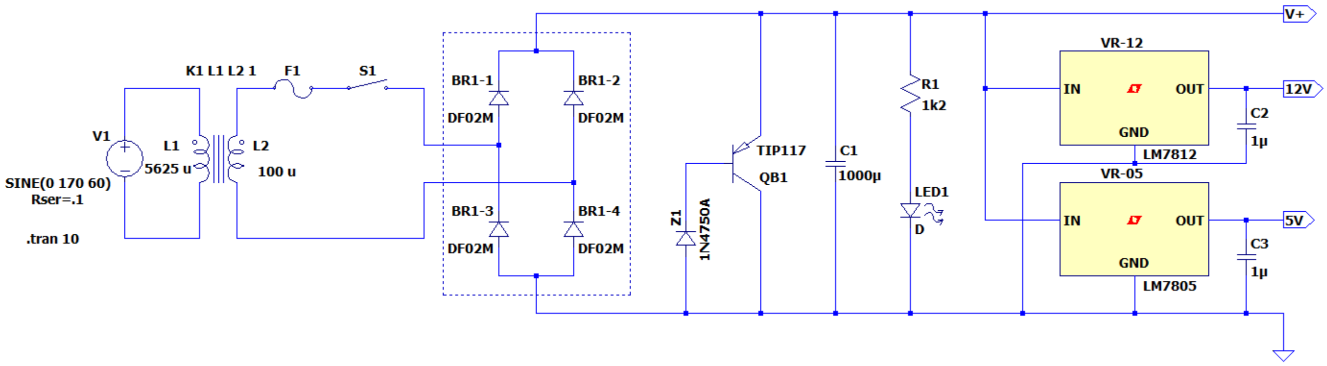


Figure 2.1 Linear Power Supply Schematic including transformer and 120 V source.

2.2 Components

Table 2.1: Linear Power Supply Component List

Digikey Part Number	Designation	Description	Current Limit	#
SBB400-ND	--	Breadboard	10 A	1
732-11376-ND	--	Fuseholder Block	20 A	1
DF02MDI-ND	BR1	Bridge Rectifier	1 A	1
P5197-ND	C1	1000 µF Capacitor	--	1
10-ECA-2DHG010-ND	C2, C3	1 µF Capacitor	--	2
486-1234-ND	F1	1A Fuse	1 A	2
754-1273-ND	LED1	Clear Green LED	25 mA	1
TIP117G-ND	QB1	PNP Darlington Transistor	2 A (IC) 50 mA (IB)	1
2057-SW-R3-2B-B-SB5-13-ND	S1	SPDT Rocker Switch	3 A	1
ED10561-ND	TB1-TB4	Terminal Block	6 A	4
MC7805CTGOS-ND	VR-05	5V Voltage Regulator	1 A	1
MC7812CTGOS-ND	VR-12	12V Voltage Regulator	1 A	1
1N4750AFS-ND	Z1	27V Zener Diode	37 mA	1

3 BJT Adjustable Voltage Regulator

The BJT adjustable voltage regulator is a device which can regulate its output based on voltage or current. Like a common bench top power supply, either the voltage or the current can be limiting. LEDs are included to indicate which one is actively being regulated.

3.1 Schematic

Changes: Some functions moved to the Linear Power Supply circuit. LED3 moved to remove current limiting issue caused by its forward bias voltage drop. R4 added for upper limit on current draw. P2 value increased for higher activation voltage. C4 added to help smooth output.

