Breadboard Assignment - Power

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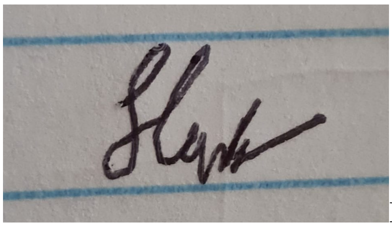
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Date

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Chapter 1

Introduction

1.0.1 Design problem statement

Design a circuit on a single breadboard, consisting of less than 20 components, that is able to drive a stepper motor at 1.5A and 12V using a 3V3 input logic signal running at maximum 1mA.

1.0.2 Context Diagram

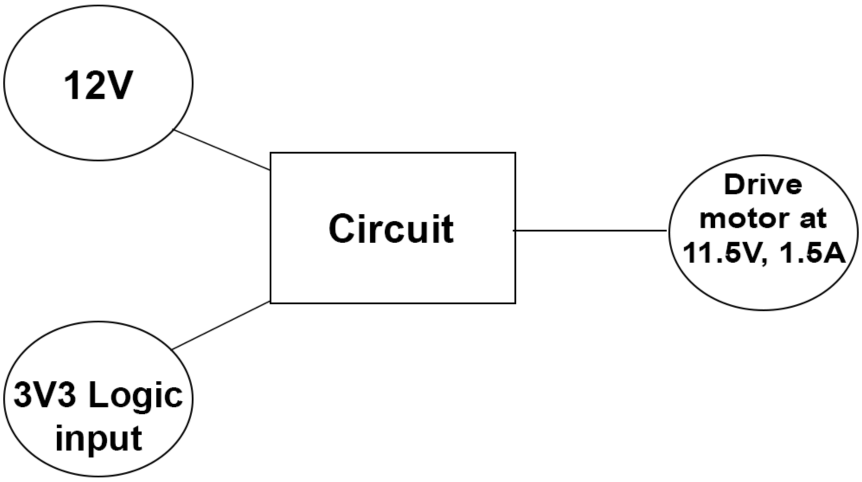

Figure 1.1: Context Diagram for Circuit

1.0.3 High-Level Requirements Diagram

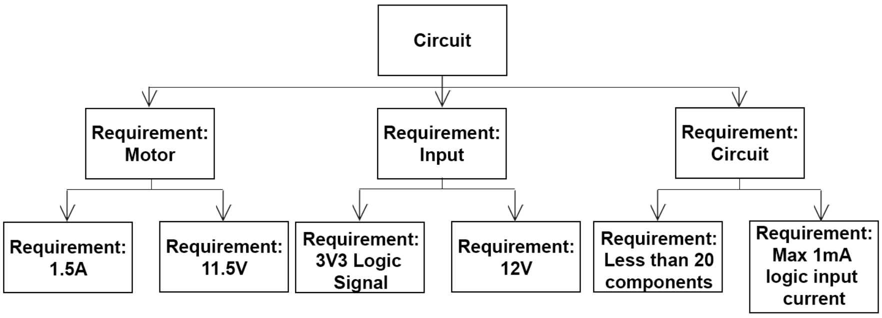

Figure 1.2: High-Level Requirement Diagram for circuit

1.0.4 Specifications and Requirements

Requirements:

- Circuit to drive a stepper motor
- Circuit must fit on a single breadboard
- Components must be sourced from White Lab
- Load on at greater than 2.4V, and off at less than 0.5V

Specifications:

- Input of 12V
- Input logic signal of 3V3
- Load must be at least 11.5V at 1.5A
- No more than 20 components
- Input logic signal must draw a maximum of 1mA
- Switching speed ON-OFF/OFF-ON at less than 1us

1.0.5 Discussion

The circuit needs to be able to switch on and off depending on the input logic signal being high or low, with the further requirements of it switching off at less than 0.5V and on at greater than 2.4V, which means the circuit needs to be able to check the voltage and switch the load depending the input. The best way to check for voltage input will be to use a transistor as a switching mechanism as they switch on at 0.7V or higher. 11.5V at 1.5A is extremely high so that will need to be accounted for as basic components might not be able to run at those specifications. To check the switching times, the load and the input logic signal will need to be put onto an oscilloscope which will be able to check timing differences, voltage output and current output of the circuit. Components just from white lab implies we will have a limited selection to choose from, and with the high voltage and current requirements, we will have to check data sheets to verify the components we will want to use will be able to handle the high voltage and current, and to see if they will have low enough switching speeds to handle that requirement.

