Scara Robot Electrical Systems

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Abstract

The electrical system is composed of a motherboard, a power supply and the driver control module. The driver control module receives coordinates from the motherboard and a count from the motor encoder. The motherboard is a stm32 Nucleo powered by 5V through the power supply. The power supply receives power from the wall plug and delivers power for all components including 48V to the DC brushed motor.

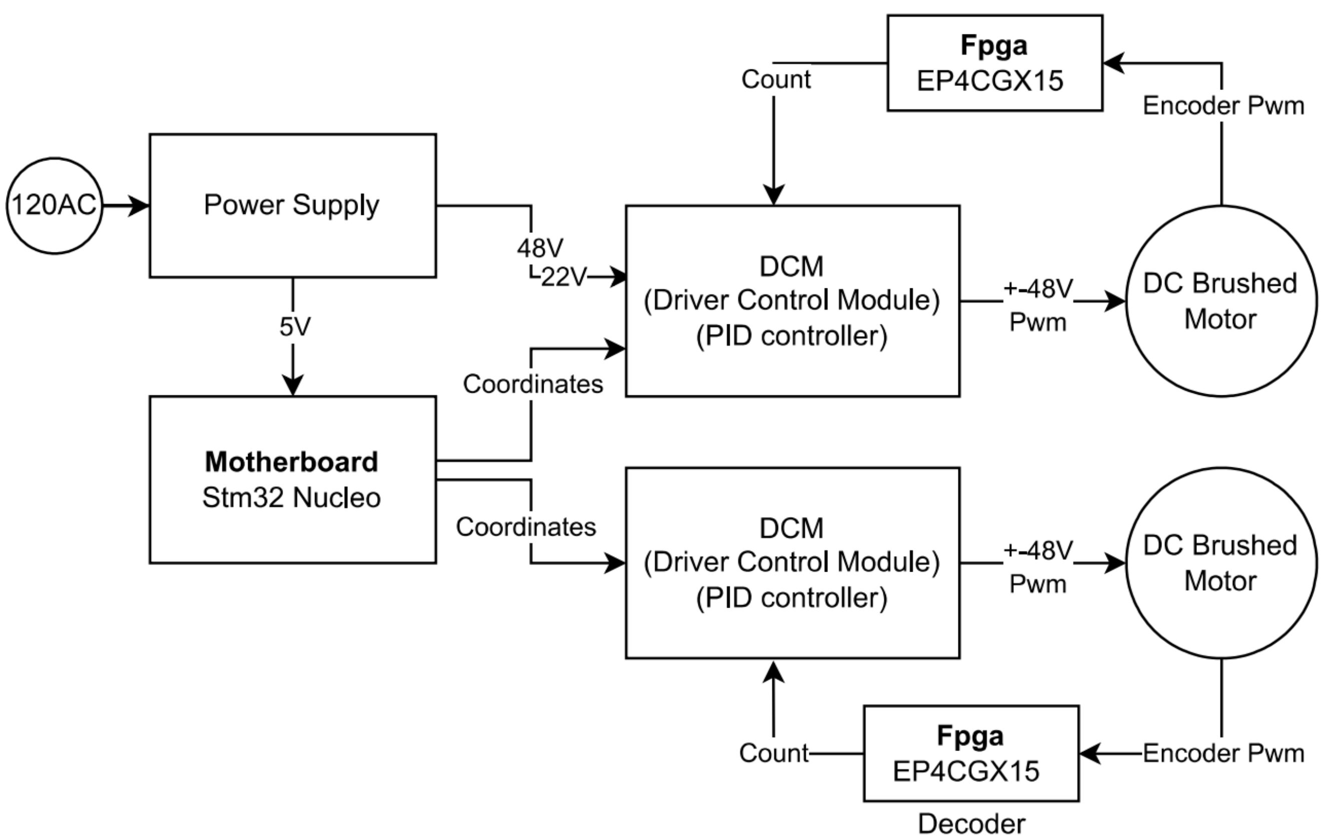


Figure 1.0: Hardware diagram

Acronymes

PSM: Power supply module
DCM : Driver control module
MCU: microcontroller unit
GUI: graphical user interface
RTOS: Real-time operating system
RCG: Requirement Constraints and Goals
USART: universal synchronous and asynchronous receiver-transmitter
PCB: Printed Circuit Board

Motherboard

The motherboard is the brain of the operation. It is where all the heavy computation is performed, such as trajectory planning and homing logic. The requirements are that the motherboard has to physically connect to the robot, receive 5V from the power supply and send the desired position to the driver control module.

MCU selection

The MCU had to satisfy a couple of RCGs. One of the requirements was to have at least 60Kbits of SRAM, to have headroom for matrix multiplication required in the trajectory planning. Also, the clock speed had to be above 16 Mhz to meet the control frequency requirements of the PID controller. Furthermore we had to have more than 6 USART ports to send the desired coordinates to the DCMs for all 4 motors (2 for the Base, 2 for the Elbow, and 1 for Linear Actuator and gripper). For these reasons the chosen MCU was the STM32F4.

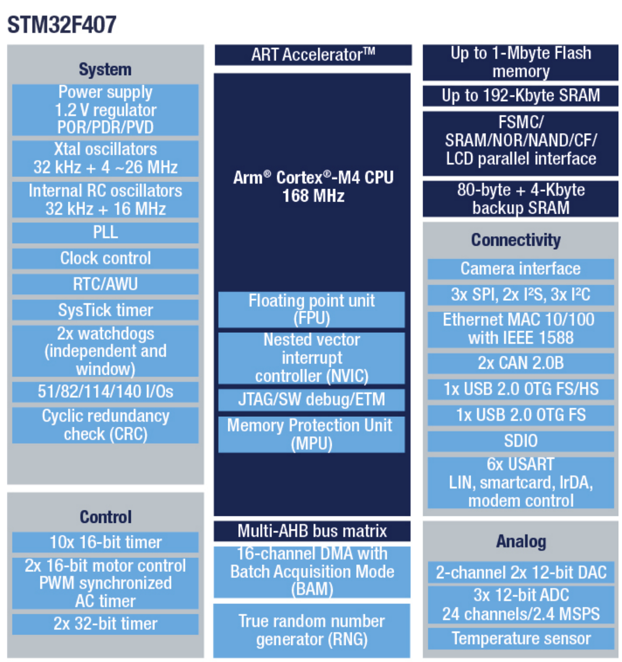


Figure 2.0: STM32L476RG Hardware diagram[1]

The STM32L476RG provides a fast clock speed at 168Mhz and 192kbyte of SRAM, and has 6 USART ports, thus meeting our requirements.

Furthemore, the possibility to run Rtos increases the ability to perform heavy tasks in real time such as path planning and digital filters. And the choice to use HAL with CubeMX helps for fast prototyping and testing.

In this design the motherboard is only composed of the microcontroller board. This was a combined decision with the mech and elec team to increase the safety, facilitate the wiring and increase the modularity of the system. One safety concern is the clearance between the MCU signals and the high voltage delivered by the power supply. With our design we have only one ribbon cable carrying 48V from the power supply to the DCM and another signal ribbon cable from the motherboard to the DCM, giving a higher clearance between the MCU and the high voltage. Another safety concern is the temperature of these boards: if the power supply is mounted together with the other boards the temperature would rise and could damage the electrical system, so we separated the power supply with the proper cooling and used ribbon cables for this high voltage and high current system. Furthermore this design enables for an easy change of motherboard to a more powerful computer able to perform more advanced tasks such as computer vision and/or a GUI.

Power Supply Module

The power supply module is where all the power is delivered for all boards and components.

Circuit

RCGs

Some of the requirements for the circuit were: Convert 120AC to 22DC at 20Amps and 48V at 5 Amps. And we had a constraint of 20 Amps for each transformer.

Linear power supply

Our team opted to design a linear power supply over a switching mode power supply since our team had prior experience with such systems thus increasing the robustness of our design.

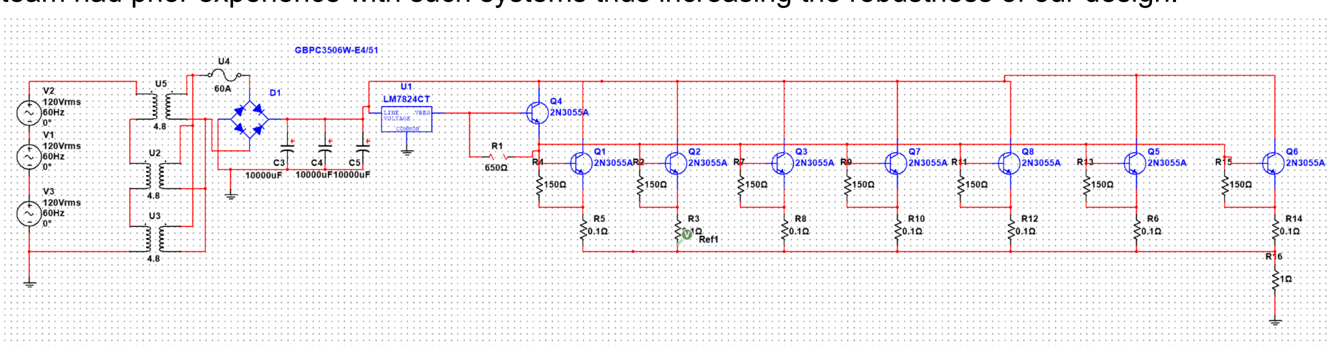


Figure 3.0: Power supply circuit

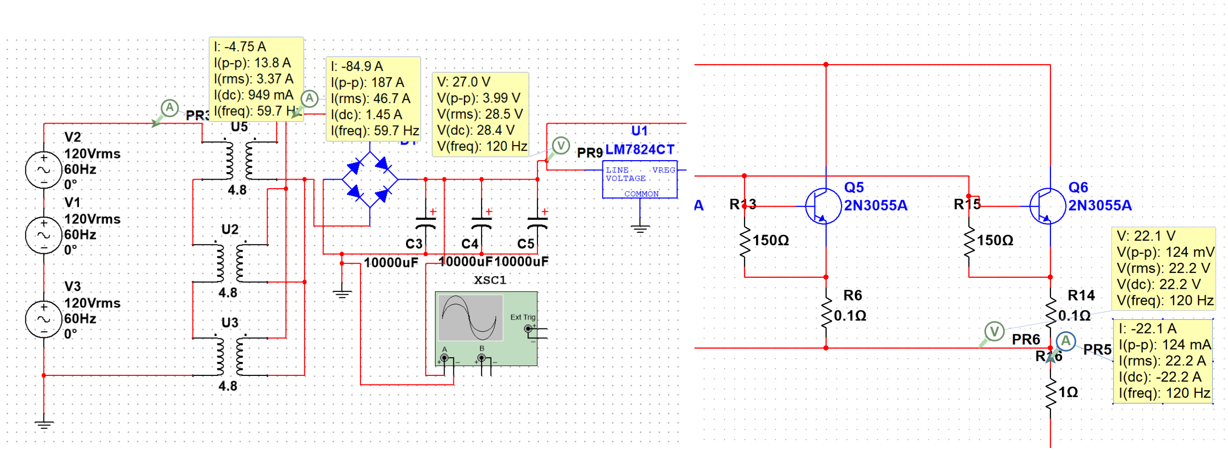


Figure 3.2: Power supply simulation

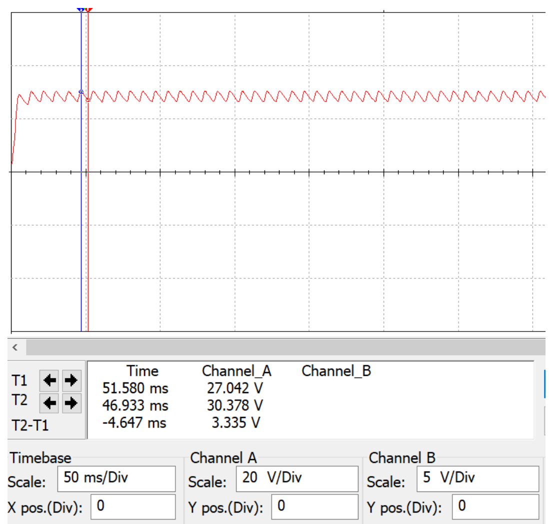


Figure 3.3: Response from oscilloscope

The system is rather simple: it has a 120AC input from the wall plug and which is reduced to 25 Vrms. This voltage goes through a full bridge rectifier and smoothing capacitor to create a DC voltage. Then we used a voltage regulator and 8 BJTs to increase the delivered current up to 25Amps. And as can be seen in figure 3.2 the system successfully delivers 22V at 22A

Boost converter

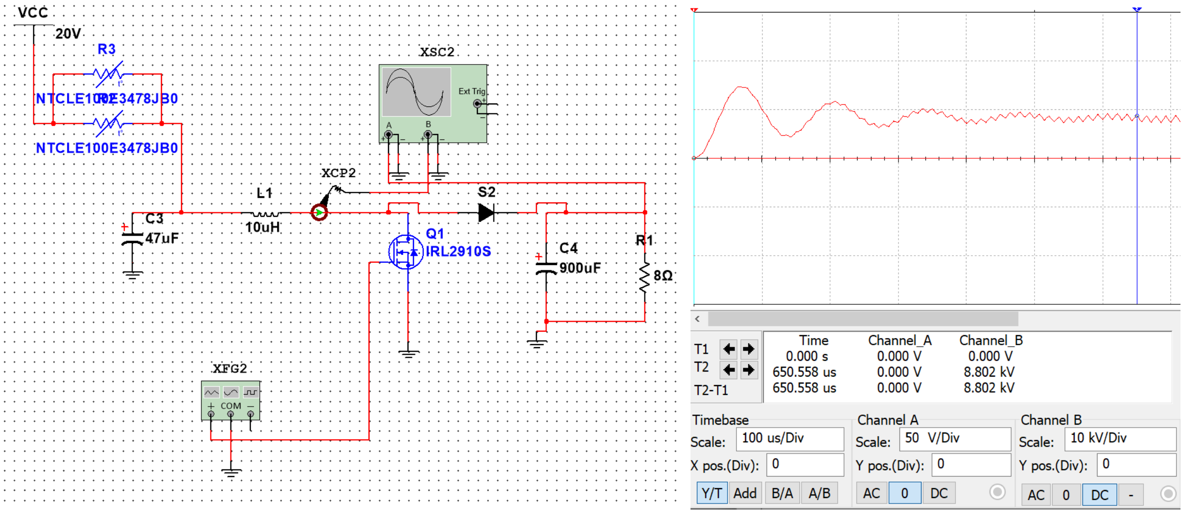


Figure 4.0: Boost converter simulation

In order to convert the 22V to 48V we used a boost converter. Above in figure 4.0 we can see a simulation of the circuit with the function generator inputting a 50% pwm to the mosfet. For protection we used a ntc to prevent the inrush current to go above 15A which could damage the linear power supply.

Although this circuit boosts the voltage successfully it is highly unstable and for this reason we need to control the pwm to prevent that. Using Matlab simulink we recreated the circuit and built a simulation of a PID that outputs the pwm inputted into the mosfet gate and receives a scaled down output voltage as feedback thus successfully boosting the voltage to exactly 48V as can be seen in Figure 4.2 .