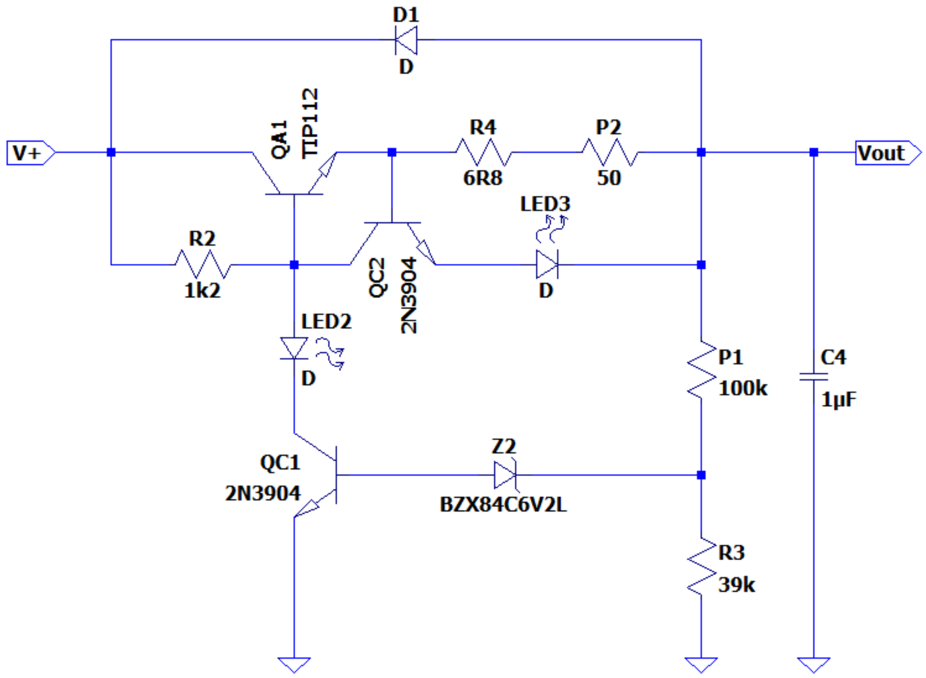


Figure 3.1: BJT Adjustable Voltage Regulator Schematic

3.2 Components

Table 3.1: BJT Adjustable Voltage Regulator Component List

Part	Designation	Description	Current Limit	#
SBB206-ND	--	Breadboard	10 A	1
10-ECA-2DHG010-ND	C4	1000 µF Capacitor	--	1
1N4007-TPMSCT-ND	D1	Diode	1 A	1
754-1273-ND	LED2, LED3	Clear Green LED	25 mA	3
PTV09A-4015F-B104-ND	P1	100k Ω Linear Potentiometer	0.05 W	1
3362P-1-500LF-ND	P2	50 Ω Potentiometer	0.5 W	1
TIP112GOS-ND	QA1	NPN Darlington Transistor	2 A (IC) 50 mA (IB)	1
2N3904TFCT-ND	QC1, QC2	NPN Transistor	200 mA (IC) 625 mW	2
A138077CT-ND	R4	6.8 Ω Resistor	524 mA	1
ED10561-ND	TB1, TB2	Terminal Block	6 A	2
BZX79C6V2-ND	Z2	6.2 V Zener Diode	75 mA	1

4 BJT DC Motor Driver

The BJT DC Motor Driver is a device which allows a motor to be controlled with 3.3 V signals. The PWM signal modulates the voltage applied to the DC motor terminals. D changes the polarity of the terminal voltage and therefore the driven direction. B disables voltage PWM signal and provides an electrical path for dynamic braking.

4.1 Schematic

Changes: Resistor values changed for $V_{out} = 30$ V, $I_L = 2$ A and control signals between 3.3 V → 5 V.