Chapter 2

Subsystem Design

2.0.1 Calculations and Solution Description

Input logic signal =<1mA:

V = 3.3V, I =<1mA

$$R = V/I = 3.3/0.001 = 3300\Omega$$

Using the E-series value, we can use a 3.3kΩ resistor to ensure current never exceeds 1mA.

Note:

Resistors in white lab have a 1/4th watt power rating, meaning that they cannot handle more than 1/4th of a watt, so that will need to be factored into calculations depending how high the voltage and current is through a path

Breadboards typically cannot take more than 1A through the board without having drastic loss of voltage, so to account for this it is ideal to instead connect the points straight onto the transistors to avoid lowering the output voltage and current across the load

Although MOSFET's were a working solution to the problem, we were not allowed to use MOSFET's in our solution as they were not being given out in white lab. Although I had a working solution with a P MOSFET, upon reflection in the context of the assignment and the next stage, it made sense to use just basic transistors instead as the cost of a MOSFET is alot more than that of transistors and since our project is budget constrained and transistors would work just as well, it made sense to use the cheaper option that worked.

With the given information that the load was going to be connected above our circuits, it made sense to use low side switching to achieve the job. Another note, is the transistors rated enough to handle 1.5A, needed more than 1mA to power the transistor, so a pair of transistors in a darlington pair configuration was needed to successfully meet the requirements.

Since a pretty basic transistor is required to run the circuit, I selected to us a 2N2222. Although it can handle both the input of 1mA, 3V3 and 12V, the power rating on the collector side is too high as it can only handle 625 mW. With a gain of 75:

$$I_B = 1mA$$

$$I_C = \beta \times I_B = 75 \times 1mA = 75mA$$

$$R = V/I = 12/0.075 = 160\Omega$$

However, $P = I^2R = 0.075^2 \times 160 = 0.9W$, which is greater than 625 mW and 0.25W that the resistors can handle, so we need to put them in parallel and I selected to use four 680 Ω resistors

$$R = (1/680 + 1/680 + 1/680 + 1/680)^-1 = 170\Omega$$

$$P = I^2R = 0.01875^2 \times 680 = 0.23W$$

I decided to use a TIP41C as it had the right ratings to handle the the current and voltage on collector side and could be powered from the 100mA on the base side. To demonstrate a load a 8Ω resistor can be used as it produces the right amount of current:

$$R = V/I = 12/1.5 = 8\Omega$$

The circuit is powered using a constant 12V input, which is used to power the transistors and the load. The first transistor is being powered with a 3.3V input logic signal which is being used to switch the transistor and off as a way to signify the states of the motor being on and off. The first transistor is used to up the current such that the second transistor has enough current to switch on, which upon switching on is allows for the motor to run at least at 11.5V at 1.5A. The load in the schematic below is to signify the position of the motor in the circuit.

