University of Moratuwa
Faculty of Engineering
Department of Electronic & Telecommunication Engineering

21st of May, 2025

EN2160: Electronic Design Realization

Production Documents for Closed Loop Stepper Motor Project

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1 Introduction

This production report details the development of a closed-loop stepper motor control system designed for high-performance and cost-effective motion control applications. This project focuses on building a dedicated motor driver from scratch using a Texas Instruments C2000 series microcontroller. The system implements Field-Oriented Control (FOC) and real-time feedback to achieve precise position and speed control, along with fault detection. The report outlines the complete production process, including hardware and software design, integration, testing and evaluation procedures, and cost estimation, providing a comprehensive plan for future scalability and manufacturing.

2 Block Diagram

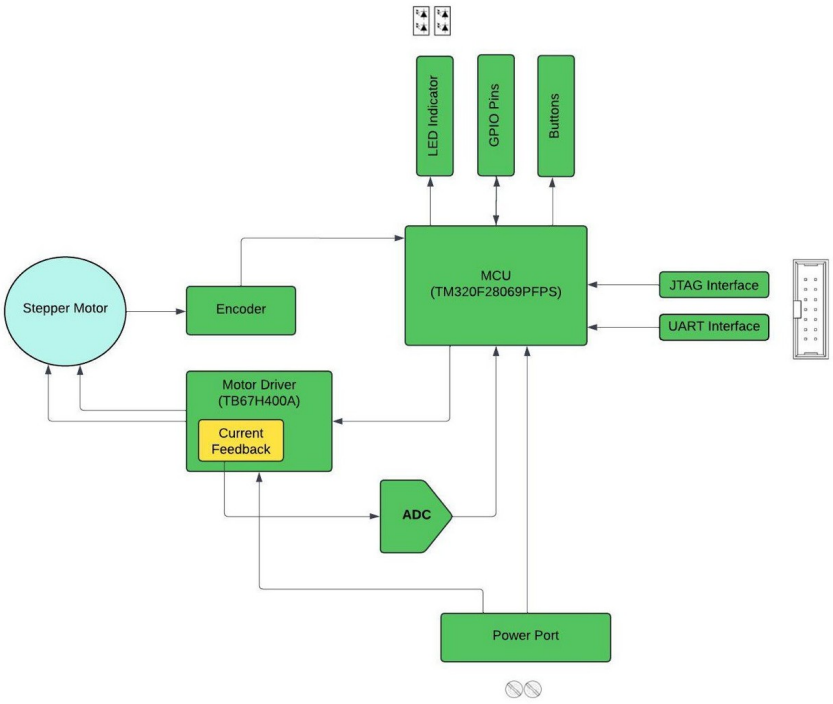
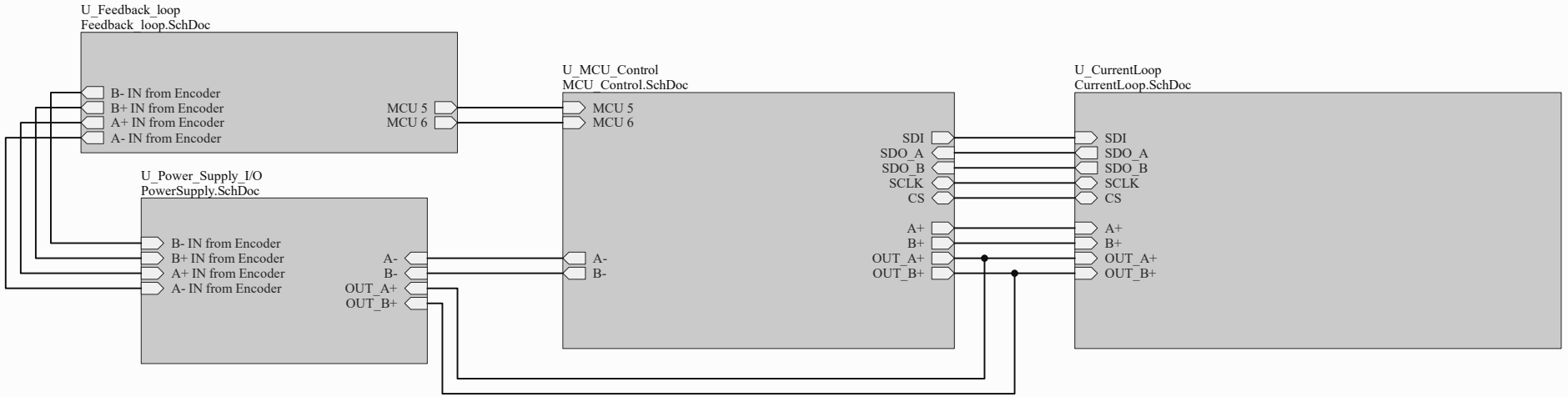