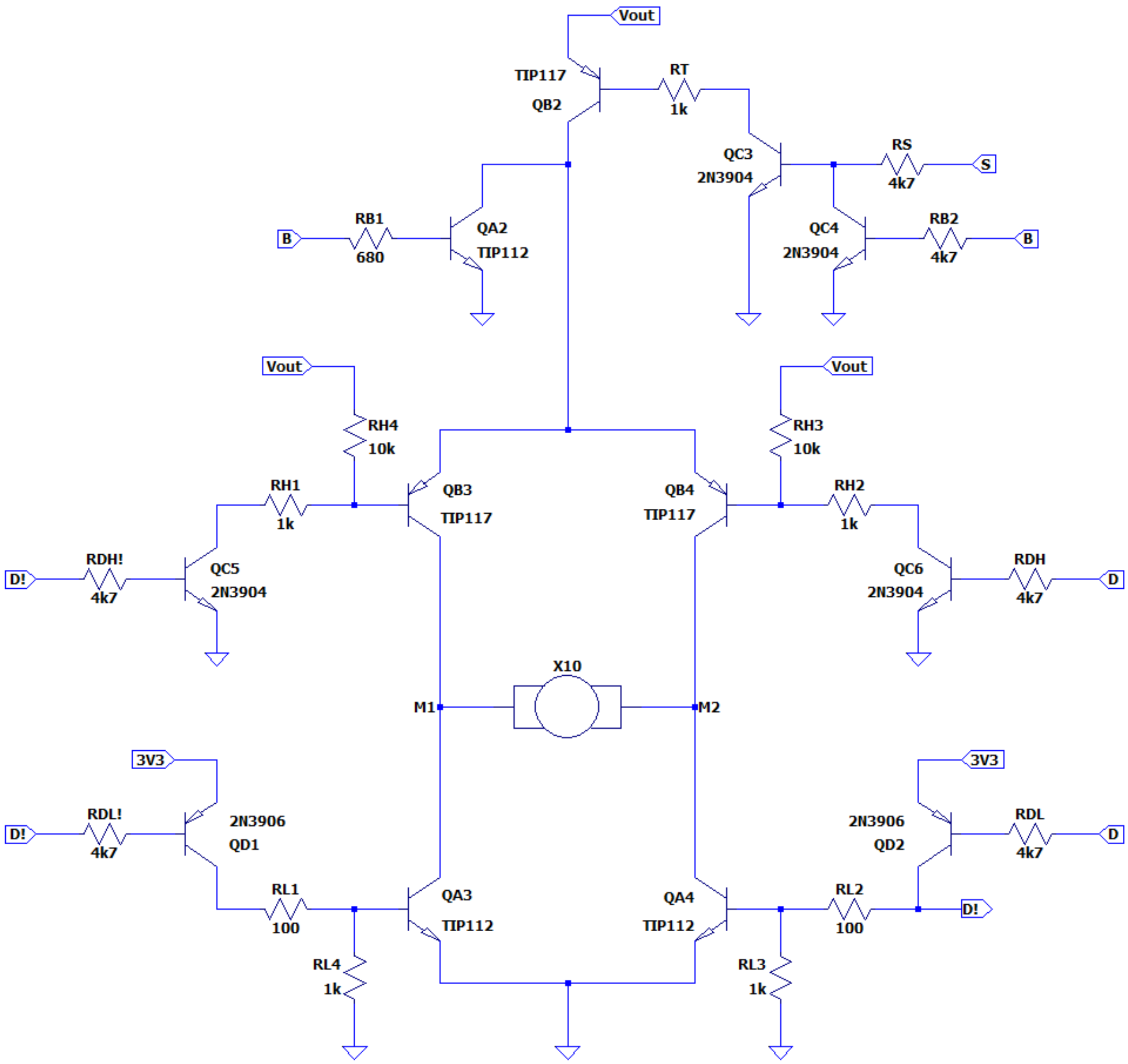


Figure 4.1: BJT Motor Drive Schematic

4.2 COMPONENTS

Table 4.1: BJT DC Motor Driver Component List

Part	Designation	Description	Current Limit	#
SBB400-ND	--	Breadboard	10 A	1
TIP111GOS-ND	QA2, QA3, QA4	NPN Darlington Transistor	2 A (IC) 50 mA (IB)	3
TIP116G-ND	QB2, QB3, QB4	PNP Darlington Transistor	2 A (IC) 50 mA (IB)	3
2N3904TFCT-ND	QC3, QC4, QC5, QC6	NPN Transistor	200 mA (IC) 625 mW	4
2N3906TFCT-ND	QD1, QD2	PNP Transistor	200 mA (IC) 625 mW	2
ED10561-ND	TB3, TB4, TB5, TB6,TB7, TB8	Terminal Block	--	6

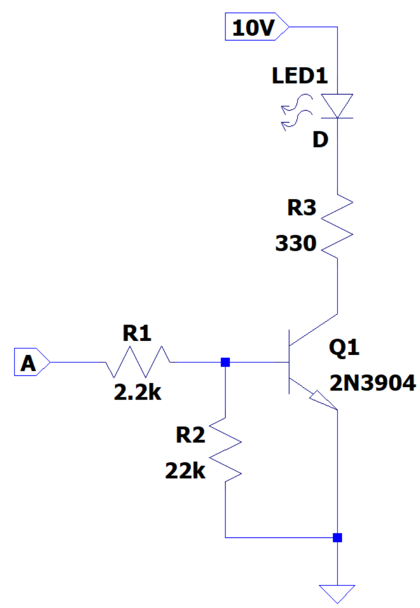
5 Testing Components

For testing various components use the following test circuits.

5.1 BJT Transistors

Testing the BJT Transistors, 2N3904 and 2N3906, can be done using the transistor to control an LED with a 3.3 V supply. Three resistors are required. R_1 limits the base current from the input signal A (5 V/0 V). R_2 pulls the base of the transistor to a known state when the input signal A is not present. R_3 protects the diode by limiting the current.

Toggle A between 0 V/5 V to see the LED turn Off/On



$$I_{C1} = 20 \text{ mA (from LED datasheet)}$$

$$I_{B1} = \frac{I_{C1}}{10} = 2 \text{ mA}$$

$$R_1 = \frac{V_A - V_{B1}}{I_{B1}} = \frac{5 \text{ V} - 0.7 \text{ V}}{2 \text{ mA}} = 2.2 \text{ k}\Omega$$

$$R_2 = 10\, R_1 = 10\,(2.2 \text{ k}\Omega) = 22 \text{ k}\Omega$$

$$R_3 = \frac{V_s - V_{FB} - V_{CE(SAT)}}{I_{C1}} = \frac{10 \text{ V} - 2.5 \text{ V} - 0.2 \text{ V}}{20 \text{ mA}} = 330\ \Omega$$

$$P_1 = \frac{V_{R1}^2}{R_1} = \frac{(4.3 \text{ V})^2}{2.2 \text{ k}\Omega} = 8.4 \text{ mW}, \qquad P_2 = \frac{V_{R2}^2}{R_2} = \frac{(0.7 \text{ V})^2}{22 \text{ k}\Omega} = 22\ \mu\text{W}$$

$$P_3 = \frac{V_{R3}^2}{R_3} = \frac{(7.3 \text{ V})^2}{330\ \Omega} = 161 \text{ mW}$$

$$P_{Q1} = V_{BE} I_{B1} + V_{CE} I_{C1} = (0.7 \text{ V})\left(\frac{4.3 \text{ V}}{2200\ \Omega} - \frac{0.7 \text{ V}}{22000\ \Omega}\right) + (0.2 \text{ V})\left(\frac{10 \text{ V} - 2.5 \text{ V} - 0.2 \text{ V}}{330\ \Omega}\right) = 5.8 \text{ mW}$$

$$I_{C2} = 20\text{ mA (from LED datasheet)}$$

$$I_{C1} = I_{B2} = 2\text{ mA}$$

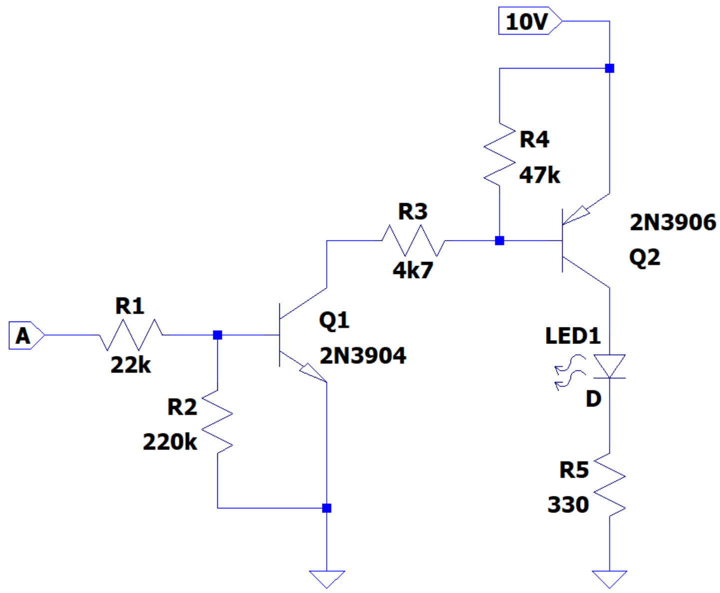
$$I_{B1} = \frac{I_{C1}}{10} = 200\ \mu\text{A}$$

