ELECTRONIC SPEED CONTROL (ESC) UNIT HARDWARE DESIGN OF A BRUSHLESS DC MOTOR

Kuartis Technical Assignment

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Contents

1 Introduction

Brushless DC motors have substantial advantages over Brushed DC motors. They provides higher efficiency, longer life-time, higher speed comapred to brushed DC motors. Due to those characteristics, they are preferred in many industries, including automotive and automation. However, they have some drawbacks in terms of control. Due to their more complex structures compared to brushed DC motors, they demand more precise control. This paper focuses on a design of Electronic Speed Control (ESC) unit for a 3-phase 2-poles brushless DC motor with 24V and 10A of rated voltage and current respectively.

2 Structure & Operation

Brushless DC motor is simply a DC motor that utilizes variation of reluctance for rotation. It consists of permanent magnet rotor and wound stator. There is two types of BLDC motors based on their rotor orientation. Those are inrunner and outrunner type motors. Figure 1 shows the structure of 3 phase 4-poles inrunner and outrunner type BLDC motors. It should be noted that number of poles and phases may vary depending on the application. However, minimum number of phases that a BLDC can have is 3 to obtain seamless rotation.

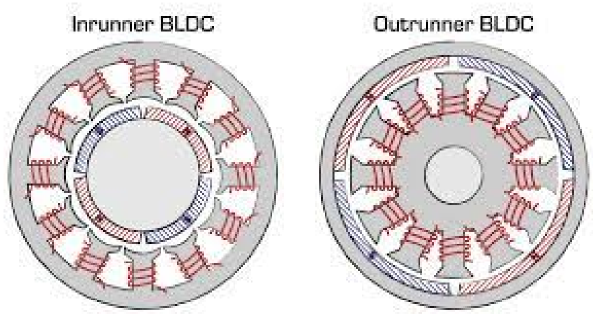

Figure 1: Structure of an inrunner type 4 pole 3-phase brushless DC motor.

2.1 Control Techniques for BLDC Motor

Three types of control techniques are widely used in industry. The first one is trapezoidal control. This control technique involves only one phase change at a time, making the control simple. The second is sinusoidal control. This technique involves energizing phases with a sinusoidal PWM shape. Figure 2 shows the what the generated PWM signal looks like. The third method is Field Oriented Control. This technique is the hardest compared to others. This technique involves calculation of Clarke and Park transform from rotor position -hall sensor readings in this case- to obtain which coils to be energized. Once the phases are determined, PWM signal is generated by performing inverse Clarke and inverse Park transformation.

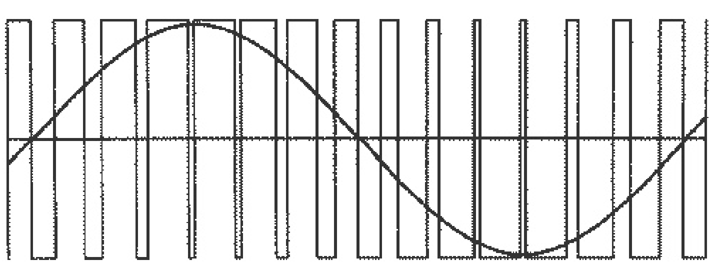

Figure 2: Sinusoidal PWM signal shape.

2.2 System Level Block Diagram

Figure 3 shows the general block diagram of the unit in the system level. System starts operating with gate driver to be powered up. After that, internal 12V LDO functions. Once gate driver produces output of 12V, 3.3V output is produced from an external LDO, resulting in the ESP32 to be powered up. Then, gate signals are produced from the controller. If USB input is active, programming is active. Otherwise, microcontroller stays in the normal operation state.

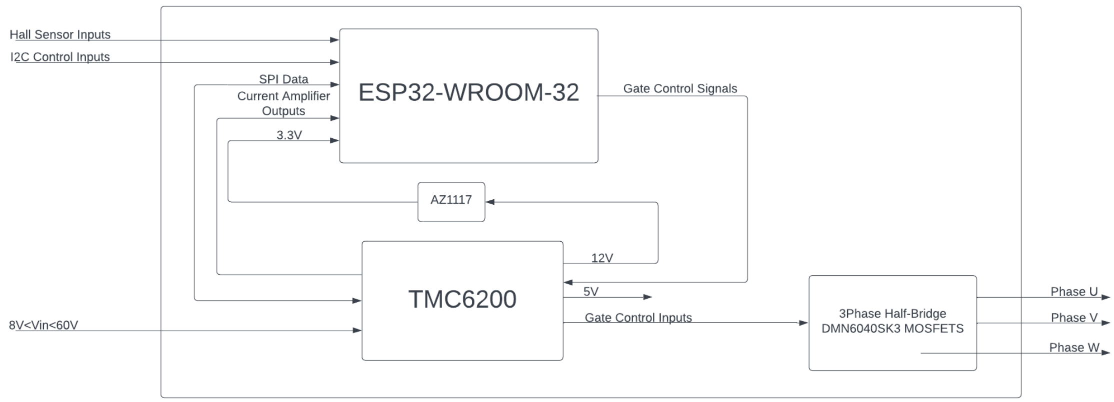

Figure 3: A block diagram summarizing the operation.