Figure 1: Block Diagram of the System

3 Hardware Design

3.1 Schematic



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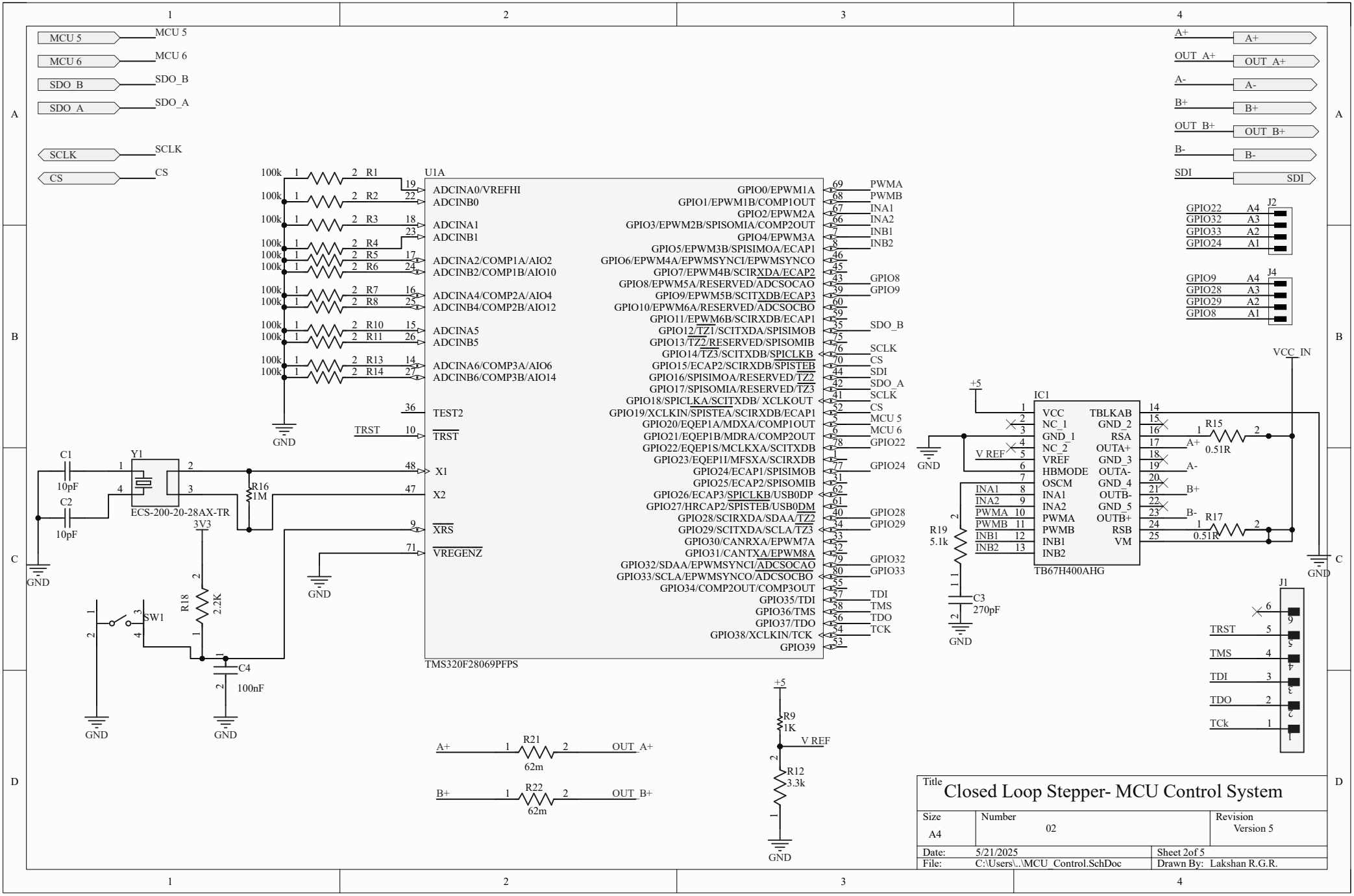
File:	C:\Users\..\top_level.SchDoc	Drawn By:	Jayathissa M.P.N.V.