$$R_1 = \frac{V_A - V_{B1}}{I_{B1}} = \frac{5\text{ V} - 0.7\text{ V}}{200\ \mu\text{A}} = 22\text{ k}\Omega$$

$$R_2 = 10R_1 = 220\text{ k}\Omega$$

$$R_3 = \frac{V_s - V_{BE} - V_{CE}}{I_{C1}}$$

$$R_3 = \frac{10\text{ V} - 0.7\text{ V} - 0.2\text{ V}}{2\text{ mA}} = 4.7\text{ k}\Omega$$



$$R_4 = 10\ R_3 = 47\text{ k}\Omega$$

$$R_5 = \frac{V_s - V_{CE} - V_{FB}}{I_{C2}} = \frac{10\text{ V} - 2.5\text{ V} - 0.2\text{ V}}{20\text{ mA}} = 330\ \Omega$$

$$P_1 = \frac{V_{R1}^2}{R_1} = \frac{(4.3\text{ V})^2}{22\text{ k}\Omega} = 840\ \mu\text{W}, \qquad P_2 = \frac{V_{R2}^2}{R_2} = \frac{(0.7\text{ V})^2}{220\text{ k}\Omega} = 2.2\ \mu\text{W}$$

$$P_3 = \frac{V_{R3}^2}{R_3} = \frac{(9.1\text{ V})^2}{4.7\text{ k}\Omega} = 17.6\text{ mW}, \qquad P_4 = \frac{V_{R4}^2}{R_4} = \frac{(0.7\text{ V})^2}{47\text{ k}\Omega} = 10.4\ \mu\text{W}, \qquad P_5 = \frac{V_{R5}^2}{R_5} = \frac{(7.3\text{ V})^2}{330\ \Omega} = 161\text{ mW}$$

$$P_{Q1} = V_{BE}I_{B1} + V_{CE}I_{C1} = (0.7\text{ V})\left(\frac{4.3\text{ V}}{22\text{ k}\Omega} - \frac{0.7\text{ V}}{220\text{ k}\Omega}\right) + (0.2\text{ V})\left(\frac{10\text{ V} - 0.7\text{ V} - 0.2\text{ V}}{4.7\text{ k}\Omega}\right) = 521\ \mu\text{W}$$

$$P_{Q2} = V_{BE}I_{B2} + V_{CE}I_{C2} = (0.7\text{ V})\left(\frac{9.1\text{ V}}{4.7\text{ k}\Omega} - \frac{0.7\text{ V}}{47k\ \Omega}\right) + (0.2\text{ V})\left(\frac{10\text{ V} - 2.5\text{ V} - 0.2\text{ V}}{330\ \Omega}\right) = 5.8\text{ mW}$$

5.2 Darlington Transistor

Testing the Darlington Transistors, TIP111 and TIP116, can be done using similar circuits for testing the standard BJT transistors.

Toggle A between 0 V/5 V to see the LED turn Off/On

$$I_{C1} = 20 \text{ mA (from LED datasheet)}$$

$$I_{B1} = \frac{V_A - V_{B1}}{R_1} = \frac{5 \text{ V} - 2.8 \text{ V}}{2.2 \text{ k}\Omega} = 1 \text{ mA}$$

$$I_{C1(Active)} = I_{B1}\beta = 1 \text{ mA} \cdot 1000 = 1 \text{ A}$$

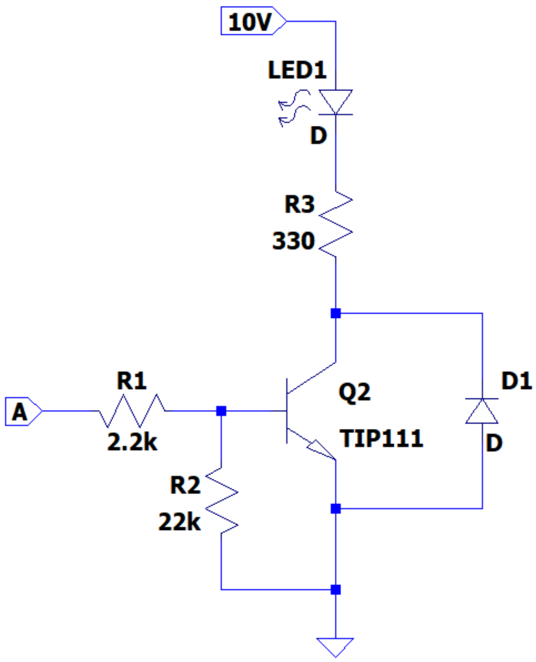
$$R_2 = 10\, R_1 = 10\,(2.2 \text{ k}\Omega) = 22 \text{ k}\Omega$$

$$I_{C1} = \frac{V_S - V_{FB} - V_{CE(SAT)}}{R_3} = \frac{10 \text{ V} - 2.5 \text{ V} - 2.5 \text{ V}}{330\ \Omega} = 15 \text{ mA}$$

$$P_1 = \frac{V_{R1}^2}{R_1} = \frac{(2.2 \text{ V})^2}{2.2 \text{ k}\Omega} = 2.2 \text{ mW},$$