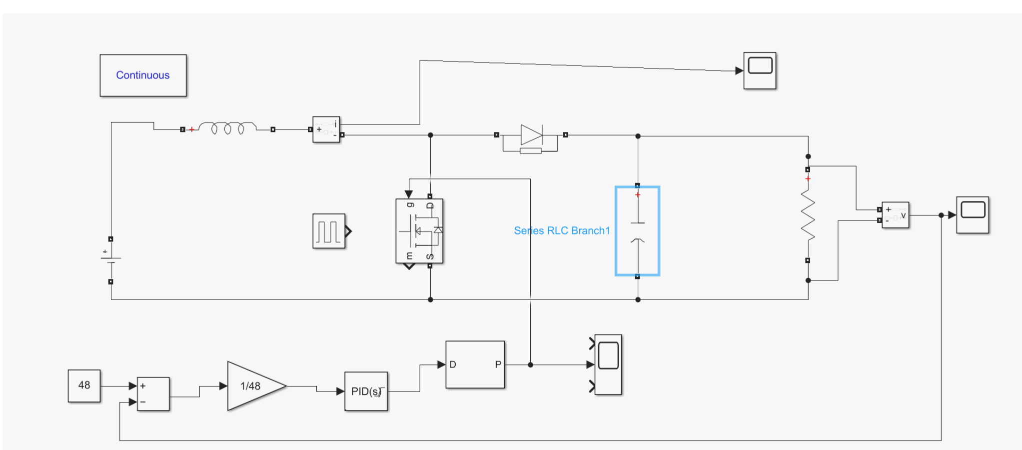


Figure 4.1: Simulink model

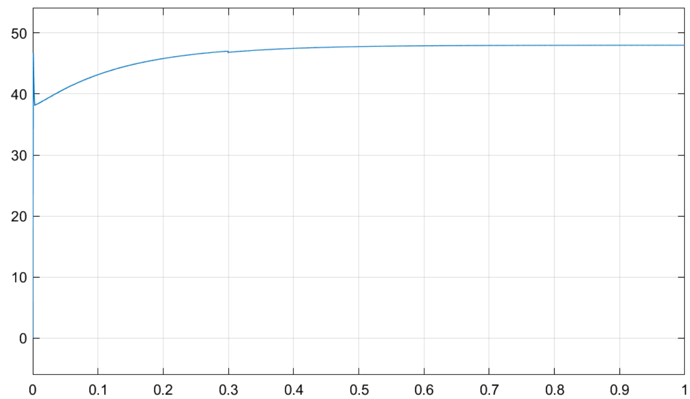


Figure 4.2: Output of simulink model

Component selection

For the linear power supply, we used 3 Hammond 500VA transformers in parallel since each can deliver 25 Vrms at 20 Arms, and through simulation we could determine that the system required about 45Arms. Also, for safety we added a fuse of 60 Amps to prevent overcurrent and the destruction of the transformers.

The chosen full bridge rectifier was the GBJ5010-BP which has a max forward current of 50A and a max forward voltage of 1000V.

The chosen capacitance was calculated to be 30000uF using the following formula:

$$C >= \frac{(I_{max} * T_{discharge})}{(V_{beforedischarge} - V_{afterdischarge})} \tag{1}$$

Imax is 20A, Voltage before discharge has a maximum of 35V and a minimum of 29V as per lm7824 datasheet, and T discharge is equal to 1/60hz giving C>= 20,750uF, for a more stable response we choose 30,000uF capacitance.

Then to regulate the voltage we choose the Lm7824 but since the max current of the voltage regulator is 1Amp we added 8 BJTs to increase the output current up to 25A. One important component that we had to choose carefully was the 0.1 Ohm resistor , which has to have a maximum power rated as above 2.5W since each consumes a max of 5A.

For the boost converter we used the following formula to calculate the inductance and capacitance

$$L > \frac{D * Vin * (1 - D)}{(freq * 2 * Iout)}; D = 1 - \frac{V_o}{V_i} \tag{2}$$

$$Cap > \frac{Iout}{(Vripple * freq)} \text{[4]} \tag{3}$$

Thus for a pwm frequency of 70Khz, a Iout equal to 5 Amps and a Vripple of 0.1V we get C>714uF and L>7.8uH.

PCB

RCGs

The power supply PCB has to be small enough to fit in the case developed by the mech team. Thus we had a constraint of a max area of 300mm^2. And the temperature could not exceed 50 degrees Celsius. Another constraint was the PCB minimum trace width. This can be calculated with the formulas below:

$$Area[mils^2] = (Current[Amps]/(k * (TempRise[deg.C^0])^{0.44}))^{(1/0.725)} \tag{4}$$

$$Width[mils] = Area[mils^2]/(Thickness[oz] * 1.378[mils/oz])\text{[3]} \tag{5}$$

Formula 3.0: Minimum trace width

Thus with a maximum current as 20A, the maximum temperature rise as 40degrees, the thickness as 4oz and k=0.048 as per IPC-2221 for external layers gives us a minimum width of 2.07mm.

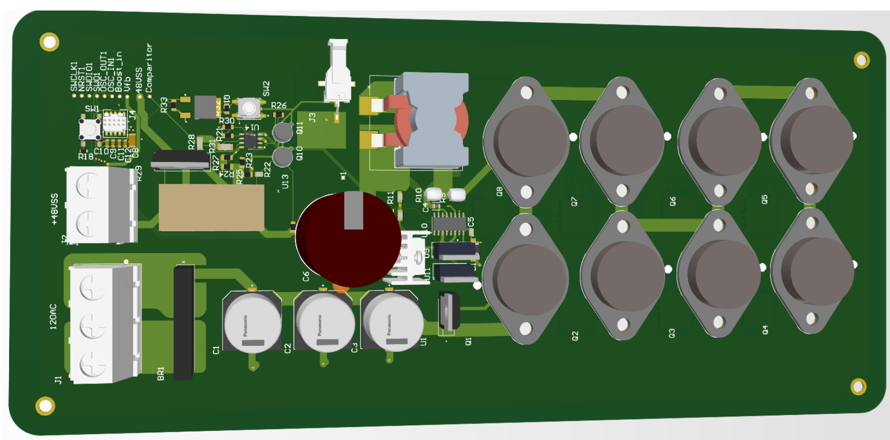


Figure 5.1: Top 3d View

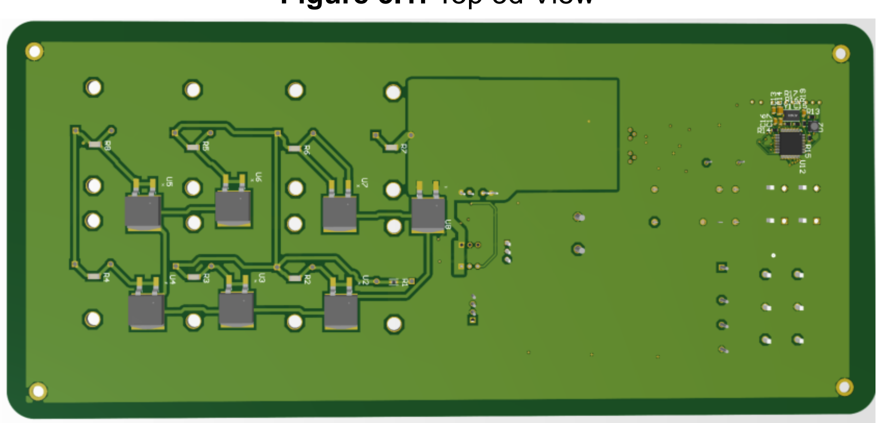


Figure 5.2: Bottom 3d view of the pcb

The width constraint was achieved by using the rules on Altium designer as shown below, which constraints the width for a minimum of 2.08mm for high current nets. Also we added a high voltage clearance recommended as per IPC-2221 of 0.83mm for 48V. Furthermore the board size does not exceed 200mm^2 thus achieving all our requirements.

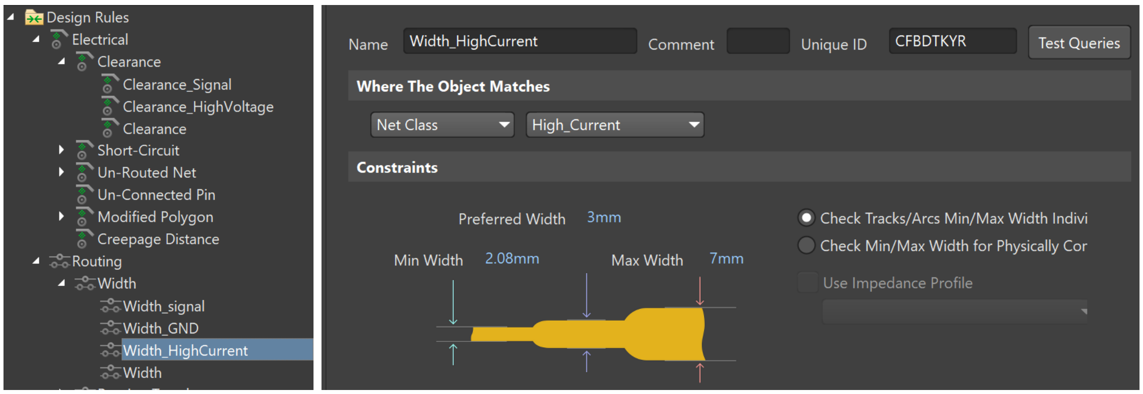


Figure 5.3: PSM Design rules

Organization

In order to optimize the space a multilayer board was chosen with the middle layers with 1oz thickness to trace signals and small current nets. Furthermore, all the resistors and capacitors were chosen to be above 0805 package since smaller than those are really hard to stuff in the PCB.

The components were aligned and grouped as the circuit was designed. As you can be seen on the layers on Appendix A or in figure 5.1 we have the input in one end of the board and closeby we have the full bridge rectifier and the smoothing capacitors, on the right side of the board we dedicated to add the BJTs and at last at the left top of the board we have the overcurrent protection and the microcontroller.
The connectors were chosen to be able to withstand the high current and also fit 8 gauge wires. Furthermore the mounting holes were grounded and are fit for m4 screws that will attach to a heat sink for heat dissipation.

The design also includes multiple labeled testing points for debugging purposes and 1 switch to simulate the overcurrent and another to reset the MCU.

For more information such as silk screen, traces and bill of material, refer to appendix B where assembly drawings, schematic prints and the used components part numbers can be found.

Driver Control Module

The driver control module receives the coordinates signal from the motherboard and the count from the FPGA. With that it controls the speed and position of the motor using a PID controller and thus achieving the desired position.

Circuit

RCGs

The DCM needs to output a 48V pwm to the motor and also must be able to rotate both ways. The motor cannot exceed 5Amps and the goal is to reduce the inrush current as much as possible.

Hbridge

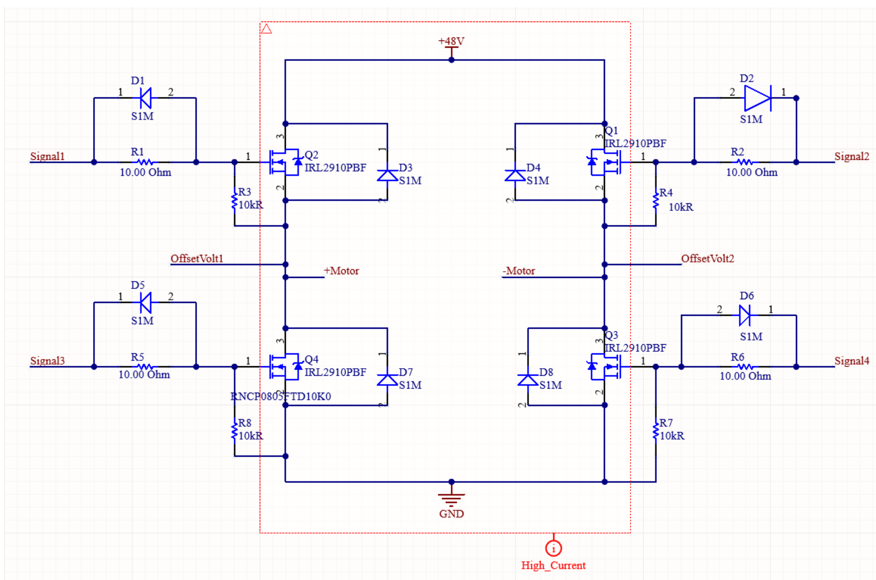


Figure 6.0: H Bridge

The HBridge is the main part of the Driver control module and where the current and voltage is delivered to the motor inputs. As can be seen in figure 6.0 we are using exclusively IRL2910 N-mosfets. This power mosfet was carefully chosen since it has a max continuous drain current of 48Amps and a maximum drain to source voltage Vds of 100V which is way more than we need and complies with all our requirements and constraints. The 10k resistors were added to drain the gate voltage and increase the switching speed of the mosfets. Furthermore, for safety reasons we also added flyback diodes to prevent overcurrent at the drain of the mosfet.

These input signals (Signal 1,2,3,4) come from the gate drivers described in the next section.

Gate drivers

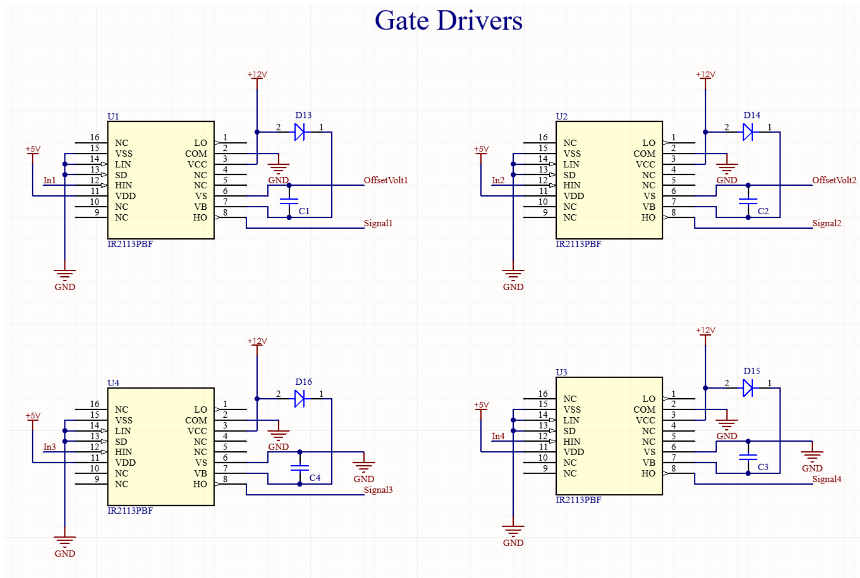


Figure 6.1: Gate driver ICs

4 gate drivers were used to send the pwm signals from the microcontroller to the power mosfets. With a 10Ohms resistor gate current can go up to 60V/10Ohms = 6Amps, which the microcontrollers cannot handle. Thus a gate drivers are incredibly helpful in those situations to produce enough high current to drive the gate of the power mosfet.

Optocouplers

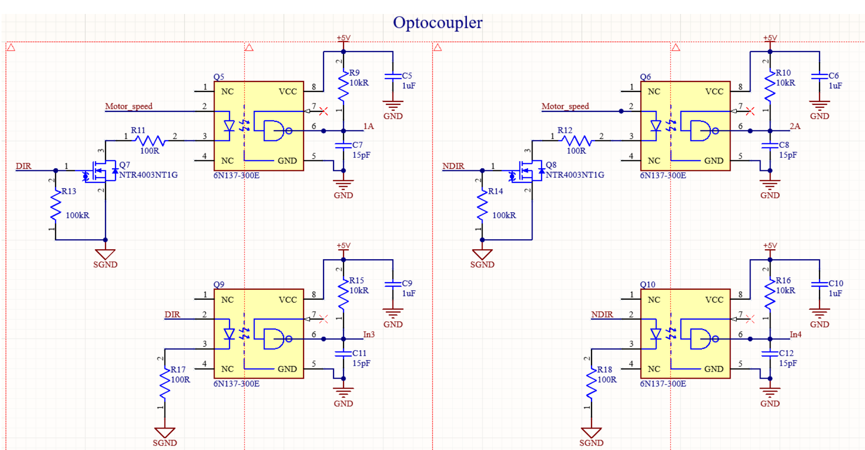


Figure 6.2: Optocouplers

Finally for safety purposes, optocouplers were used to connect the high Voltage circuit and the microcontroller, separating the grounds and reducing noise to the pwm signal.