2.0.2 Circuit Schematic

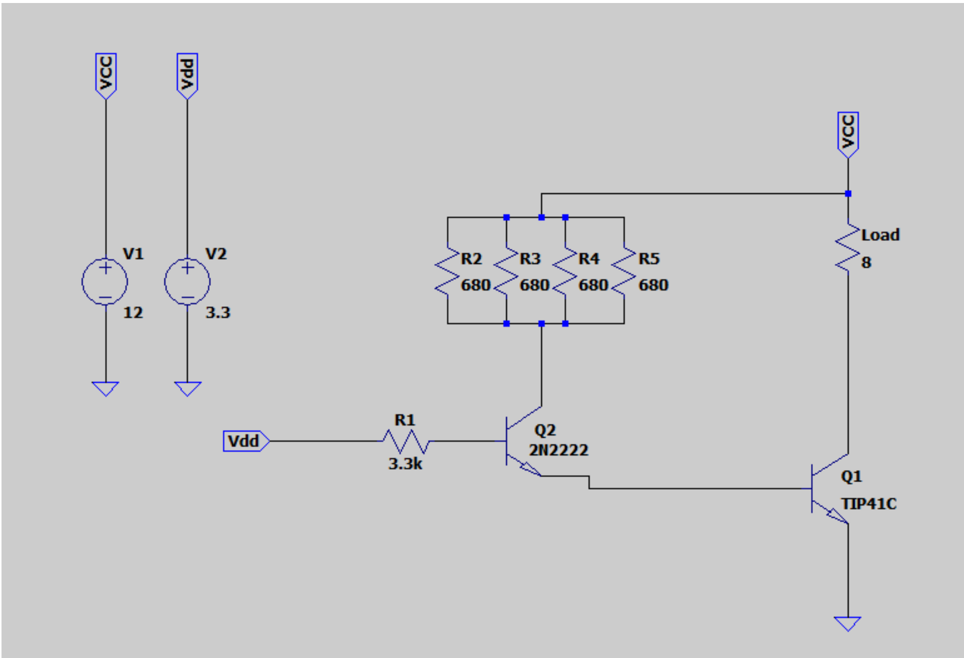

Figure 2.1: Circuit Schematic

Chapter 3

System Integration Design

3.0.1 Integration

The base circuit we have created can be used to power one pole of the motor in one direction. The stepper motor is a 4 pole motor and we have been given instruction we are only required to run 1 of those poles. However, this motor in the current design is only able to run in one direction as the design only has a state of on or off, neither of which can be used to change the direction of turning, which would be required for reversing the micro-mouse as given in the main project outline.

We know that the circuit is required to use low side switching, so as seen in the original schematic, we will face no problems with that, however in order for us to change the direction of the motor, we will be required to change how the motor is powered, as the motor works that based on direction of voltage flow through it will dictate the direction the motor turns, so we would need to have two different circuits powering the system such that the motor would turn based on what instruction it has been given. We haven't been given much information relating to how the motor will be powered, but for the current design we can assume that it would essentially be two circuits similar to the ones we have made to power the motor in two different directions. With this acknowledgement, we can assess diferent methods for our integration process. One of the ideas we talked about in class was the H-bridge design.

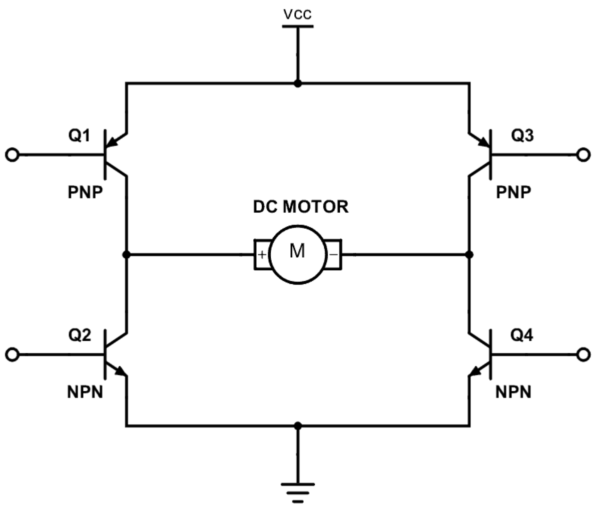

Figure 3.1: H-Bridge

The H-bridge design shown above works as follows, if each of the transistors above are replaced with switches, we can control the flow of voltage, so if Q1 and Q4 are closed, and Q2 and Q3 are open, the voltage will flow through the motor from left to right, and if Q1 and Q4 are open, and Q2 and Q3 are closed, it will instead flow from right to left which will allow the direction of the current to be controlled based on which switches are open.[1] These switches can be controlled using logic signals similar to what we showed in the breadboard assignment to control the flow. Since both Q2 and Q3, and Q1 and Q4 are linked, each pair can be commanded off the same input signal so only two inputs are needed, one to signify turning clockwise, and the other turning anti-clockwise. We should be able to slot our current designs into the H-bridge without alot of major changes necessary.