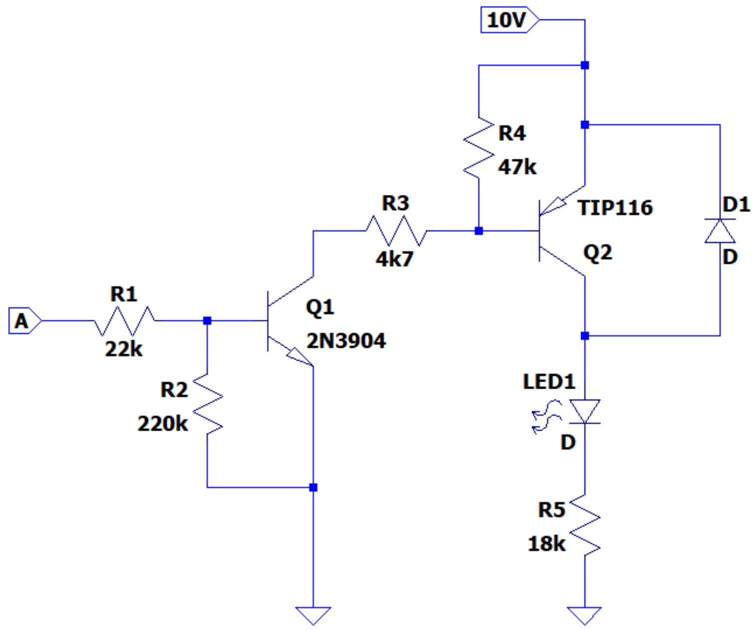
$$P_2 = \frac{V_{R2}^2}{R_2} = \frac{(2.8 \text{ V})^2}{22 \text{ k}\Omega} = 356\ \mu\text{W}$$

$$P_3 = \frac{V_{R3}^2}{R_3} = \frac{(4.7 \text{ V})^2}{330\ \Omega} = 67 \text{ mW}$$



$$P_{Q1} = V_{BE}I_{B1} + V_{CE}I_{C1} = (2.8 \text{ V})\left(\frac{2.2 \text{ V}}{2200\ \Omega} - \frac{2.8 \text{ V}}{22000\ \Omega}\right) + (2.5 \text{ V})\left(\frac{10 \text{ V} - 2.5 \text{ V} - 2.5 \text{ V}}{330\ \Omega}\right) = 40.3 \text{ mW}$$

$I_{C2} = 20$ mA (from LED datasheet)



$$I_{C1} = I_{B2} = 2 \text{ mA}$$

$$I_{B1} = \frac{I_{C1}}{10} = 200 \text{ µA}$$

$$R_1 = \frac{V_A - V_{B1}}{I_{B1}} = \frac{5 \text{ V} - 0.7 \text{ V}}{200 \text{ µA}} = 22 \text{ kΩ}$$

$$R_2 = 10R_1 = 220 \text{ kΩ}$$

$$I_{C1} = \frac{V_s - V_{BE} - V_{CE}}{R_3}$$

$$I_{C1} = \frac{10 \text{ V} - 2.8 \text{ V} - 0.2 \text{ V}}{4.7 \text{ kΩ}} = 1.5 \text{ mA}$$

$$I_{C1(Active)} = I_{B2}\beta = 1.5 \text{ mA} \cdot 1000 = 1.5 \text{ A}$$

$$R_4 = 10\, R_3 = 47 \text{ kΩ}$$

$$I_{C2} = \frac{V_s - V_{CE} - V_{FB}}{R_5} = \frac{10 \text{ V} - 2.5 \text{ V} - 2.5 \text{ V}}{330 \text{ Ω}} = 15 \text{ mA}$$

$$P_1 = \frac{V_{R1}^2}{R_1} = \frac{(4.3 \text{ V})^2}{22 \text{ kΩ}} = 840 \text{ µW}, \qquad P_2 = \frac{V_{R2}^2}{R_2} = \frac{(0.7 \text{ V})^2}{220 \text{ kΩ}} = 2.2 \text{ µW}$$

$$P_3 = \frac{V_{R3}^2}{R_3} = \frac{(7 \text{ V})^2}{4.7 \text{ kΩ}} = 10.4 \text{ mW}, \qquad P_4 = \frac{V_{R4}^2}{R_4} = \frac{(2.8)^2}{47 \text{ kΩ}} = 167 \text{ µW}, \qquad P_5 = \frac{V_{R5}^2}{R_5} = \frac{(5 \text{ V})^2}{330 \text{ Ω}} = 75 \text{ mW}$$

$$P_{Q1} = V_{BE}I_{B1} + V_{CE}I_{C1} = (0.7 \text{ V})\left(\frac{4.3 \text{ V}}{22 \text{ kΩ}} - \frac{0.7 \text{ V}}{220 \text{ kΩ}}\right) + (0.2 \text{ V})\left(\frac{10 \text{ V} - 2.8 \text{ V} - 0.2 \text{ V}}{4.7 \text{ kΩ}}\right) = 432 \text{ µW}$$

$$P_{Q2} = V_{BE}I_{B2} + V_{CE}I_{C2} = (2.8 \text{ V})\left(\frac{7 \text{ V}}{4.7 \text{ kΩ}} - \frac{2.8 \text{ V}}{47 \text{ kΩ}}\right) + (2.5 \text{ V})\left(\frac{10 \text{ V} - 2.5 \text{ V} - 2.5 \text{ V}}{330 \text{ Ω}}\right) = 41.9 \text{ mW}$$