Simulation

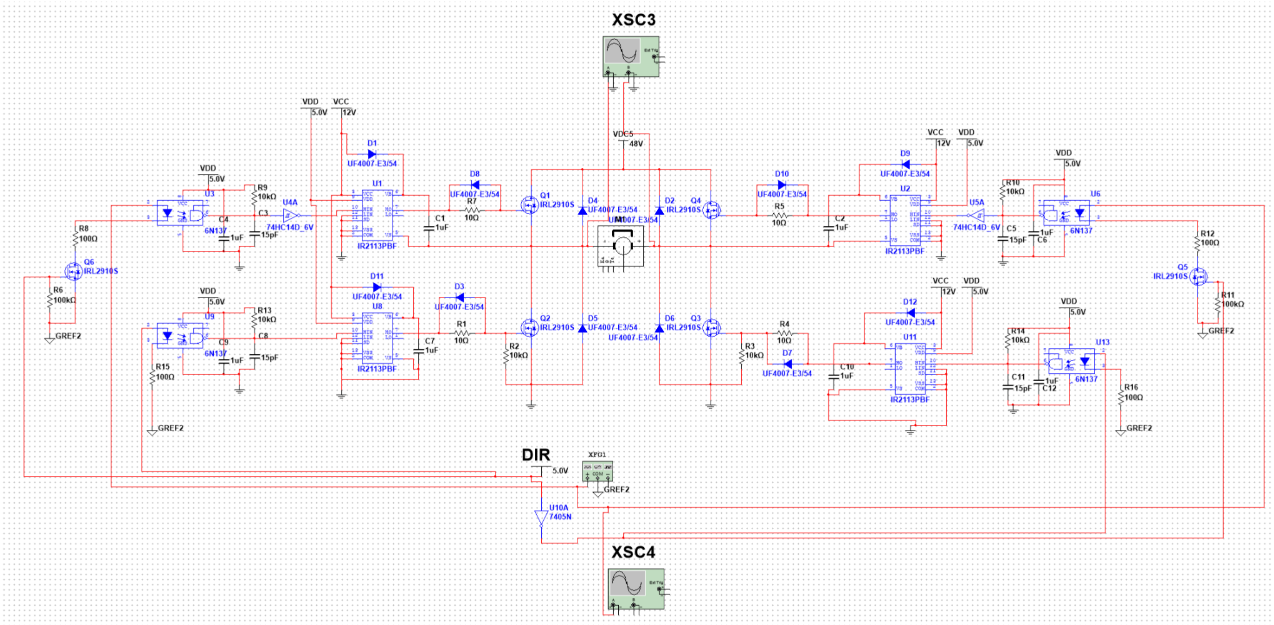


Figure 7.0: Full Driver Control Module circuit simulation

As can be seen in figure 7.0 we simulated the Hbridge integrated with the gate driver ic and the optocouplers.

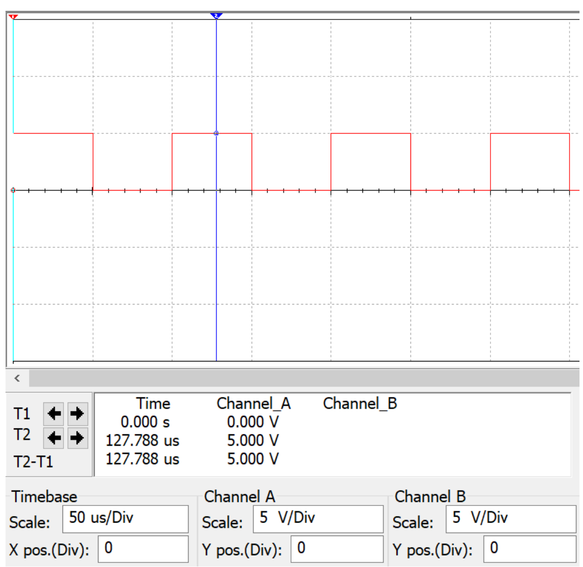
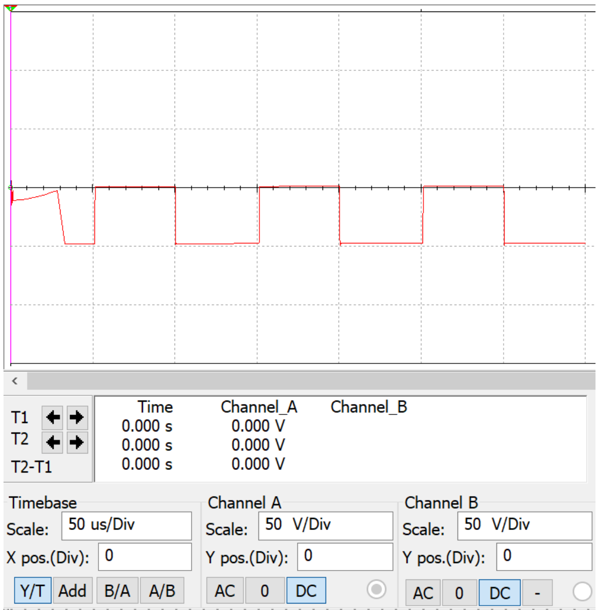


Figure 8.0: Function generated pwm at 10khz (XSC4 Output)



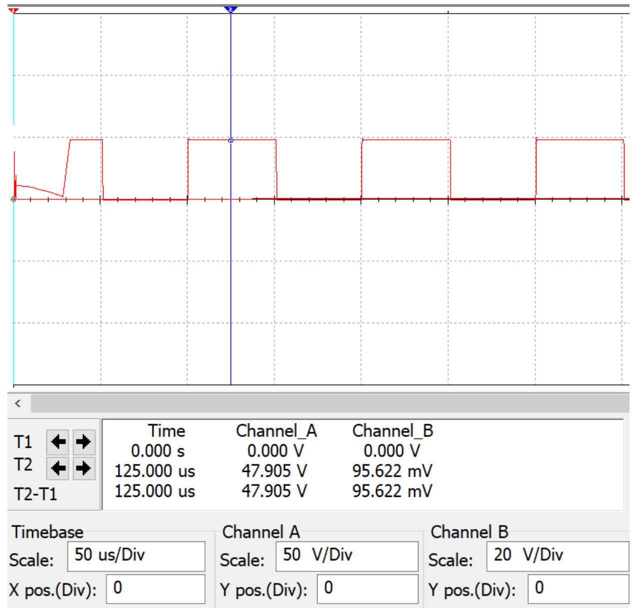


Figure 8.1: Motor output **Figure 8.2:** Motor output reversed direction

As can be seen in Figure 8.0 we are inputting a 10kHz pwm into the hbridge and depending on the direction signal we get the output from figure 8.1 which spins the motor clockwise or we get the output from figure 8.2 which spins the motor counterclockwise.

PCB

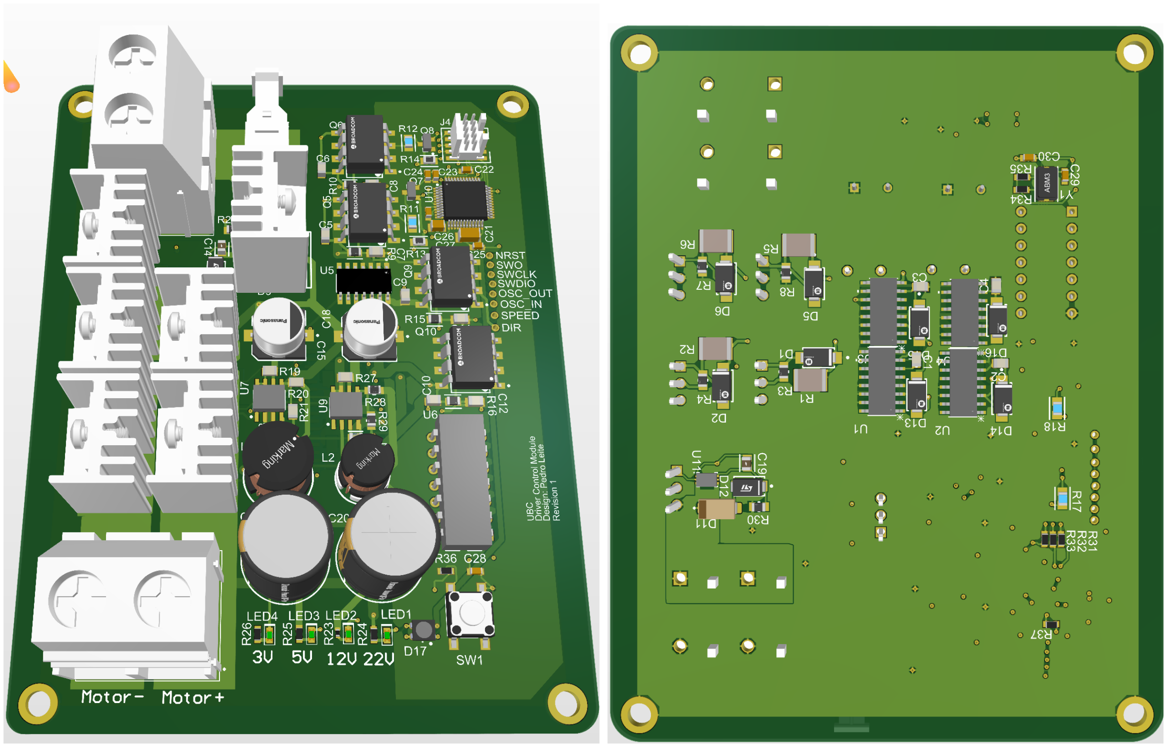


Figure 9.0: 3d view of the DCM PCB

RCGs

The DCM PCB has to be small enough to fit in the base. Thus we had a constraint of a max area of 100mm^2. Another constraint was the PCB minimum trace width. This could be calculated using the same formula as in (5). Thus the traces must not exceed 1.1mm and must have a clearance of minimum of 0.87mm. Again, these requirements were met by using the rules in altium which helps to ensure that these requirements are me.

Organization

Again we used a multilayer board to optimize for space and did not exceed 0805 for the same reasons. The connectors chosen were the same as the power supply board since it meets all the requirements for voltage, current and wire gauge.

We added a heat sink for each mosfet to dissipate the high current going through them which can damage if it gets too high.

For more information such as silk screen, traces and bill of material, refer to appendix B where assembly drawings, schematic prints and the used components part numbers can be found.

Sensor

Fpga selection

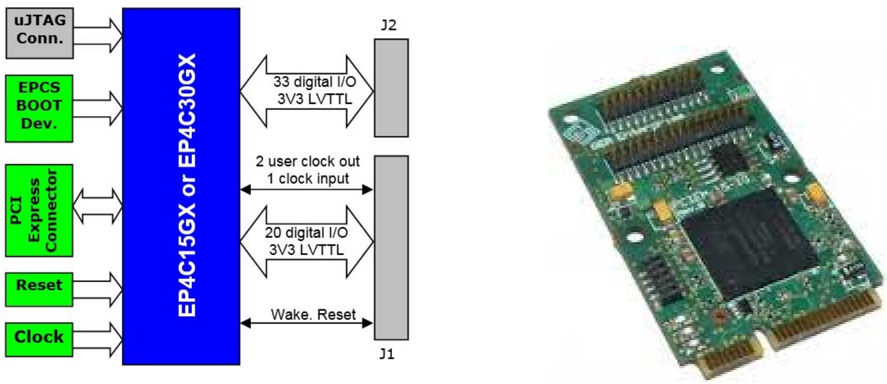


Figure 10.0: EP4CGX15 Fpga[2]

The selected FPGA was the EP4CGX15 Fpga with a 53 I/O pins card. This is a relatively simple FPGA but it has a good amount of I/O pins to connect with the multiple encoders of the robot and it is enough for our application.

Quadrature decoder

In order to get the position information from the encoder we need to decode the signals using a FPGA. For this reason we designed a state machine using system verilog that will be loaded to the fpga and sent to the stm32 as a count, which will then be converted to an angle.

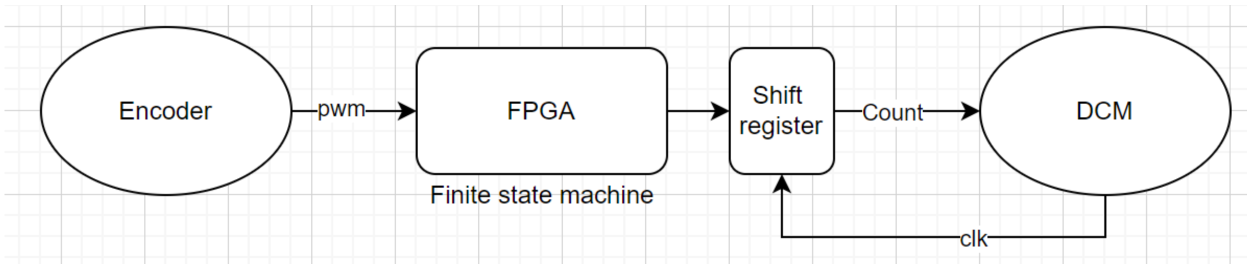


Figure 11.0: Quadrature decoder system architecture

Finite State Machine

The finite state machine has to receive 2 pwms from the encoder and depending on the direction we will increase or decrease the count output.

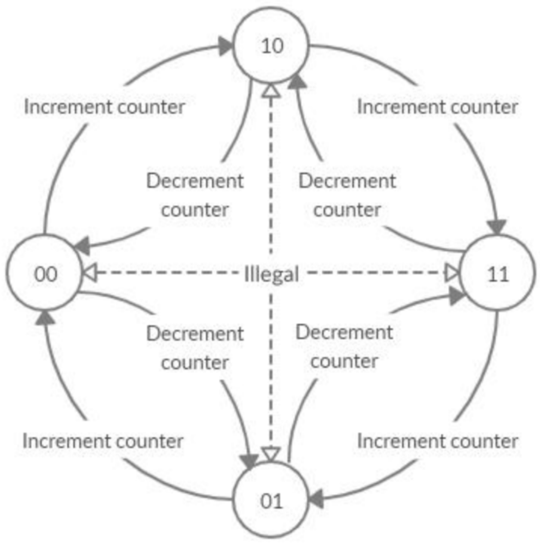


Figure 12.0: Finite state machine diagram[5]

Using verilog we can implement the State machine shown in figure 12.0. Thankfully the state machine is simple due to the nature of the A&B inputs which can only have 2 possible paths at a time. After implementing the code we get the following waveform:

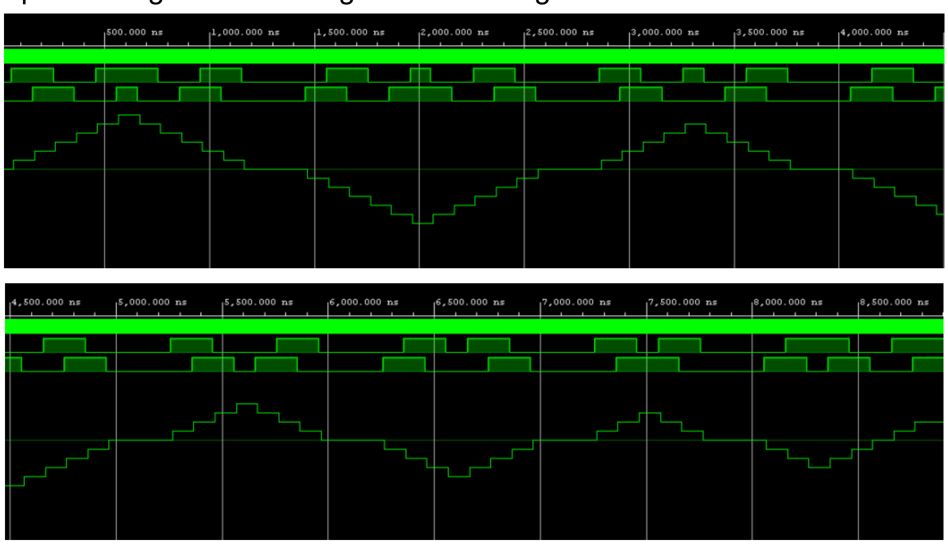


Figure 13.0: Finite State machine testbench with all possible outputs

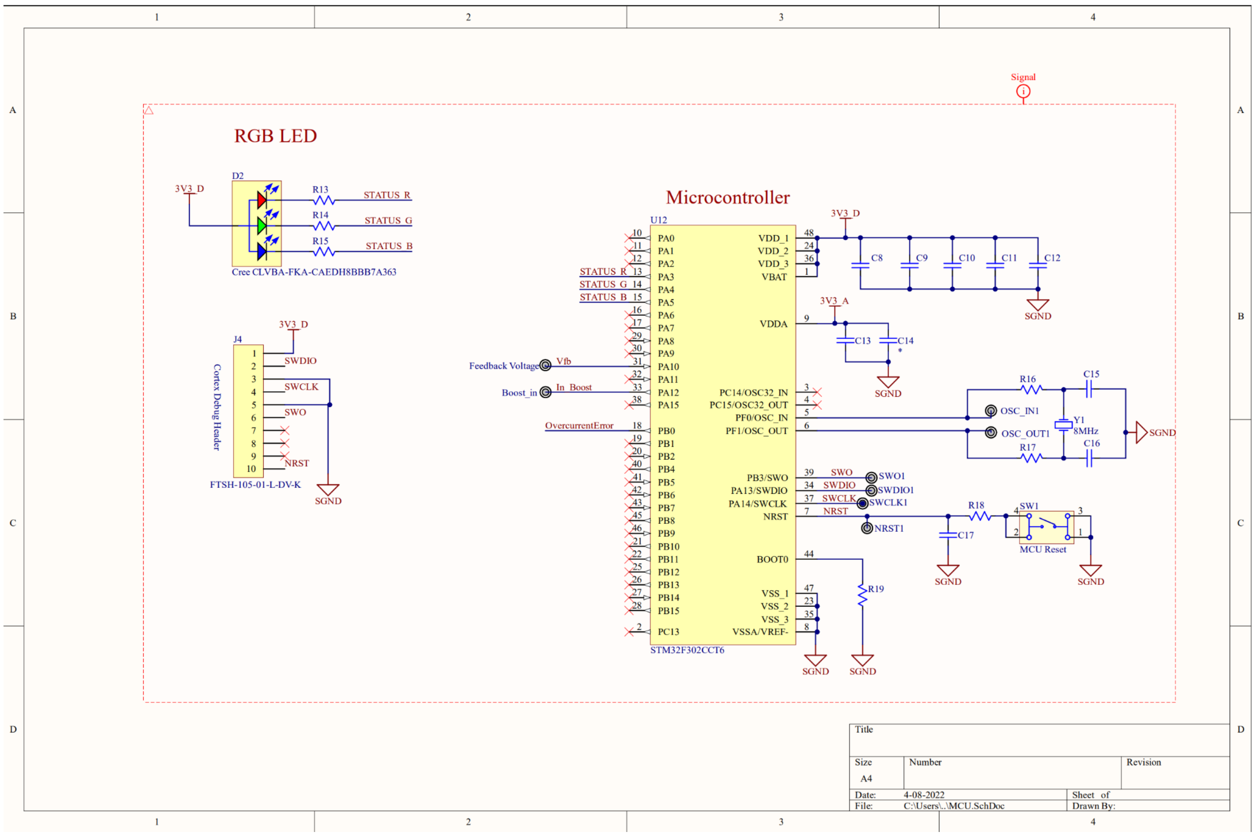
As can be seen in figure 13.0 the finite state machine is responding as intended and the count goes up and down. (for the full code implementation please look into appendix C)
One caveat of our design that can't be seen in the waveform is that the count starts at 500 and goes up to 1000, that is because we wanted to avoid negative numbers. Thus since our encoder has 500 possible positions it can go from 0 to 1000, with 0 being -180° and 1000 being 180°.
After that we send the output from the decoder to a shift register and the microcontroller will send a stream of 9 clock cycles to retrieve the whole output from the shift register.