MCU 5
MCU 6
SDO_B
SDO_A
SCLK
CS
U1A
ADCINA0/VREFHI
ADCINB0
ADCINA1
ADCINB1
ADCINA2/COMP1A/AIO2
ADCINB2/COMP1B/AIO10
ADCINA4/COMP2A/AIO4
ADCINB4/COMP2B/AIO12
ADCINA5
ADCINB5
ADCINA6/COMP3A/AIO6
ADCINB6/COMP3B/AIO14
TEST2
TRST
X1
X2
XRS
VREGENZ
GPIO0/EPWM1A
GPIO1/EPWM1B/COMP1OUT
GPIO2/EPWM2A
GPIO3/EPWM2B/SPISOMIA/COMP2OUT
GPIO4/EPWM3A
GPIO5/EPWM3B/SPISIMOA/ECAP1
GPIO6/EPWM4A/EPWMSYNCI/EPWMSYNCO
GPIO7/EPWM4B/SCIRXDA/ECAP2
GPIO8/EPWM5A/RESERVED/ADCSOCAO
GPIO9/EPWM5B/SCITXDB/ECAP3
GPIO10/EPWM6A/RESERVED/ADCSOCBO
GPIO11/EPWM6B/SCIRXDB/ECAP1
GPIO12/TZ1/SCITXDA/SPISIMOB
GPIO13/TZ2/RESERVED/SPISOMIB
GPIO14/TZ3/SCITXDB/SPICLKB
GPIO15/ECAP2/SCIRXDB/SPISTEB
GPIO16/SPISIMOA/RESERVED/TZ2
GPIO17/SPISOMIA/RESERVED/TZ3
GPIO18/SPICLKA/SCITXDB/ XCLKOUT
GPIO19/XCLKIN/SPISTEA/SCIRXDB/ECAP1
GPIO20/EQEP1A/MDXA/COMP1OUT
GPIO21/EQEP1B/MDRA/COMP2OUT
GPIO22/EQEP1S/MCLKXA/SCITXDB
GPIO23/EQEP1I/MFSXA/SCIRXDB
GPIO24/ECAP1/SPISIMOB
GPIO25/ECAP2/SPISOMIB
GPIO26/ECAP3/SPICLKB/USB0DP
GPIO27/HRCAP2/SPISTEB/USB0DM
GPIO28/SCIRXDA/SDAA/TZ2
GPIO29/SCITXDA/SCLA/TZ3
GPIO30/CANRXA/EPWM7A
GPIO31/CANTXA/EPWM8A
GPIO32/SDAA/EPWMSYNCI/ADCSOCAO