6 Appendix

6.1 2022

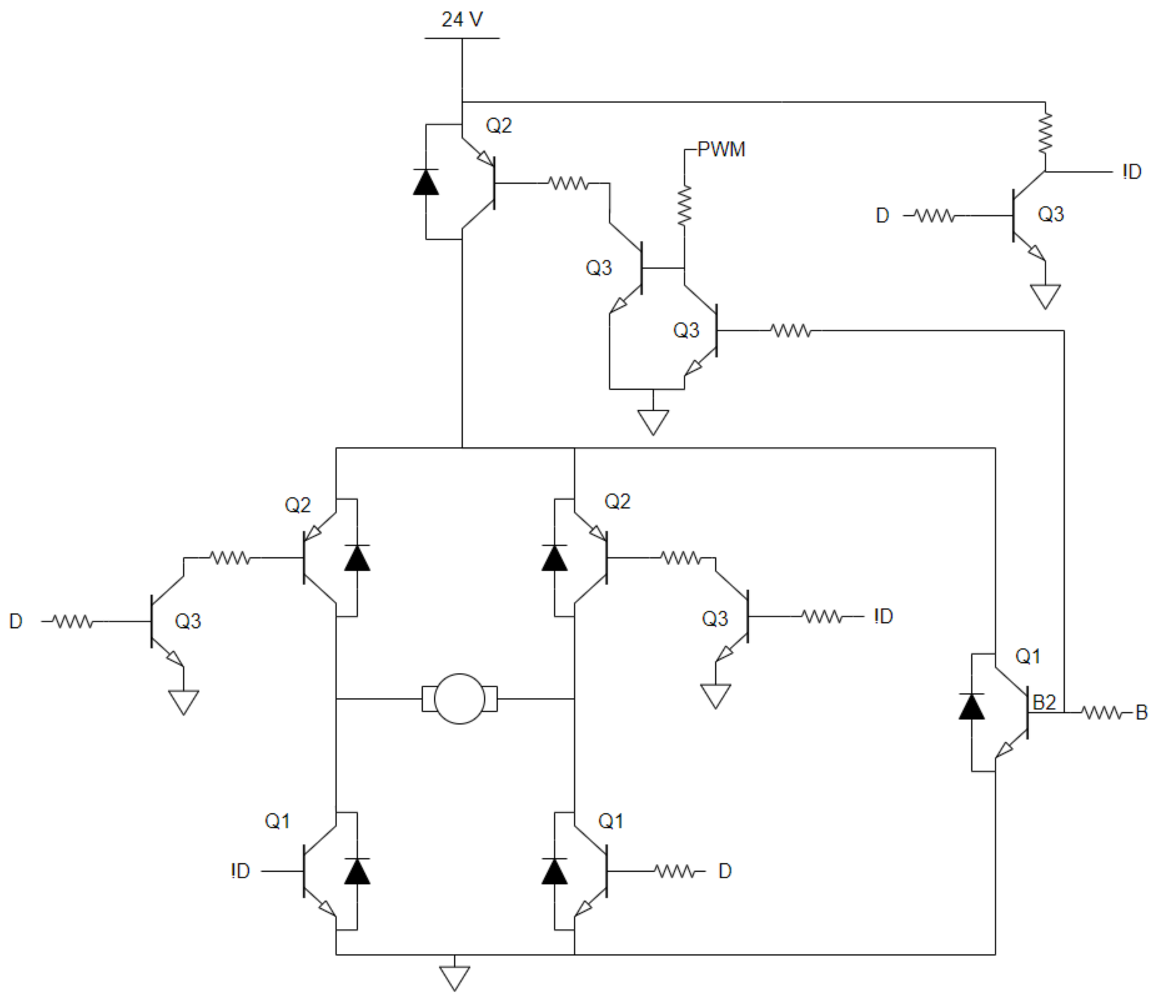


Figure 6.1: BJT H-Bridge Motor Driver 2022

6.2 2023

This version of the BJT Adjustable Voltage Regulator has a faulty current limiting branch. QC2 saturates but is unable to draw all of the base current from QA1 away because of the LED3 forward bias voltage drop.

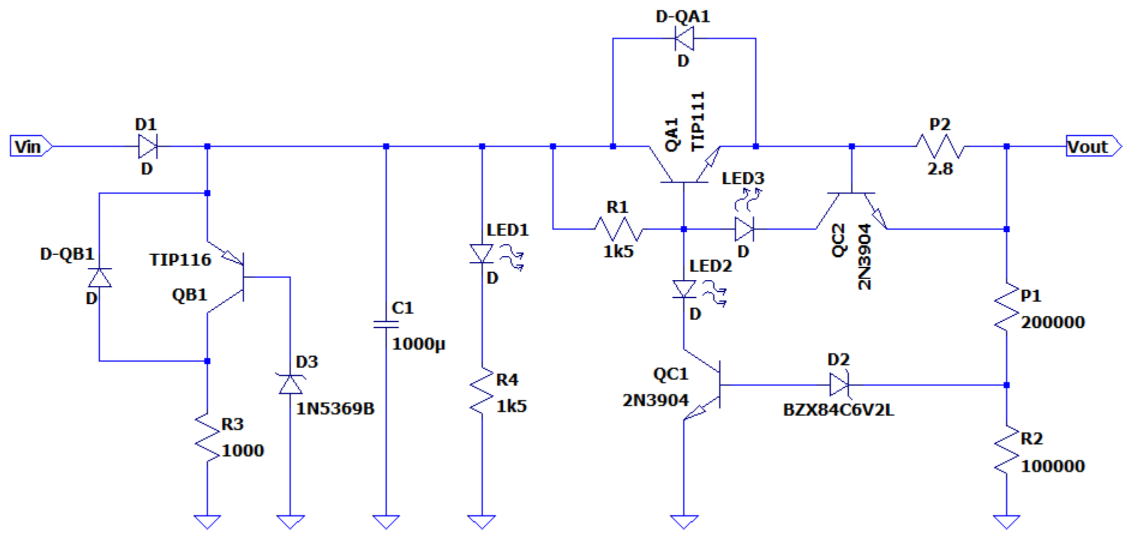


Figure 6.2: BJT Adjustable Voltage Regulator 2023 (unfixed)

Changes: Added D4 (fixes the current limiting) and D5 (allows capacitor to be charged from load).