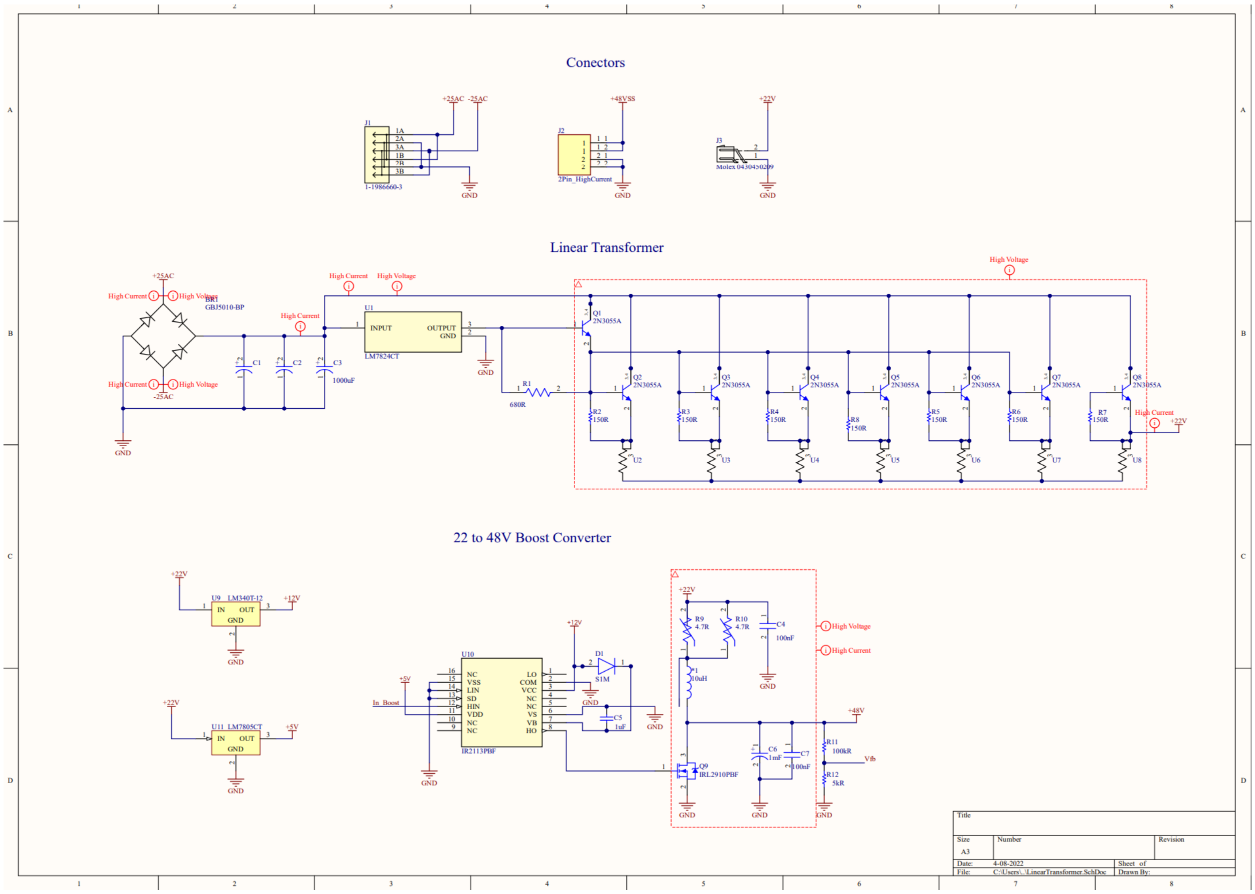
Reference

[1] https://www.st.com/en/microcontrollers-microprocessors/stm32f407zg.html
[2]https://marketplace.intel.com/s/offering/a5b3b0000004c57AAA/mini-pcie-fpga-card-with-53-io-and-ep4cgx15-fpga?language=en_US
[3]https://www.7pcb.com/trace-width-calculator.php
[4]https://learn.adafruit.com/diy-boost-calc/the-calculator
[5]https://www.researchgate.net/figure/a-State-machine-based-quadrature-decoding-algorithm-and-b-modified_fig2_3091172

APPENDIX A

POWER supply




Conectors
+25AC -25AC
J1
1A
2A
3A
1B
2B
3B
1-1986660-3
GND
+48VSS
J2
2Pin_HighCurrent
GND
+22V
J3
Molex 0430450209
GND
Linear Transformer
+25AC
High Current
High Voltage
BR1
GBJ5010-BP
-25AC
GND
C1
C2
C3
1000uF
U1
INPUT
OUTPUT
GND
LM7824CT
R1
680R
Q1
2N3055A
Q2
Q3
Q4
Q5
Q6
Q7
Q8
R2
R3
R4
R5
R6
R7
R8
150R
U2
U3
U4
U5
U6
U7
U8
+22V
22 to 48V Boost Converter
U9 LM340T-12
IN
OUT
GND
+12V
U11 LM7805CT
+5V
U10
NC
VSS
LIN
SD
HIN
VDD
LO
COM
VCC
VS
VB
HO
IR2113PBF
In_Boost
D1
S1M
C5
1uF
R9
4.7R
R10
4.7R
C4
100nF
10uH
+48V
C6
1mF
C7
100nF
R11
100kR
R12
5kR
Vfb
Q9
IRL2910PBF
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Number
Revision
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4-08-2022
Sheet of
File:
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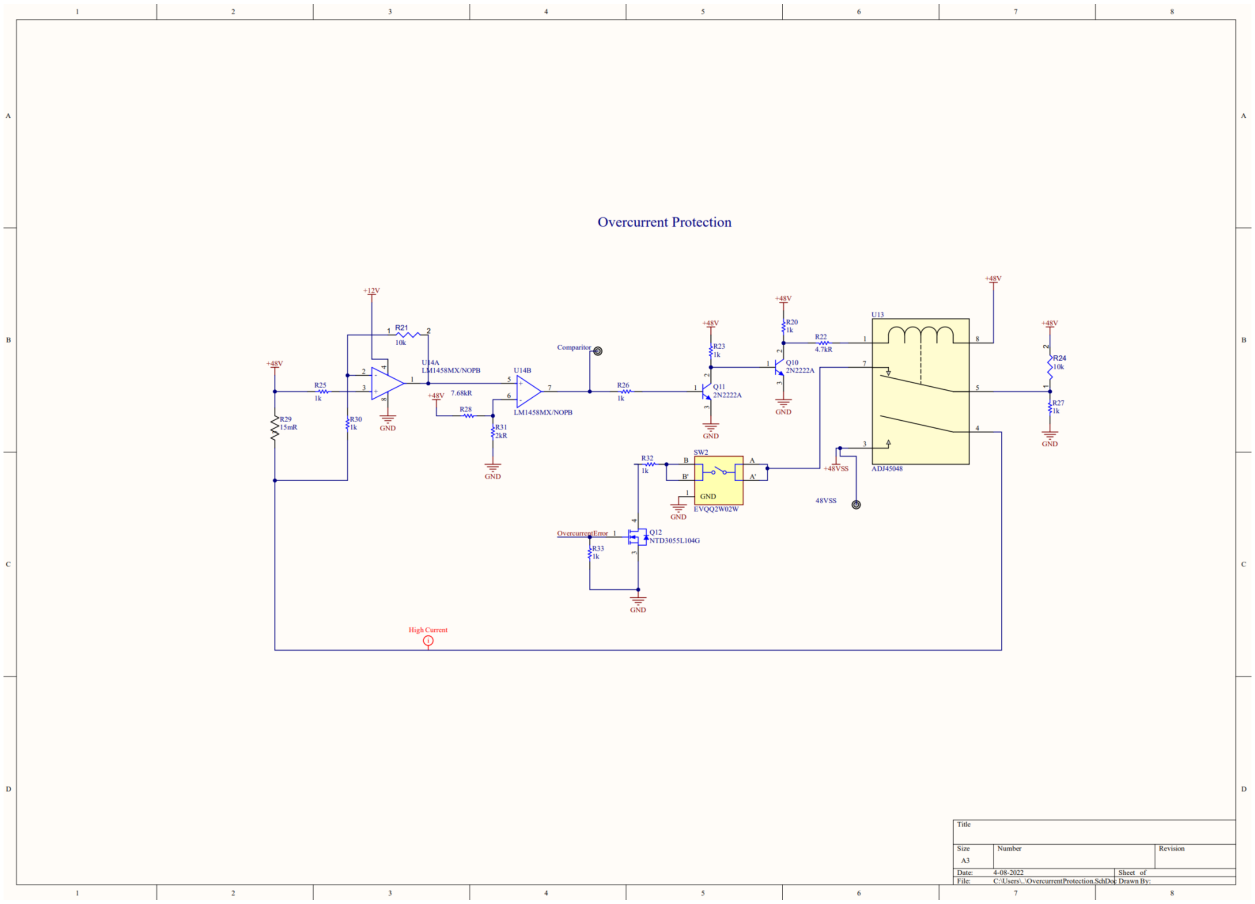
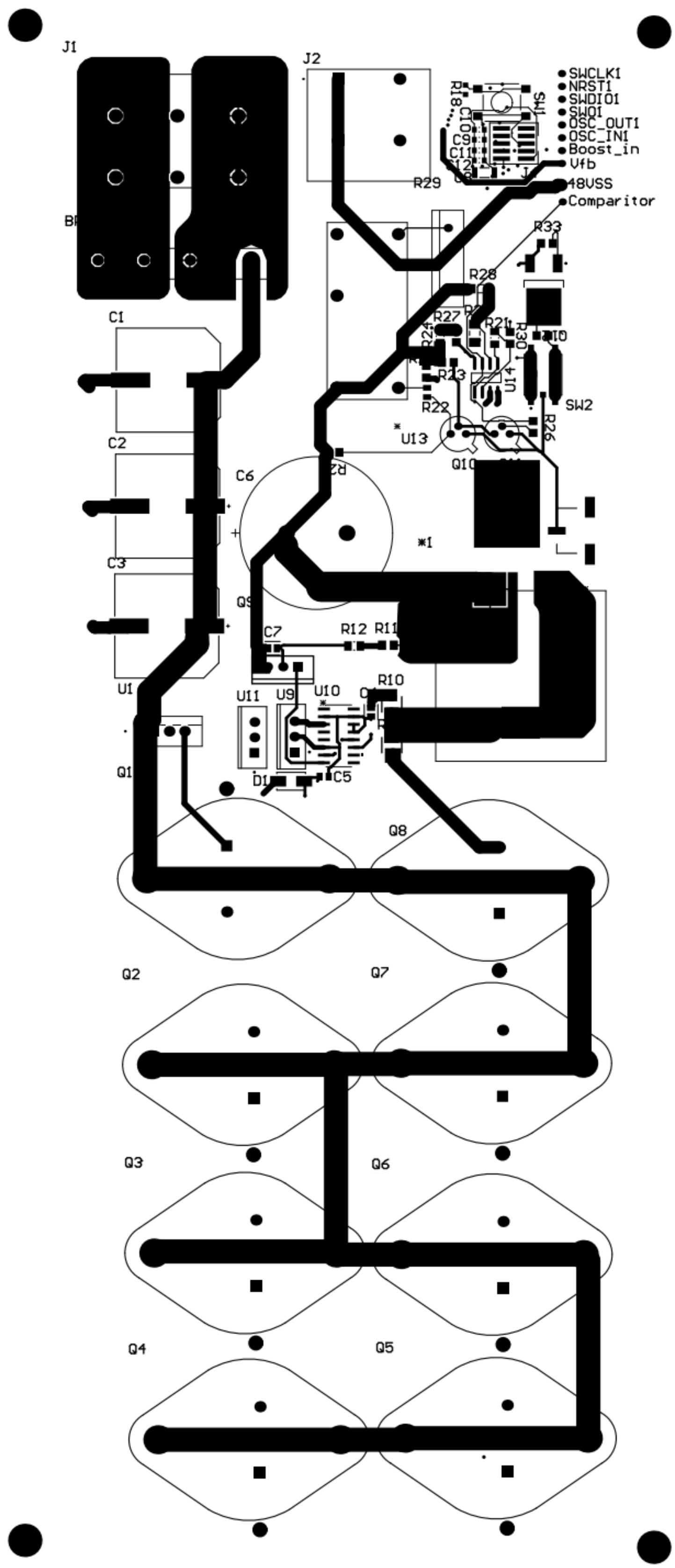
Drawn By:



Overcurrent Protection
+12V
R21
10k
U14A
LM1458MX/NOPB
U14B
LM1458MX/NOPB
+48V
R25
1k
R29
15mR
R30
1k
GND
7.68kR
R28
R31
2kR
Comparitor
R26
1k
R23
1k
Q11
2N2222A
R20
1k
Q10
2N2222A
R22
4.7kR
U13
ADJ45048
R24
10k
R27
1k
SW2
EVQQ2W02W
R32
1k
+48VSS
48VSS
OvercurrentError
Q12
NTD3055L104G
R33
1k
High Current
Title
Size
A3
Number
Revision
Date:
4-08-2022
Sheet of
File:
C:\Users\..\OvercurrentProtection.SchDoc
Drawn By:

Top Layer



J1
J2
SWCLK1
NRST1
SWDIO1
SWO1
OSC_OUT1
OSC_IN1
Boost_in
Vfb
48VSS
Comparitor
R29
R33
R28
R27
R21
R30
R24
R23
R22
U14
SW2
R26
U13
Q10
C1
C2
C3
C6
C7
R12
R11
R10
U1
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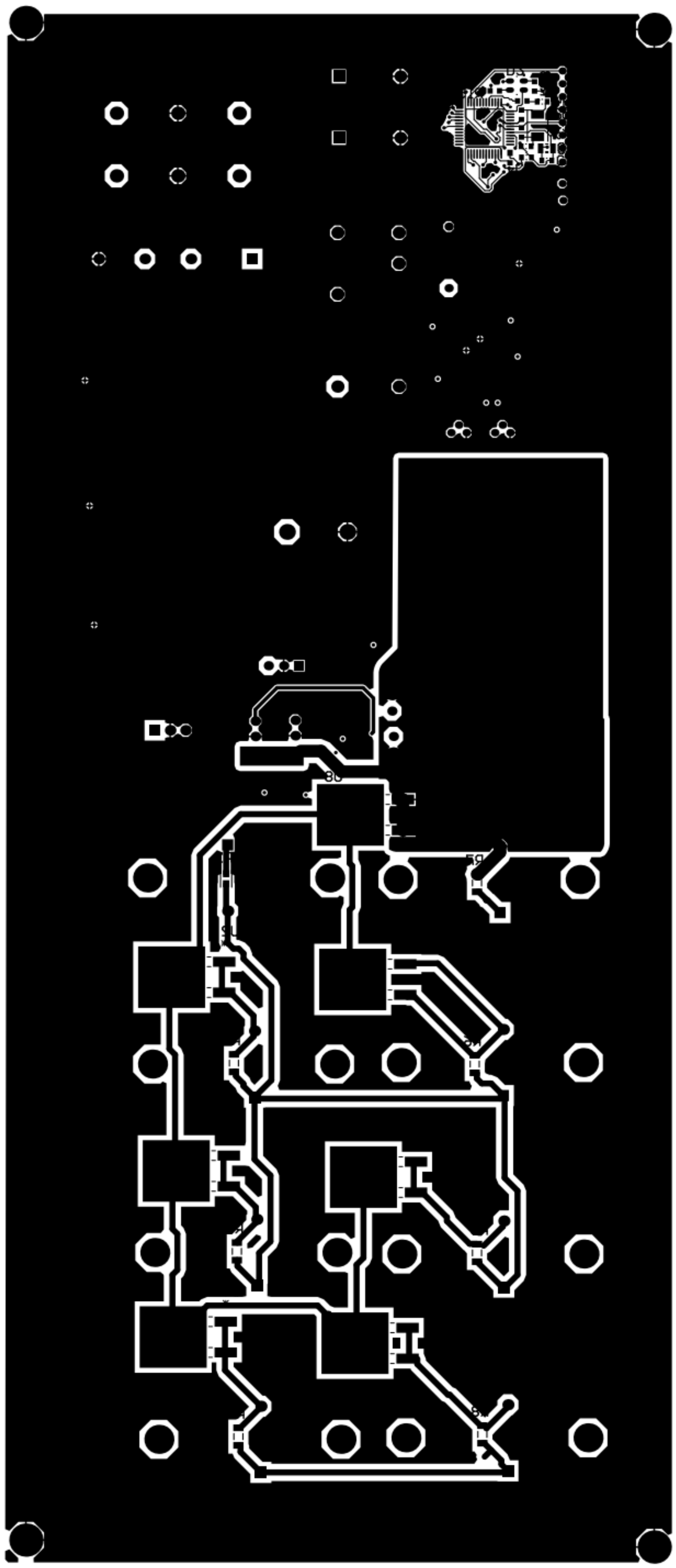
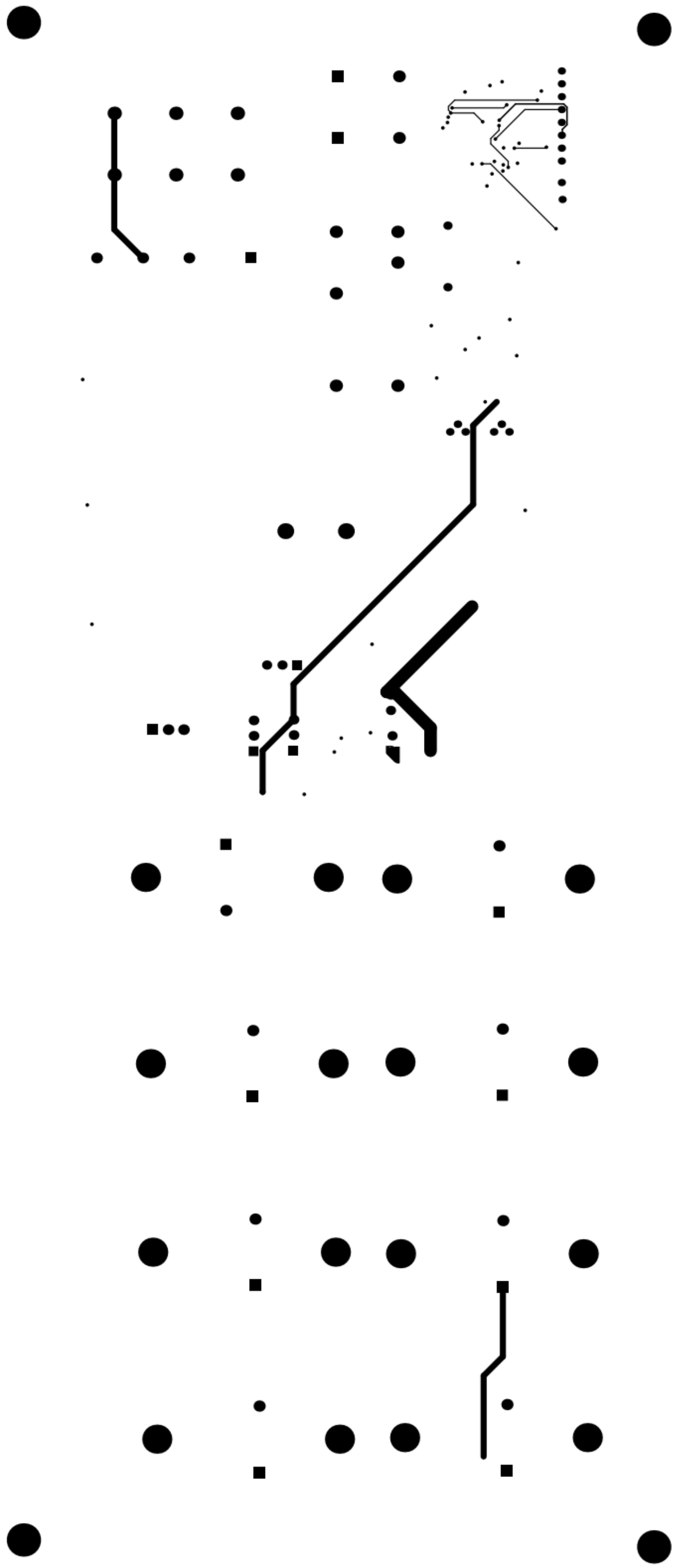
Q6
Q4
Q5

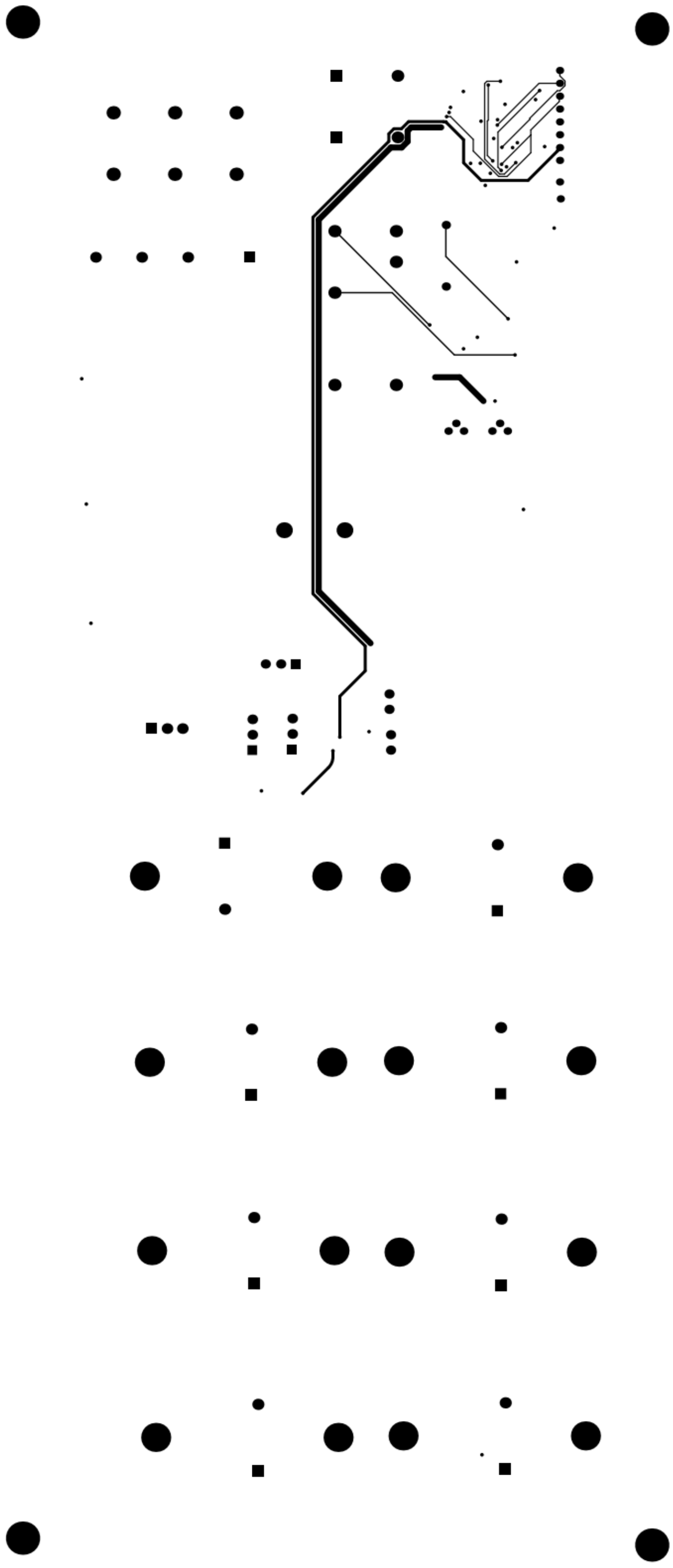
Bottom Layer



Signal Layer 2



Signal Layer 2



Bill Of materials

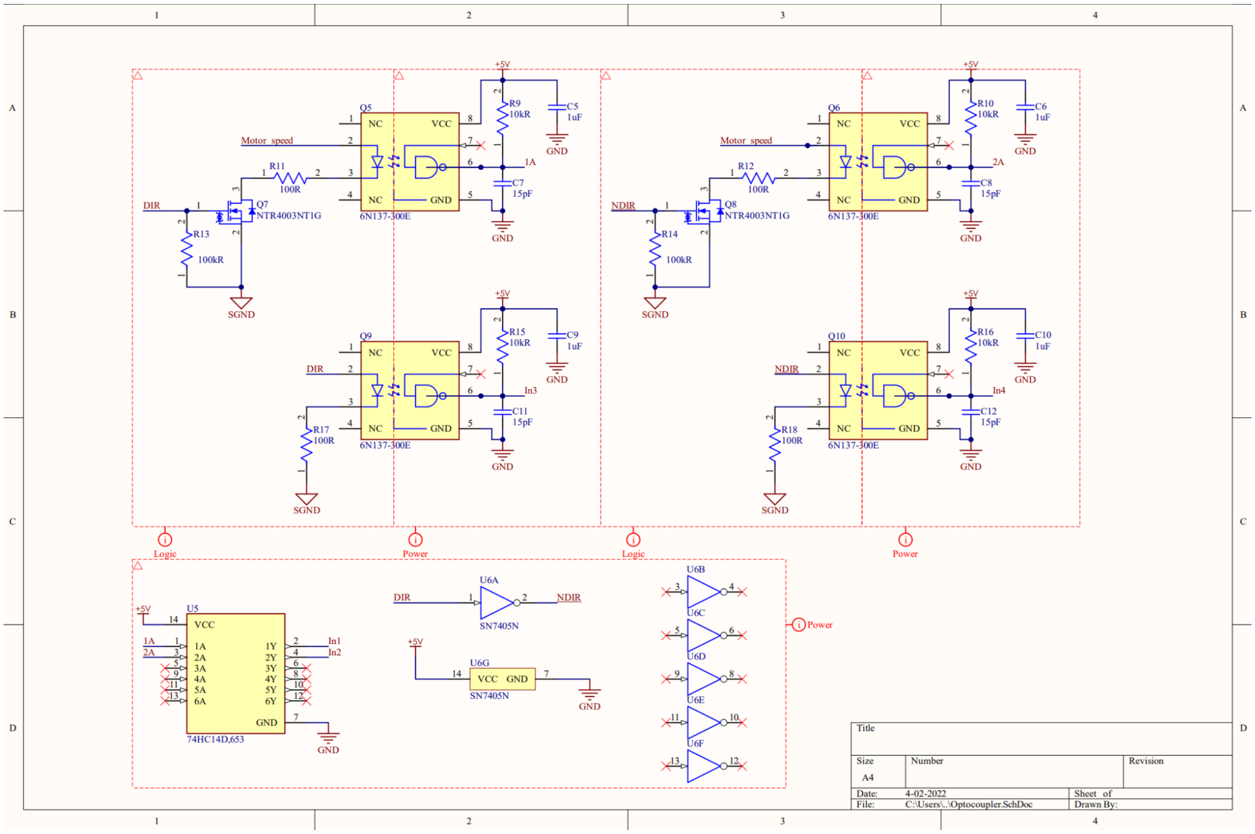
Comment Description Designator Footprint LibRef Quantity