3 Hardware Design of BLDC Driver

3.1 Requirements

- Nominal voltage: 24V
- Nominal Current: 10A
- Control Input Interface (discrete, SPI or I2C)
- LED indicators
- Hall Latches Inputs

3.2 Controller IC Selection

Brushless DC motor operates at high speed. Therefore, controller should operate also high speed for robustness. Therefore, ESP32-WROOM-32U is selected as controller. The below list demonstrates why this controller is picked.

- ESP32 can operate at 240 MHz. Moreover, it has dual core. Therefore, this controller can satisfy the speed requirement.
- All GPIO pins on ESP32 can be configurable for I2C, SPI, UART (not needed for this case) interfaces and PWM output. This eases the control interface implementation.
- Such features can be obtained for a very low price, around 2.5$.

3.3 Programming Interface

The controller should be programmed in order to operate as desired. Therefore, a programming interface should be implemented. For this purpose, CP2102-GMR, a USB to UART bridge, is used. In order to program ESP32, GPIO0 should be held low and EN to GND. Figure **??** shows the logic circuitry for this purpose. With no power, all labeled signals are not defined. With power input either in input connector or USB connector, all signals reach its steady state. This state keeps ESP32 in boot state. If USB connector is not connected, no UART messages are generated and delivered to ESP32, resulting in normal operation state.

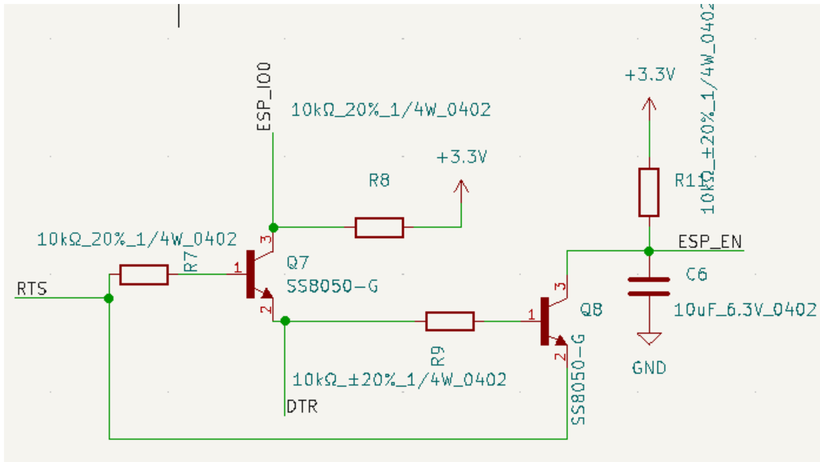

Figure 4: Logic circutry to keep ESP32 in boot state.

3.4 Gate Driver Selection

In order to deliver 10A, MOSFETs are needed and they should be controlled by the controller. However, the chosen controller is capable of delivering 3.3V, which is not sufficient for MOSFETs to be saturated. Therefore, a gate driver capable of delivering at least 10V to deliver the required power. For this purpose, TMC6200 is chosen. It accepts from 8V to 60V. Moreover, it has additional features such as SPI interface for configure and control. It has also current sense amplifier per phase. It has also two internal regulators, giving output 5V and 12V. 12V regulator is used also as power supply of external regulator, which will be usedfor the delivery of power to the ESP32 and logic input supply.

3.5 MOSFET Selection

In order to activate the proper phase with proper power, a controllable transistor can be used. For this purpose, DMN6040S3 is used. Its low price and strong power dissipation makes it then best alternative for this application. It can deliver 20A and bear 60V.

3.6 LED Indicators

There is 4 LEDs implemented. Controller active LED, which is green, drive enable LED, which is also green, fault LED, which red and programming LED, which is blue.

4 PCB Design

Figure 5 shows the PCB designed for the driver. First of all, all the related components are added to project symbol and footprint library. 3D models of the components are associated with those models. In addition, 2 layers are used. Due to majority of SMD components, more than two layers is considered as not necessary. Copper zones are used where it is applicable. Moreover, power and signal tracks are seperated as much as possible.

For models used for ESP32 and micro USB connector, design rules checker throws a set of errors due to the models constructed. In fact two models are constructed as it should be. This errors may be solved by adjusting the design rules. However, erronous other connections may be missed. Therefore, no action is taken for this problem.