GPIO33/SCLA/EPWMSYNCO/ADCSOCBO
GPIO34/COMP2OUT/COMP3OUT
GPIO35/TDI
GPIO36/TMS
GPIO37/TDO
GPIO38/XCLKIN/TCK
GPIO39
TMS320F28069PFPS
PWMA
PWMB
INA1
INA2
INB1
INB2
GPIO8
GPIO9
SDO_B
SCLK
CS
SDI
SDO_A
SCLK
CS
MCU 5
MCU 6
GPIO22
GPIO24
GPIO28
GPIO29
GPIO32
GPIO33
TDI
TMS
TDO
TCK
R1
R2
R3
R4
R5
R6
R7
R8
R10
R11
R13
R14
100k
GND
C1
10pF
C2
10pF
Y1
ECS-200-20-28AX-TR
R16
1M
3V3
R18
2.2K
SW1
C4
100nF
A+
OUT_A+
A-
B+
OUT_B+
B-
SDI
R21
62m
R22
62m
+5
R9
1K
V REF
R12
3.3k
J2
GPIO22
GPIO32
GPIO33
GPIO24
J4
GPIO9
GPIO28
GPIO29
GPIO8
VCC_IN
IC1
VCC
NC_1
GND_1
NC_2
VREF
HBMODE
OSCM
INA1
INA2
PWMA
PWMB
INB1
INB2
TBLKAB
GND_2
RSA
OUTA+
GND_3
OUTA-
GND_4
OUTB-
GND_5
OUTB+
RSB
VM
TB67H400AHG
R15
0.51R
R17
0.51R
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TMS
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TDO
TCk
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A4
Number
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Revision
Version 5
Date:
5/21/2025
Sheet 2of 5
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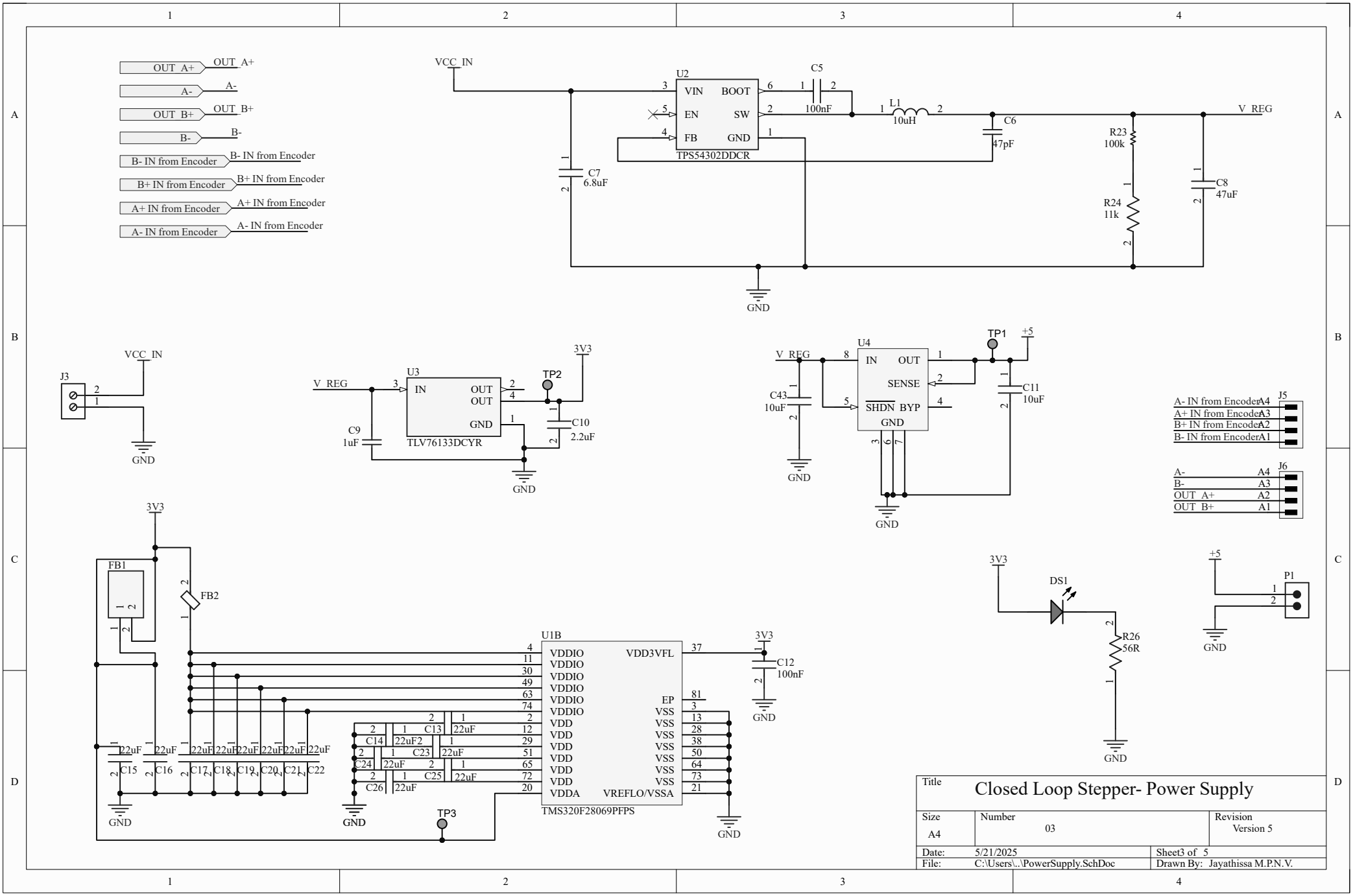
Drawn By:
Lakshan R.G.R.