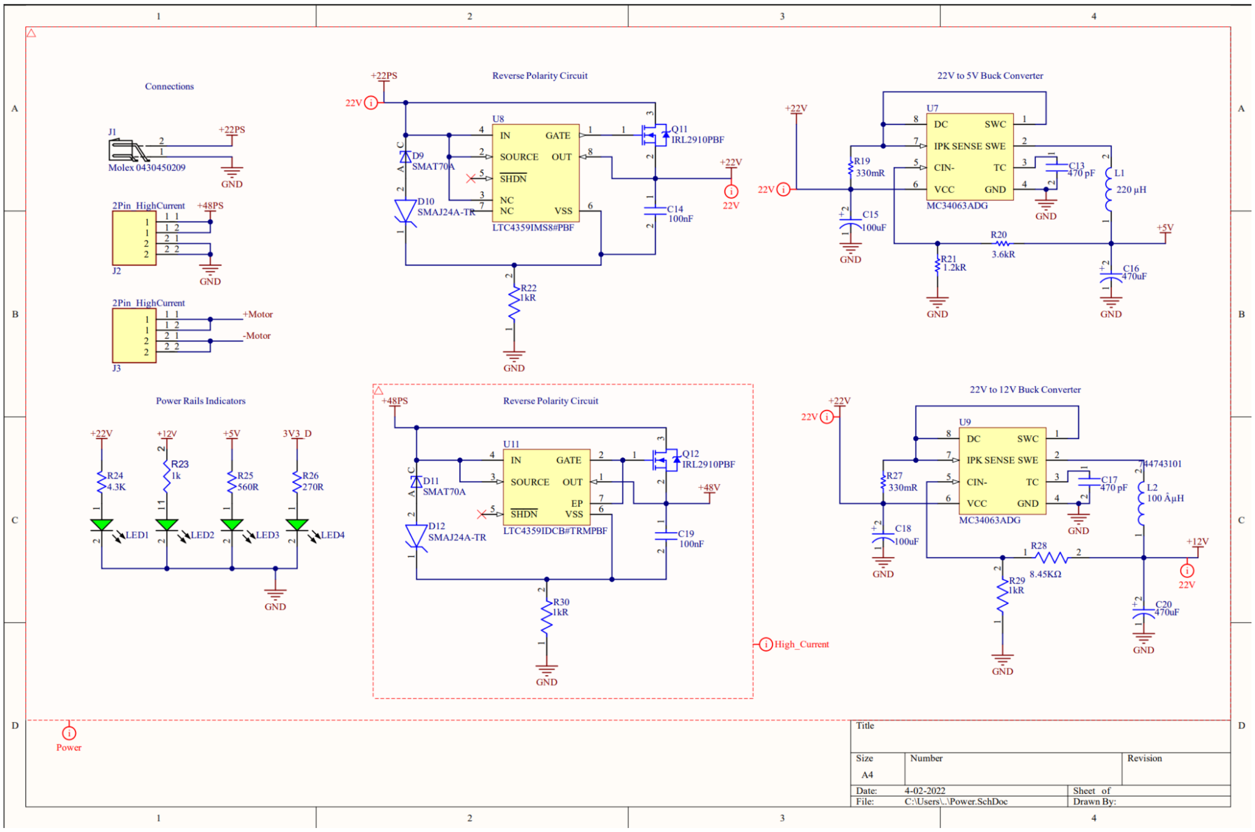
"Inductor_10uH" "Inductor Power Shielded Wirewound 10uH 10% 100KHz Ferrite 28A 0.0025Ohm DCR Automotive Tray"
"*1" "IND_PQ2617" "Inductor_10uH" "1"
"Thru-Hole Test Point" "" "48VSS, Boost_in, Comparitor, Feedback Voltage, NRST1, OSC_IN1, OSC_OUT1, SWCLK1, SWDIO1, SWO1" "TESTPOINT" "CMP-020-0001-1" "10"
"GBJ5010-BP" "GBJ5010 Series 1.1 V 50 A Through Hole Glass Passivated Bridge Rectifier - GBJ" "BR1"
"GBJ_MCC" "GBJ5010-BP" "1"
"EEV-FK1H102M" "CAP ALUM 1000UF 20% 50V SMD" "C1, C2, C3" "FP-FK-J16-MFG" "CMP-05427-000011-1"
"3"
"CL21B104KACNNNC" "CL21 Series 0805 100nF 25V ±10% Tolerance X7R Multilayer Ceramic Chip Capacitor" "C4, C7"
"FP-CL21-IPC_C" "CMP-13271-002854-1" "2"
"GRM21BR71H105KA12L" "" "C5" "CAPC2013X135X45LL10T25" "CMP-1036-04761-2" "1"
"LGG2P102MELA45" "105degC Ultra Smaller-Sized Snap-in Terminal Type, 1000 μ F, 220 V, -40 to 105°C, RoHS"
"C6" "CAP_A45_NCH" "Cap1000uF" "1"
"1206" "" "C8" "1206 CAPACITOR (TDK C-SERIES)" "1206 Ceramic Capacitor" "1"
"0603" "" "C9, C10, C11, C12, C13, C15, C16, C17" "0603 CAPACITOR (TDK C-SERIES)" "0603 Ceramic Capacitor" "8"
"0805" "" "C14" "0805 CAPACITOR (TDK C-SERIES)" "0805 Ceramic Capacitor" "1"
"S1M" "DIODE GEN PURP 1KV 1A SMA" "D1" "FP-403AE-MFG" "CMP-2000-04942-3" "1"
"Cree CLVBA-FKA-CAEDH8BBB7A363" "RGB LED" "D2" "Cree CLVBA-FKA-Series (4-SOJ)" "Cree CLVBA-FKA-CAEDH8BBB7A363" "1"
"1-1986660-3" "No Description Available" "J1" "CONN3_1-1986660-3_TEC" "1-1986660-3" "1"
"2Pin_HighCurrent" "2 Posn Power Connector, Black, 10.16mm, 1-1986660-" "J2" "TE_1-1986660-2" "2Pin_HighCurrent"
"1"
"Molex 0430450209" "CONN HEADER SMD R/A 2POS" "J3" "Molex 0430450209"
"CMP-029-000006-1" "1"
"FTSH-105-01-L-DV-K" "10-Pin 1.27mm Shrouded Cortex Debug Connector" "J4" "Samtec FTSH-105-01-L-DV-K" "Samtec FTSH-105-01-L-DV-K" "1"
"2N3055A" "Complementary Silicon High-Power Transistor, 3-Pin TO-204, Tray" "Q1, Q2, Q3, Q4, Q5, Q6, Q7, Q8"
"ONSC-TO-204-3-1-07" "CMP-1048-01046-1" "8"
"IRL2910PBF" "N-Channel 100 V 55A (Tc) 200W (Tc) Through Hole TO-220AB" "Q9" "IRL2910""IRL2910PBF"
"1"
"2N2222A" "High Speed Switch, 0.6 A IC, -65 to 175 degC, 3-Pin TO-18, RoHS, Bulk" "Q10, Q11"
"STM-TO-18-3" "CMP-2000-05381-1" "2"
"NTD3055L104G" "Power MOSFET, 12 A, 60 V, Logic Level, N-Channel, 3-Pin DPAK, Pb-Free, Tube" "Q12"
"ONSC-DPAK-3-369C-01_V" "CMP-1058-00384-1" "1"
"CRCW0603680RFKEAHP" "RES Thick Film, 680O, 1%, 0.33W, 100ppm/°C, 0603" "R1"
"FP-CRCW0603-HPe3-IPC_A" "CMP-02407-004503-1" "1"
"CRCW1206150RFKEA" "" "R2, R3, R4, R5, R6, R7, R8" "RESC3216X60X45NL10T20" "CMP-2003-01812-1"
"7"
"NTC4.7Ohms" "Thermistor NTC 4.7 Ohm 5% 2-Pin Radial 2880K < -5 Bulk" "R9, R10" "NTCLE100E3478JB0"
"NTC4.7Ohms" "2"
"ERJ-6ENF1003V" "" "R11" "RESC2013X70X40ML20T20""CMP-2001-04377-1" "1"
"CRCW08055K00FKTA" "" "R12" "RESC2013X50X30ML20T20""CMP-2001-04239-1" "1"
"0603" "" "R13, R14, R15, R16, R17, R18, R19" "0603 RESISTOR (YAGEO)" "0603 Resistor" "7"
"Resistor 1k +/-1% 0805 125 mW" "Chip Resistor, 1 KOhm, +/- 1%, 0.125 W, -55 to 155 degC, 0805 (2013 Metric)" "R20, R23, R25, R26, R27, R30, R32, R33" "RESC2013X70X40ML20T20""CMP-009-00010-4""8"
"Resistor 10k +/-1% 0805 125 mW" "Chip Resistor, 10 KOhm, +/- 1%, 125 mW, -55 to 155 degC, 0805 (2012 Metric)" "R21, R24" "RESC2013X50X35ML15T15""CMP-009-00018-4""2"
"ERJ-P06J472V" "" "R22" "RESC2013X70X40LL20T20" "CMP-2001-00487-1" "1"
"ERJ-8ENF7681V" "" "R28" "RESC3216X70X50LL05T20" "CMP-2003-00493-1" "1"
"LTO100FR0150JTE3" "Resistor; Thick Film; Res 0.015 Ohms; Pwr-Rtg 100 W; Tol 5%; Radial; TO-247; Heat Sink"
"R29" "TO-247_LTO_VIS" "LTO100FR0150JTE3" "1"
"ERA8AEB202V" "" "R31" "RESC3216X70X50ML20T25""CMP-2003-04435-1" "1"
"MCU Reset" "SWITCH TACTILE SPST-NO 0.05A 12V" "SW1" "CK PTS645SK43SMTR92 LFS" "Ck PTS645SK43SMTR92 LFS" "1"
"EVQQ2W02W" "SWITCH TACTILE SPST-NO 0.02A 15V" "SW2" "FP-EVQQ2W02W-MFG"
"CMP-05618-000028-1" "1"
"LM7824CT" "No Description Available" "U1" "TO-220-3L_10P67X4P83_ONS" "LM7824CT" "1"

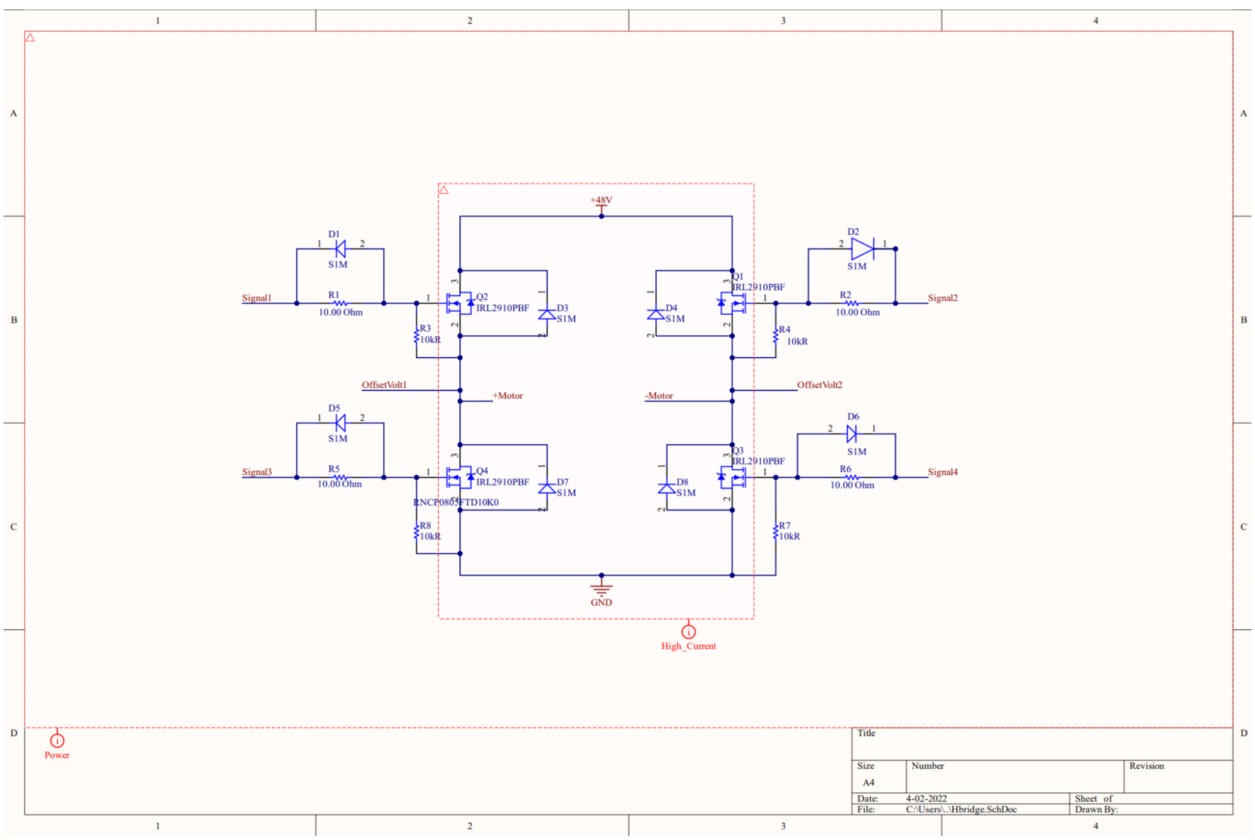
"D2TO035CR1000FTE3" "No Description Available" "U2, U3, U4, U5, U6, U7, U8" "TO-263_D2TO035_VIS" "D2TO035CR1000FTE3" "7"
"LM340T-12" "Series 3-Terminal Positive Regulators, 3-pin TO-220" "U9" "NDE0003A" "CMP-0062-02483-3" "1"
"IR2113PBF" "Half-Bridge Gate Driver IC Non-Inverting 14-DIP" "U10" "SOIC16_INF" "IR2113PBF" "1"
"LM7805CT" "Positive Voltage Regulator, 5 V, 1 A, -40 to 125 degC, 3-Pin TO-220, RoHS, Tube" "U11" "FAIR-TO-220-3" "CMP-2000-04938-1" "1"
"STM32F302CCT6" "ARM® Cortex®-M4 STM32F3 Microcontroller IC 32-Bit 72MHz 256KB (256K x 8) FLASH 48-LQFP (7x7)" "U12" "STMicroelectronics STM32F302C8T6 (48-LQFP)" "STMicroelectronics STM32F302CCT6" "1"
"ADJ45048" "No Description Available" "U13" "RELAY_ADJ450_PAN" "ADJ45048" "1"
"LM1458MX/NOPB" "IC OPAMP GP 2 CIRCUIT 8SOIC" "U14" "FP-D0008A-IPC_B" "CMP-04895-000419-1" "1"
"8MHz" "8MHz ±20ppm Crystal 18pF 140 Ohms 2-SMD, No Lead" "Y1" "ABRACON ABM3-8.000MHZ-D2Y-T" "8MHz Oscillator" "1"

APPENDIX B

Driver control Module




Connections
J1
Molex 0430450209
+22PS
GND
2Pin_HighCurrent
J2
+48PS
2Pin_HighCurrent
J3
+Motor
-Motor
Reverse Polarity Circuit
+22PS
22V
U8
IN
GATE
SOURCE
OUT
SHDN
NC
NC
VSS
D9
SMAT70A
D10
SMAJ24A-TR
LTC4359IMS8#PBF
Q11
IRL2910PBF
C14
100nF
+22V
22V
R22
1kR
GND
22V to 5V Buck Converter
U7
DC
SWC
IPK SENSE SWE
CIN-
TC
VCC
GND
MC34063ADG
R19
330mR
C13
470 pF
L1
220 µH
C15
100uF
R20
3.6kR
R21
1.2kR
+5V
C16
470uF
Power Rails Indicators
+22V
+12V
+5V
3V3_D
R24
4.3K
R23
1k
R25
560R
R26
270R
LED1
LED2
LED3
LED4
Reverse Polarity Circuit
+48PS
U11
IN
GATE
SOURCE
OUT
EP
SHDN
VSS
D11
SMAT70A
D12
SMAJ24A-TR
LTC4359IDCB#TRMPBF
Q12
IRL2910PBF
+48V
C19
100nF
R30
1kR
High_Current
22V to 12V Buck Converter
U9
DC
SWC
IPK SENSE SWE
CIN-
TC
VCC
GND
MC34063ADG
R27
330mR
C17
470 pF
744743101
L2
100 ÂµH
C18
100uF
R28
8.45KΩ
R29
1kR
+12V
22V
C20
470uF
Power
Title
Size
A4
Number
Revision
Date:
4-02-2022
File:
C:\Users\..\Power.SchDoc
Sheet of
Drawn By:


+48V
D1
S1M
Signal1
R1
10.00 Ohm
Q2
IRL2910PBF
D3
S1M
R3
10kR
D4
S1M
Q1
IRL2910PBF
D2
S1M
R2
10.00 Ohm
Signal2
R4
10kR
OffsetVolt1
+Motor
-Motor
OffsetVolt2
D5
S1M
Signal3
R5
10.00 Ohm
Q4
IRL2910PBF
D7
S1M
RNCP0805FTD10K0
R8
10kR
D8
S1M
Q3
IRL2910PBF
D6
S1M
R6
10.00 Ohm
Signal4
R7
10kR
GND
High_Current
Power
Title
Size
A4
Number
Revision
Date:
4-02-2022
File:
C:\Users\..\Hbridge.SchDoc
Sheet of
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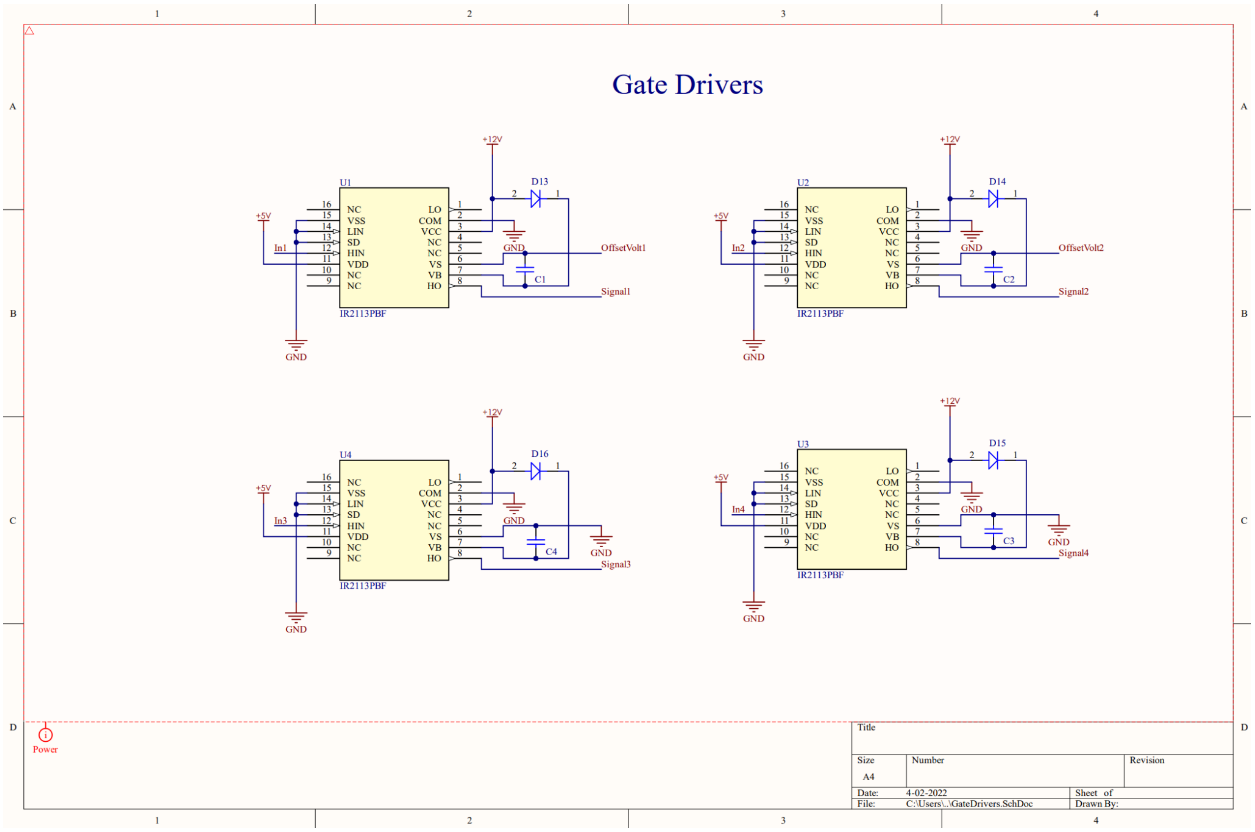
Gate Drivers
U1
IR2113PBF
U2
U3
U4
D13
D14
D15
D16
C1
C2
C3
C4
+12V
+5V
GND
In1
In2
In3
In4
OffsetVolt1
OffsetVolt2
Signal1
Signal2
Signal3
Signal4
NC
VSS
LIN
SD
HIN
VDD
LO
COM
VCC
VS
VB
HO
Power
Title
Size
A4
Number
Revision
Date: 4-02-2022
Sheet of
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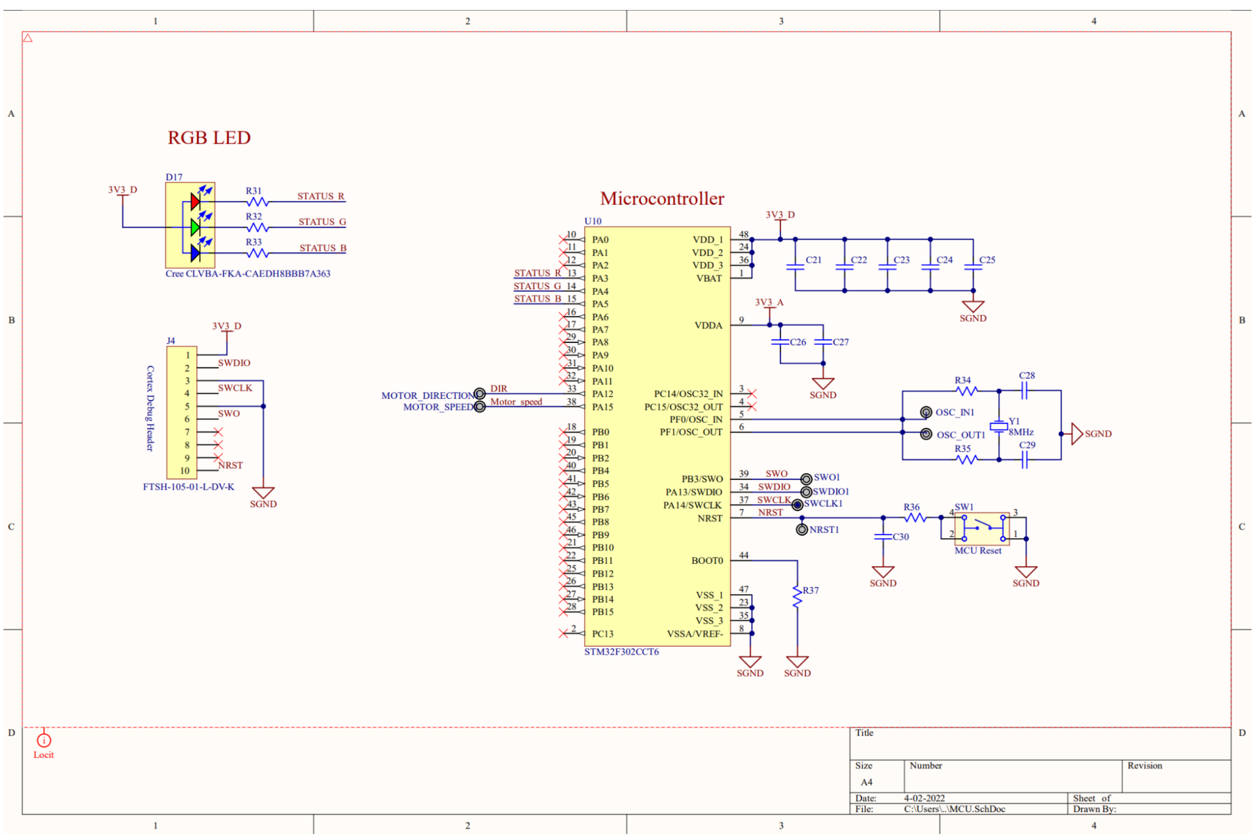
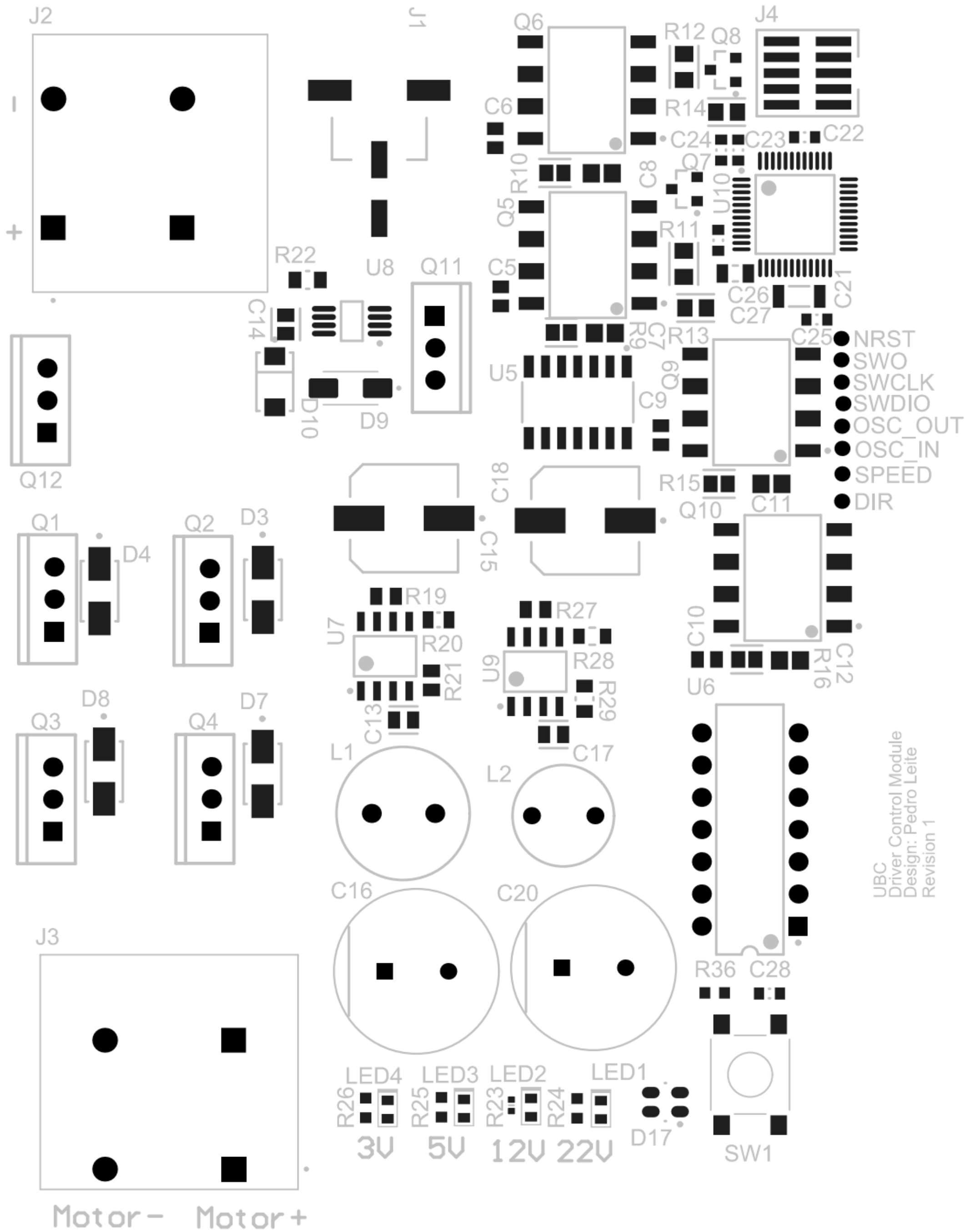
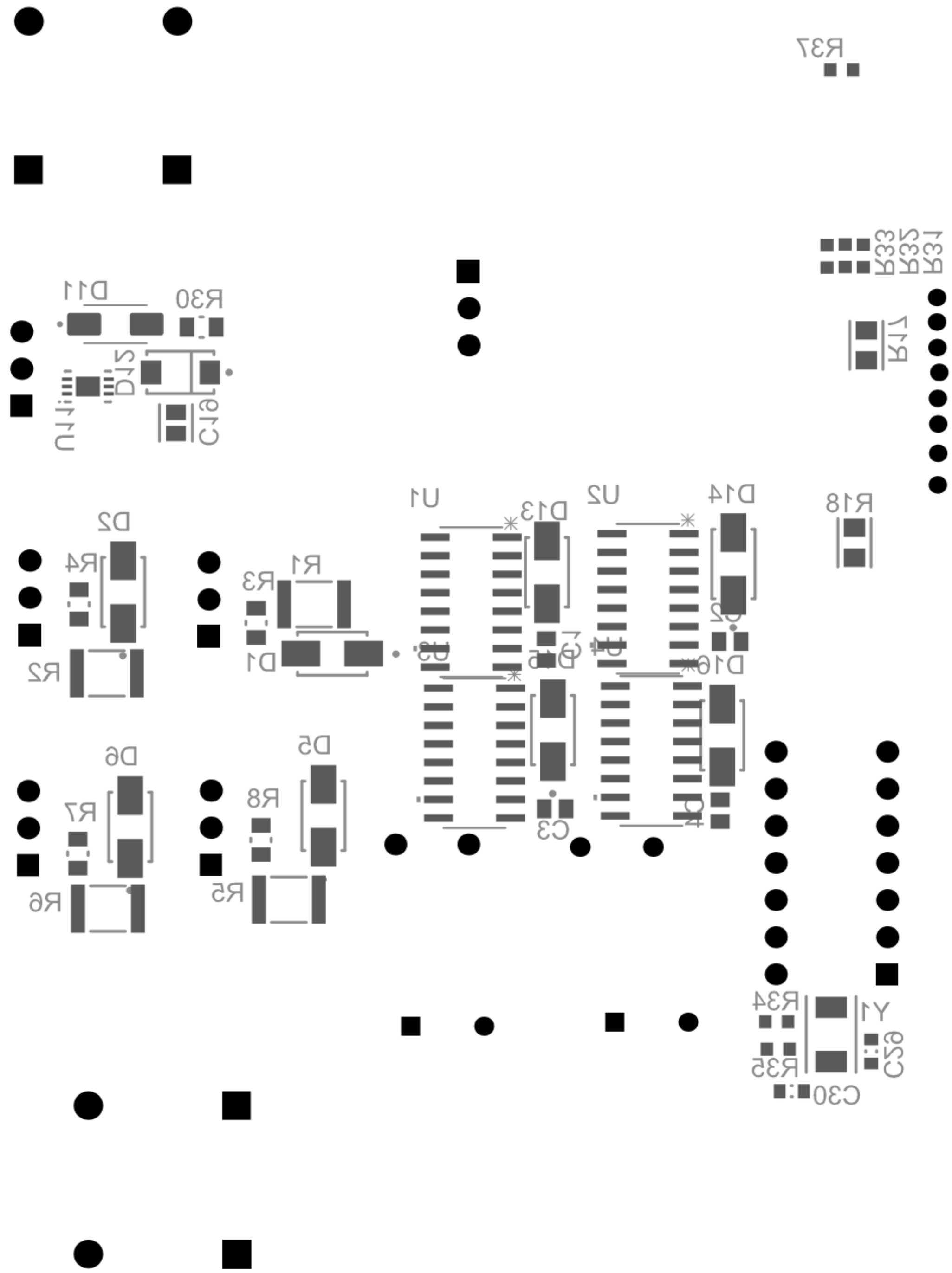
Drawn By:


RGB LED
D17
3V3_D
R31
R32
R33
STATUS_R
STATUS_G
STATUS_B
Cree CLVBA-FKA-CAEDH8BBB7A363
J4
Cortex Debug Header
SWDIO
SWCLK
SWO
NRST
SGND
FTSH-105-01-L-DV-K
Microcontroller
U10
STM32F302CCT6
VDD_1
VDD_2
VDD_3
VBAT
VDDA
3V3_A
C21
C22
C23
C24
C25
C26
C27
C28
C29
C30
MOTOR_DIRECTION
MOTOR_SPEED
DIR
Motor_speed
PC14/OSC32_IN
PC15/OSC32_OUT
PF0/OSC_IN
PF1/OSC_OUT
OSC_IN1
OSC_OUT1
Y1
8MHz
R34
R35
R36
R37
PB3/SWO
PA13/SWDIO
PA14/SWCLK
NRST
SWO1
SWDIO1
SWCLK1
NRST1
SW1
MCU Reset
BOOT0
VSS_1
VSS_2
VSS_3
VSSA/VREF-
Locit
Title
Size
A4
Number
Revision
Date: 4-02-2022
Sheet of
File: C:\Users\..\MCU.SchDoc
Drawn By:

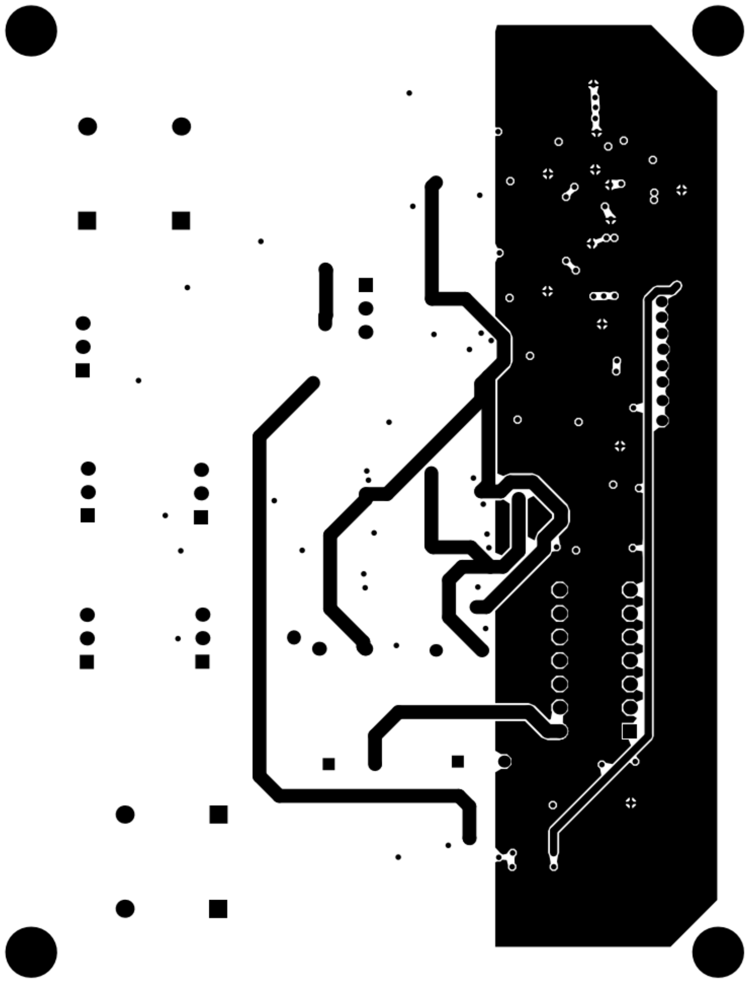
Top Layer


J2
J1
Q6
R12
Q8
J4
C6
R14
C24
C23
C22
R10
C8
Q7
U10
Q5
R11
C5
C26
C21
C27
R22
U8
Q11
C14
R9
C7
R13
C25
NRST
SWO
SWCLK
SWDIO
OSC_OUT
OSC_IN
SPEED
DIR
U5
Q9
C9
D10
D9
Q12
C18
R15
C11
Q10
C15
Q1
D4
Q2
D3
R19
R27
U7
R20
R21
U9
R28
R29
C10
R16
C12
U6
C13
C17
Q3
D8
Q4
D7
L1
L2
UBC
Driver Control Module
Design: Pedro Leite
Revision 1
C16
C20
J3
R36
C28
LED4
LED3
LED2
LED1
R26
R25
R23
R24
D17
3V
5V
12V
22V
SW1
Motor-
Motor+