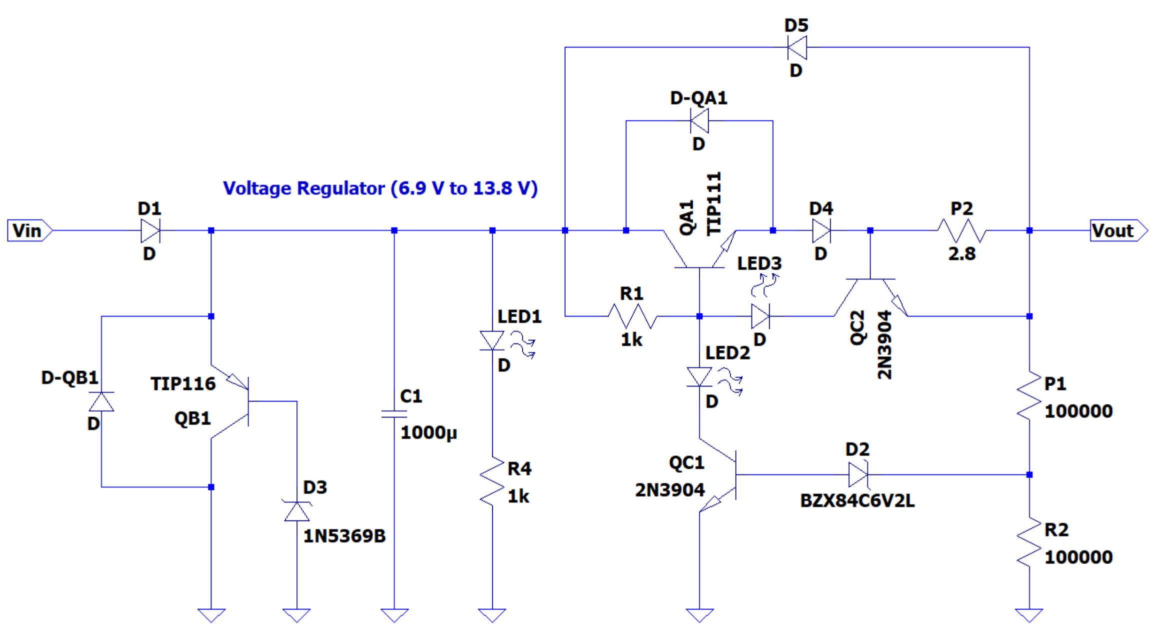


Figure 6.3: BJT Adjustable Voltage Regulator Schematic 2023

This version of the motor driver was designed with a possible voltage in of 41.4 V. Resistor value calculations were very specific and lead to many different value resistors being used.