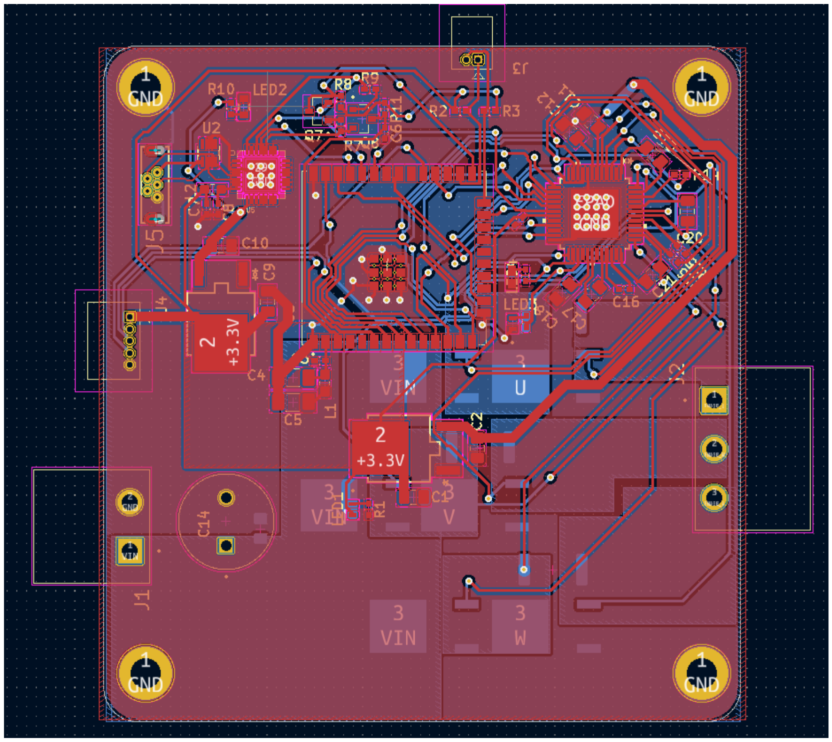

Figure 5: PCB designed for the driver.

5 3D Model

Figure 6 and Figure 7 shows the 3D views of the designed PCB front layer and bottom layer respectively.

5.1 Restrictions

- This system operates input voltage with range of 8 to 60V. Therefore, supply should be within this range. In fact, voltages below 40V is suggested due to structure of gate driver.
- In addition, control inputs will be delivered using I2C interface.
- To obtain smaller PCB, mounting hole with pad is selected. Therefore, plastic nuts or other nuts that is conductor shoud be preferred for mounting.

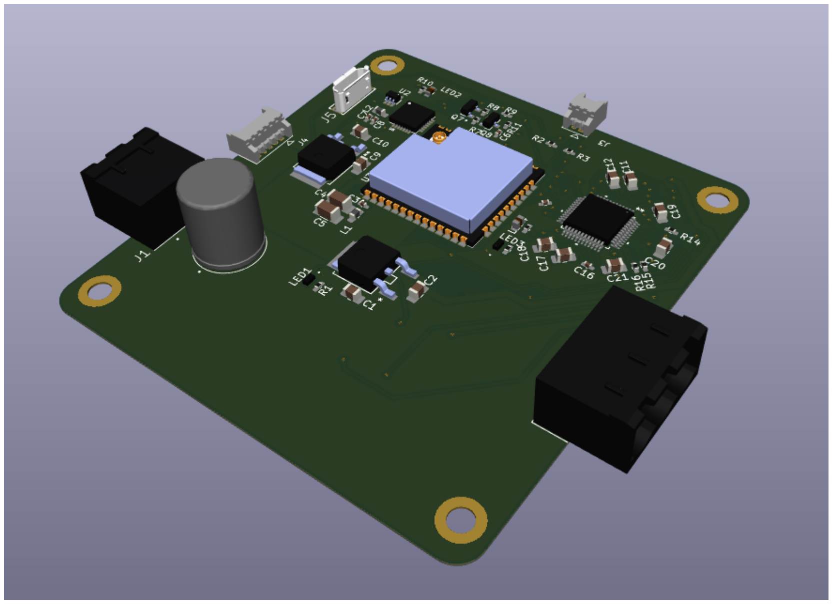

Figure 6: 3D Front view of the designed PCB.

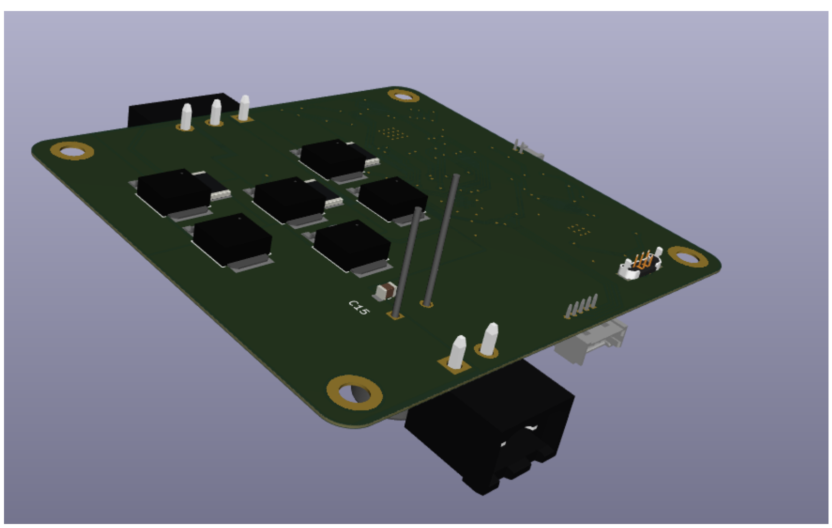

Figure 7: 3D Back view of the designed PCB.