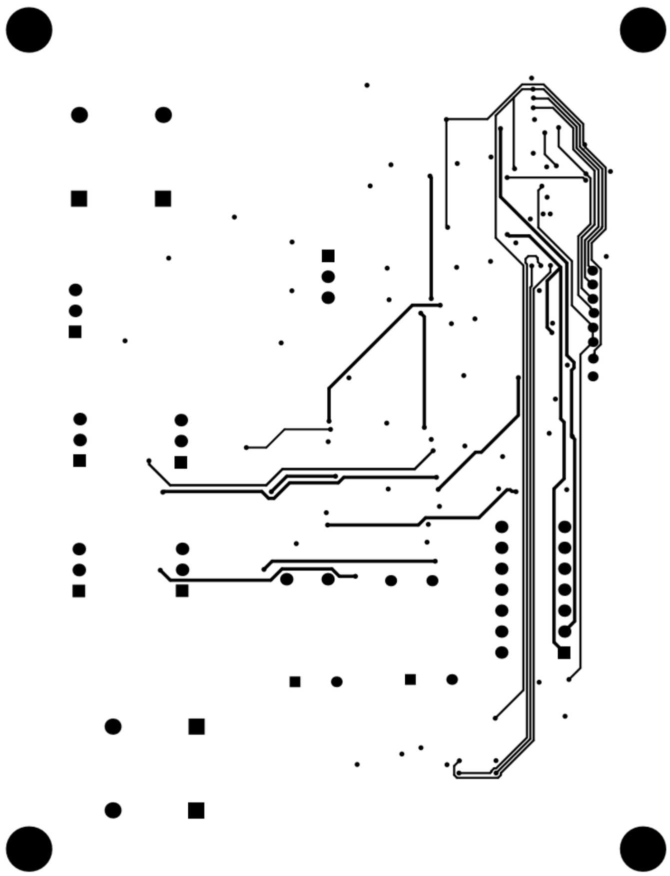
Bottom Layer



Signal layer 1



Signal Layer 2



Bill Of Material

Description Designator Footprint LibRef Quantity Category

"" "C1, C2, C3, C4, C5, C6, C9, C10" "CAPC2013X135X45LL10T25" "CMP-1036-04761-2" "8" "[NoParam], Ceramic Capacitors"
"" "C7, C8, C11, C12" "CAPC2013X94X50NL20T25" "CMP-2007-04377-1" "4" "Ceramic Capacitors"
"CAP CER 470PF 50V X7R 0805" "C13, C17" "FP-C0805C-DN-MFG" "CMP-03020-010032-1" "2" "Cap"
"CL21 Series 0805 100nF 25V ±10% Tolerance X7R Multilayer Ceramic Chip Capacitor" "C14, C19" "FP-CL21-IPC_C" "CMP-13271-002854-1" "2" ""
"CAP ALUM 100UF 20% 50V SMD" "C15, C18" "FP-FKF-MFG" "CMP-2000-06208-3" "2" ""
"CAP ALUM 470UF 20% 50V RADIAL" "C16, C20" "FP-EEUFM1H471-MFG" "CMP-05427-000073-1" "2" ""
"" "C21" "1206 CAPACITOR (TDK C-SERIES)" "1206 Ceramic Capacitor" "1" ""
"" "C22, C23, C24, C25, C26, C28, C29, C30" "0603 CAPACITOR (TDK C-SERIES)" "0603 Ceramic Capacitor" "8" ""
"" "C27" "0805 CAPACITOR (TDK C-SERIES)" "0805 Ceramic Capacitor" "1" ""
"DIODE GEN PURP 1KV 1A SMA" "D1, D2, D3, D4, D5, D6, D7, D8, D13, D14, D15, D16" "FP-403AE-MFG" "CMP-2000-04942-3" "12" ""
"SMAT70A-13, Protection Tvs Unid Irectional Sensor-peizoresist" "D9, D11" "DIOM5226X230N" "SMAT70A-13" "2" "TVS Diodes"
"TVS DIODE 24V 50V SMA" "D10, D12" "FP-SMA-MFG" "CMP-12225-000049-1" "2" "Diode"
"RGB LED" "D17" "Cree CLVBA-FKA-Series (4-SOJ)" "Cree CLVBA-FKA-CAEDH8BBB7A363" "1" ""
"CONN HEADER SMD R/A 2POS" "J1" "Molex 0430450209" "CMP-029-000006-1" "1" ""
"2 Posn Power Connector, Black, 10.16mm, 1-1986660-" "J2, J3" "TE_1-1986660-2" "2Pin_HighCurrent" "2" ""
"10-Pin 1.27mm Shrouded Cortex Debug Connector" "J4" "Samtec FTSH-105-01-L-DV-K" "Samtec FTSH-105-01-L-DV-K" "1" ""
"Radial Leaded Wire Wound Inductor WE-TI, L=220 µH" "L1" "WE-TI 1014" "CMP-1405-00005-1" "1" ""
"Radial Leaded Wire Wound Inductor WE-TI, L = 100 µH" "L2" "WE-TI-LB" "CMP-0225-00065-1" "1" ""
"LED GREEN CLEAR CHIP SMD" "LED1, LED2, LED3, LED4" "Lite-On LTST-C193KGKT-5A GREEN (1608)" "CMP-026-000009-1" "4" ""
"" "MOTOR_DIRECTION1, MOTOR_SPEED1, NRST1, OSC_IN1, OSC_OUT1, SWCLK1, SWDIO1, SWO1" "TESTPOINT" "CMP-020-0001-1" "8" ""
"N-Channel 100 V 55A (Tc) 200W (Tc) Through Hole TO-220AB" "Q1, Q2, Q3, Q4, Q11, Q12" "IRL2910""IRL2910PBF" "6" "MOSFETs"
"OPTOISO 3.75KV OPN COLL 8DIP GW" "Q5, Q6, Q9, Q10" "FP-6N137-300E-MFG" "CMP-18400-000015-1" "4" "Trans"
"Small Signal MOSFET, 30 V, 0.56 A, Single N-Channe, 3-Pin SOT-23, Pb-Free, Tape and Reel" "Q7, Q8" "ONSC-SOT-23-3-318-08_V" "CMP-1058-00759-1" "2" ""
"10R 0.75W 1% 1812 (4532 Metric) SMD" "R1, R2, R5, R6" "RESC1812(4532)_L" "CMP-1016-00264-1" "4" ""
"10kO ±1% 0.25W 0805 High Power Anti-Sulfur Thin Film Chip Resistor" "R3, R4, R7, R8, R9, R10, R15, R16" "FP-RNCP0805-MFG, FP-RNCP0805-IPC_C" "CMP-26527-007436-1" "8" "[NoParam], Chip SMD Resistors"
"100O ±0.5% 0.125W Chip Resistor 0805 Thick Film AEC-Q200 Qualified" "R11, R12, R17, R18" "FP-RK73G2A-IPC_A" "CMP-04015-102025-1" "4" ""
"RES 100K OHM 0.1% 1/8W 0805" "R13, R14" "FP-ERA6A-IPC_B" "CMP-2001-00583-2" "2" ""
"" "R19, R27" "RESC2013X70X40LL20T20" "CMP-2001-00468-1" "2" "Chip SMD Resistors"
"" "R20" "RESC2013X50X30LL20T20" "CMP-2001-03882-1" "1" "Chip SMD Resistors"
"" "R21" "RESC2013X60X40LL20T25" "CMP-2001-00589-1" "1" "Chip SMD Resistors"
"1kO ±1% 0.25W 0805 High Power Anti-Sulfur Thin Film Chip Resistor" "R22, R29, R30" "FP-RNCP0805-MFG" "CMP-26527-001902-1" "3" ""
"Chip Resistor, 1 kOhms, +/-5 %, 63 mW, -55 to 155 degC, 0402" "R23" "RESC0402(1005)_L" "CMP-009-00157-2" "1" ""
"" "R24" "0603 RESISTOR (YAGEO)" "0603 Resistor_2" "1" ""
"" "R25, R31, R32, R33, R34, R35, R36, R37" "0603 RESISTOR (YAGEO)" "0603 Resistor" "8" ""
"Res Thick Film 0603 560 Ohm 1% 0.25W(1/4W) +/-100ppm/C Molded SMD Automotive Punched T/R" "R26" "0603 RESISTOR (YAGEO)" "0603 Resistor_1" "1" "Chip SMD Resistors"
"RES 8.45K OHM 1/8W .1% SMD 0805" "R28" "FP-RT0805-MFG" "CMP-03412-018377-1" "1" "Res"

"SWITCH TACTILE SPST-NO 0.05A 12V" "SW1" "CK PTS645SK43SMTR92 LFS" "Ck PTS645SK43SMTR92 LFS" "1" ""
"Half-Bridge Gate Driver IC Non-Inverting 14-DIP" "U1, U2, U3, U4" "SOIC16_INF" "IR2113PBF" "4" ""
"IC INVERTER SCHMITT 6CH 14SO" "U5" "FP-SOT108-1-MFG" "CMP-14350-000004-1" "1" ""
"Hex inverters with open collector outputs, N0014A, TUBE" "U6" "N0014A" "CMP-1615-00873-2" "1" ""
"Step-Up / Down / Inverting Switching Regulator, 1.5 A, 3 to 40 V, 0 to 70 degC, 8-Pin SOIC (751-07), RoHS, Tube" "U7, U9" "ONSC-SOIC-8-751-07_V" "CMP-2000-04925-1" "2" ""
"Ideal Diode Controller with Reverse Input Protection, 4 to 80 V Vin, 8-pin SOP (MS8-8), -40 to 85 degC, Pb-Free" "U8" "LT-MS8-8_M" "CMP-0479-00203-1" "1" ""
"ARM® Cortex®-M4 STM32F3 Microcontroller IC 32-Bit 72MHz 256KB (256K x 8) FLASH 48-LQFP (7x7)" "U10" "STMicroelectronics STM32F302C8T6 (48-LQFP) - duplicate" "STMicroelectronics STM32F302CCT6" "1" ""
"Ideal Diode Controller with Reverse Input Protection, 4 to 80 V Vin, 6-pin SON (DCB-6), -40 to 85 degC, Pb-Free, Mini Tape and Reel" "U11" "LT-DCB-6_V" "CMP-0479-00018-1" "1" ""
"8MHz ±20ppm Crystal 18pF 140 Ohms 2-SMD, No Lead" "Y1" "ABRACON ABM3-8.000MHZ-D2Y-T" "8MHz Oscillator" "1" ""

APPENDIX C

Quadrature encoder

```
`default_nettype none
module quadrature_counter(clk, A, B, counter, out, reset);

input logic clk, A, B, reset; // A and B are output channel from encoder, Reset is
homing logic interrupt
output logic [9:0] out; //keeps the track of position

logic [1:0] state; //state machine state
logic [1:0] in;
logic [9:0] counter;

assign in = {A,B}; //concate the inputs

parameter [1:0] s0= 2'b00;
parameter [1:0] s1= 2'b01;
parameter [1:0] s2= 2'b10;
parameter [1:0] s3= 2'b11;

always_ff(posedge clk or posedge reset) begin
    if(reset) begin  //Homing logic
        counter <= 10'd500;
        state <= s0;
    end
    else begin //counter state machine
        case(state)
        s0: if(in == 2'b01) begin
                if(counter! = 10'd1) begin //only subtract if count is not 1 because 1
represents 499 anticlockwise rotations and next anticlockwise rotation will be home
                    counter <= counter - 10'd1;
                    state <= 2'b01;
                end
                else begin
                    counter <= 10'd500;
                    state <= 2'b01;
                end
            end
            else if(in == 2'b10) begin
                if(counter!=10'd999) begin //only add if count is not 999 because 999
represents 499 clockwise rotations and next clockwise rotation will be home
                    counter <= counter + 10'd1
                    state <= 2'b10;
                end
                else begin
                    counter <= 10'd500;
                    state <= 2'b10;
                end
            end

        s1: if(in == 2'b11) begin
                if(counter! = 10'd1) begin
```

```
            counter <= counter - 10'd1;
            state <= 2'b11;
        end
        else begin
            counter <= 10'd500;
            state <= 2'b11;
        end
    end
    else if(in == 2'b00) begin
        if(counter!=10'd999) begin
            counter <= counter + 10'd1
            state <= 2'b00;
        end
        else begin
            counter <= 10'd500;
            state <= 2'b00;
        end
    end

s2: if(in == 2'b00) begin
        if(counter! = 10'd1) begin
            counter <= counter - 10'd1;
            state <= 2'b00;
        end
        else begin
            counter <= 10'd500;
            state <= 2'b00;
        end
    end
    else if(in == 2'b11) begin
        if(counter!=10'd999) begin
            counter <= counter + 10'd1
            state <= 2'b11;
        end
        else begin
            counter <= 10'd500;
            state <= 2'b11;
        end
    end

s3: if(in == 2'b10) begin
        if(counter! = 10'd1) begin
            counter <= counter - 10'd1;
            state <= 2'b10;
        end
        else begin
            counter <= 10'd500;
            state <= 2'b10;
        end
    end
    else if(in == 2'b01) begin
        if(counter!=10'd999) begin
            counter <= counter + 10'd1
            state <= 2'b01;
        end
```

```
                else begin
                    counter <= 10'd500;
                    state <= 2'b01;
                end
            end
        endcase
    end
end

always_ff(posedge clk) begin //compute position
    if(counter >= 10'd500) begin
        out <= counter - 10'd500;
    end
    else begin
        out <= counter;
    end
end
endmodule
```

APPENDIX D

Mosfet

International IOR Rectifier

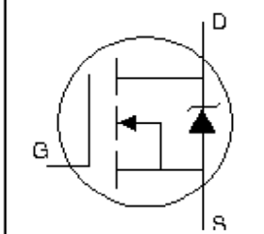
PD 9.1375

PRELIMINARY

IRL2910

HEXFET® Power MOSFET

- Logic-Level Gate Drive
- Advanced Process Technology
- Ultra Low On-Resistance
- Dynamic dv/dt Rating
- 175°C Operating Temperature
- Fast Switching
- Fully Avalanche Rated



V_{DSS} = 100V

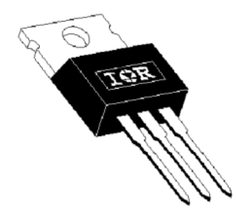
$R_{DS(on)}$ = 0.026Ω

I_D = 48A

Description

Fifth Generation HEXFETs from International Rectifier utilize advanced processing techniques to achieve extremely low on-resistance per silicon area. This benefit, combined with the fast switching speed and ruggedized device design for which HEXFET Power MOSFETs are well known, provides the designer with an extremely efficient and reliable device for use in a wide variety of applications.

The TO-220 package is universally preferred for all commercial-industrial applications at power dissipation levels to approximately 50 watts. The low thermal resistance and low package cost of the TO-220 contribute to its wide acceptance throughout the industry.



TO-220AB

Absolute Maximum Ratings

	Parameter	Max.	Units
I_D @ T_C = 25°C	Continuous Drain Current, V_{GS} @ 10V	48	
I_D @ T_C = 100°C	Continuous Drain Current, V_{GS} @ 10V	34	A
I_{DM}	Pulsed Drain Current ①	190	
P_D @T_C = 25°C	Power Dissipation	150	W
	Linear Derating Factor	1.0	W/°C
V_{GS}	Gate-to-Source Voltage	± 20	V
E_{AS}	Single Pulse Avalanche Energy ②	520	mJ
I_{AR}	Avalanche Current ①⑤	29	A
E_{AR}	Repetitive Avalanche Energy ①	15	mJ
dv/dt	Peak Diode Recovery dv/dt ③	7.4	V/ns
T_J T_{STG}	Operating Junction and Storage Temperature Range	-55 to + 175	°C
	Soldering Temperature, for 10 seconds	300 (1.6mm from case)	
	Mounting torque, 6-32 or M3 srew	10 lbf•in (1.1N•m)	

Thermal Resistance

	Parameter	Typ.	Max.	Units
$R_{\theta JC}$	Junction-to-Case	——	1.0	°C/W
$R_{\theta CS}$	Case-to-Sink, Flat, Greased Surface	0.50	——	°C/W
$R_{\theta JA}$	Junction-to-Ambient	——	62	°C/W