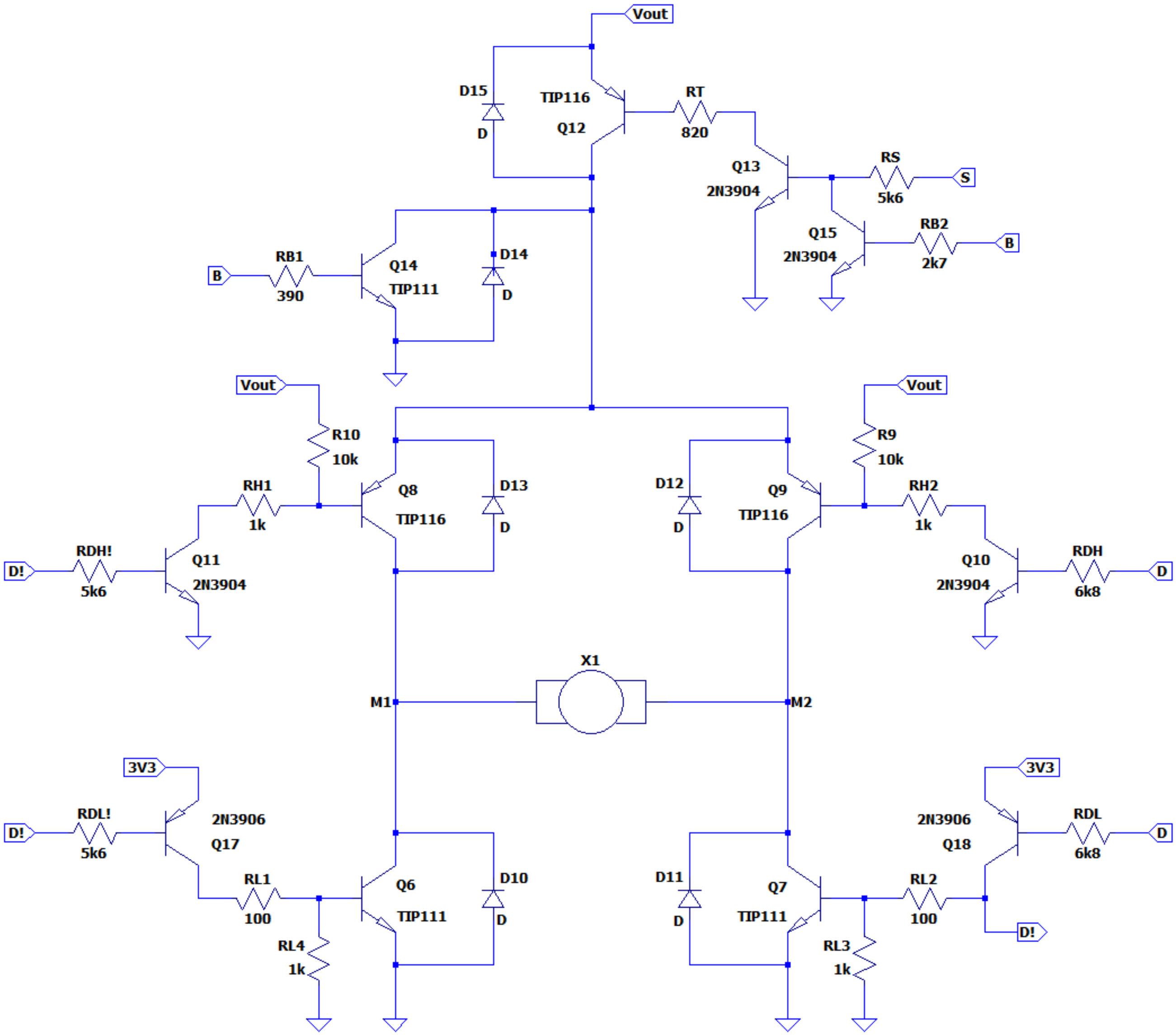


Figure 6.4: BJT Motor Drive Schematic 2023 (Labels and values unchanged)

Changes: Transistors are labelled, and resistors are duplicated to ease assembly.

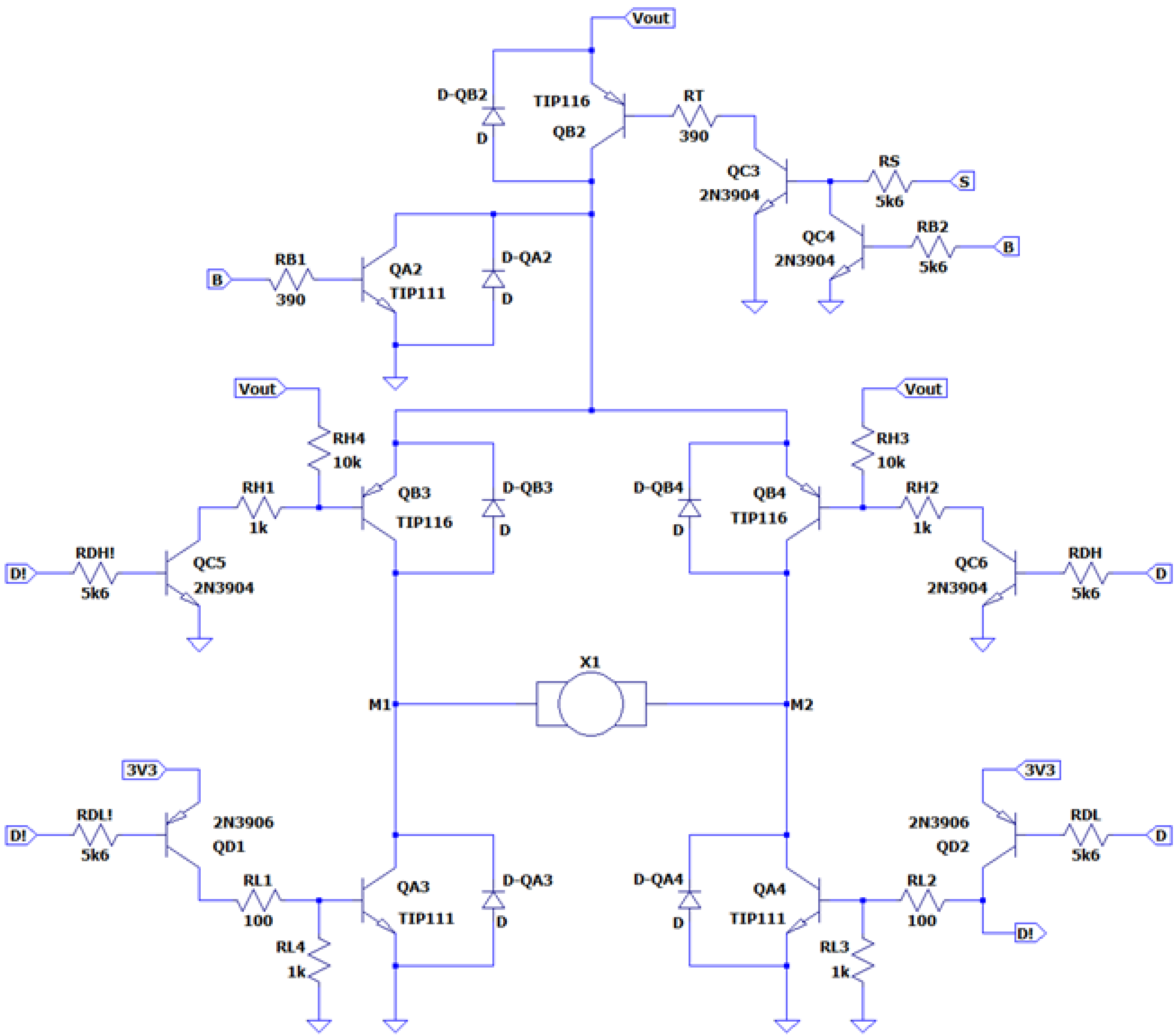


Figure 6.5: BJT Motor Drive Schematic 2023