3.0.2 System Interfacing Diagram

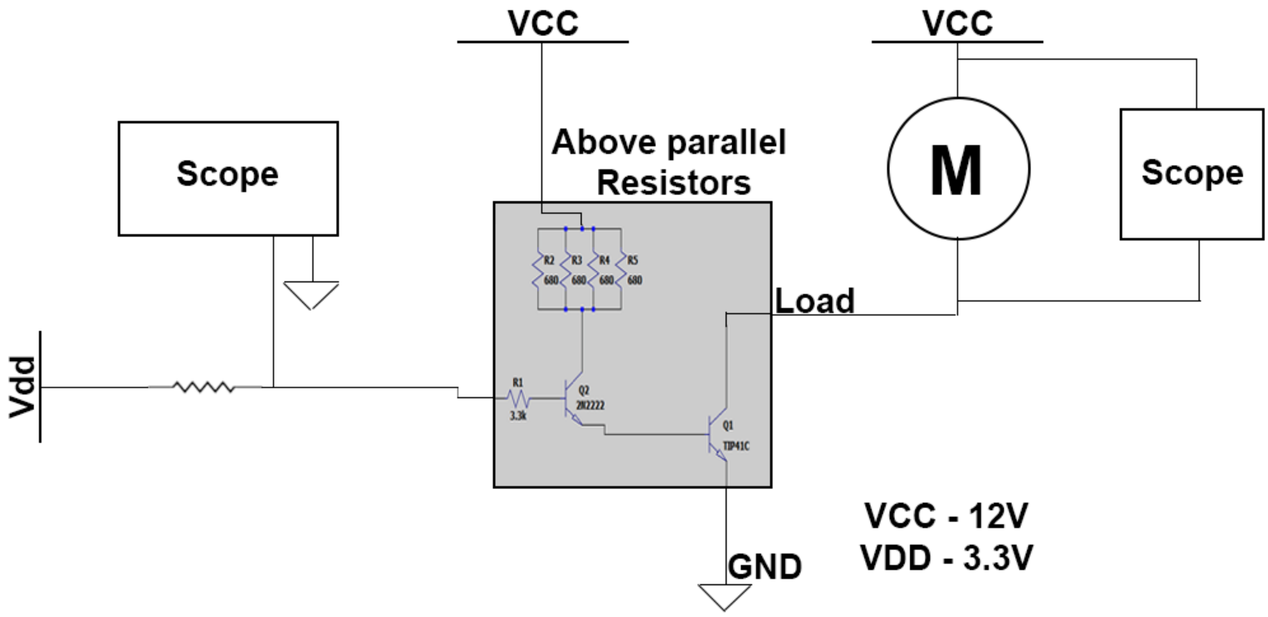

Figure 3.2: System Interfacing Diagram

Circuit above showcases the system we would need to connect to for testing, where the load connects and how the timing, voltages and current would be measured. The current and voltage are measured over the motor and the time for switching on and off is measured on an oscilloscope by comparing the difference between the scope and the motor's waveform to judge how long it takes for the transistors to switch on and off.

Chapter 4

Conclusions

My solution met most of the requirements that were tested in the demonstration, but one area I was unable to get to work efficiently was the time for the components to switch on, although the transistors were rated at switching on and off at 1ns, this was not reflected in testing as the slowness of the switch on time led to the transition time being slower. I did try several different methods such as a bypass capacitor over the 3kΩ resistor and a bypass resistor over the TIP41C transistor, but neither seemed to achieve noticeable gains that got me close enough to the 1μs goal.

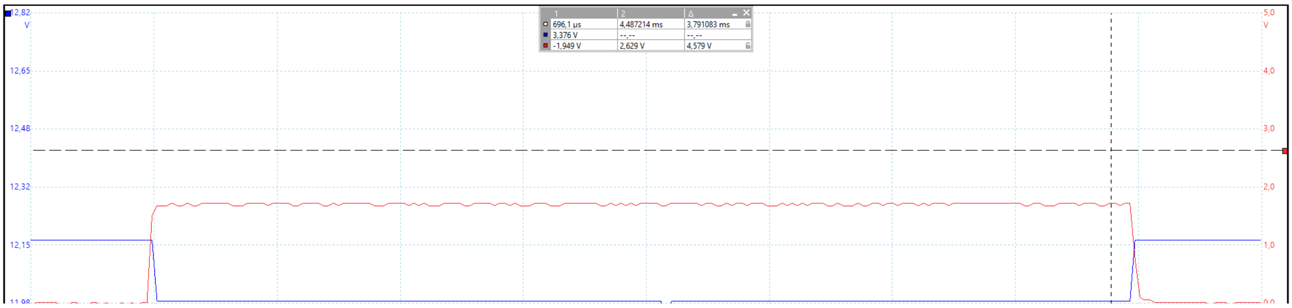

Figure 4.1: Oscilloscope Reference

In the image above, we can see the transitioning of the input 3.3V and 12V over the motor, which in the measurement was only able to achieve 4.4 μs in practice. It was one area which I was not able to meet the specifications set out before. Below are the requirements and specifications and how I tested them:

Requirement/Specification	Method used to test
Input of 12V	Measured input voltage with a multimeter
Input logic signal of 3V3	Measured logic signal using an oscilloscope
No more than 20 Components	Counted the components.
1mA on logic signal	Measured current using a multimeter
Switching speed of less than 1μs	Used two oscilloscope to measure input signal against motor signal
Load on at 2.4V	Changed the input signal to 2.4V to see if it would turn on
Load off at 0.5V	Changed the input signal to 0.5V to see if it would turn off

Table 4.1: Testing methods

Bibliography

[1] Øyvind Nydal Dahl, "What is an h-bridge?" 2018. [Online]. Available: https://www.build-electronic-circuits.com/h-bridge/