OUT_A+
A-
OUT_B+
B-
B- IN from Encoder
B+ IN from Encoder
A+ IN from Encoder
A- IN from Encoder
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BOOT
EN
SW
FB
GND
TPS54302DDCR
C5
100nF
L1
10uH
C6
47pF
C7
6.8uF
R23
100k
R24
11k
C8
47uF
V_REG
GND
J3
U3
IN
OUT
TLV76133DCYR
C9
1uF
C10
2.2uF
3V3
TP2
U4
SENSE
SHDN
BYP
C43
10uF
C11
10uF
TP1
+5
J5
J6
FB1
FB2
U1B
VDDIO
VDD
VDDA
VDD3VFL
EP
VSS
VREFLO/VSSA
TMS320F28069PFPS
C12
100nF
22uF
C13
C14
22uF2
C15
C16
C17
C18
C19
C20
C21
C22
C23
C24
C25
C26
TP3
DS1
R26
56R
P1
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Number
03
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Version 5
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5/21/2025
Sheet3 of 5
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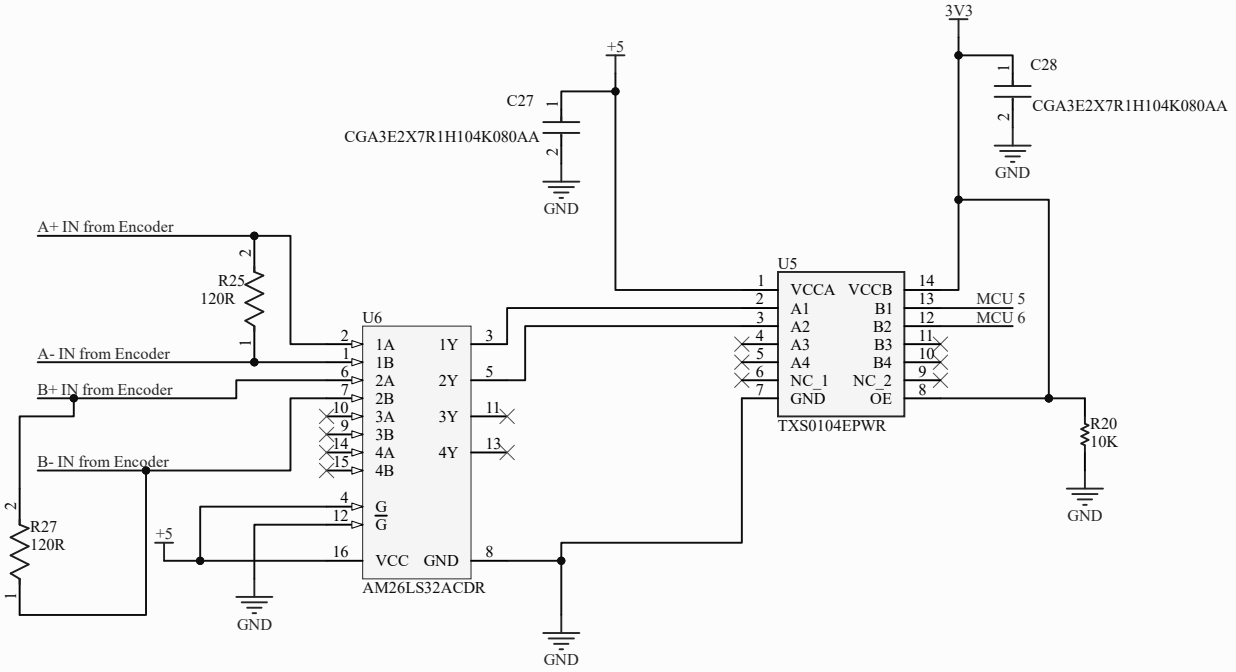

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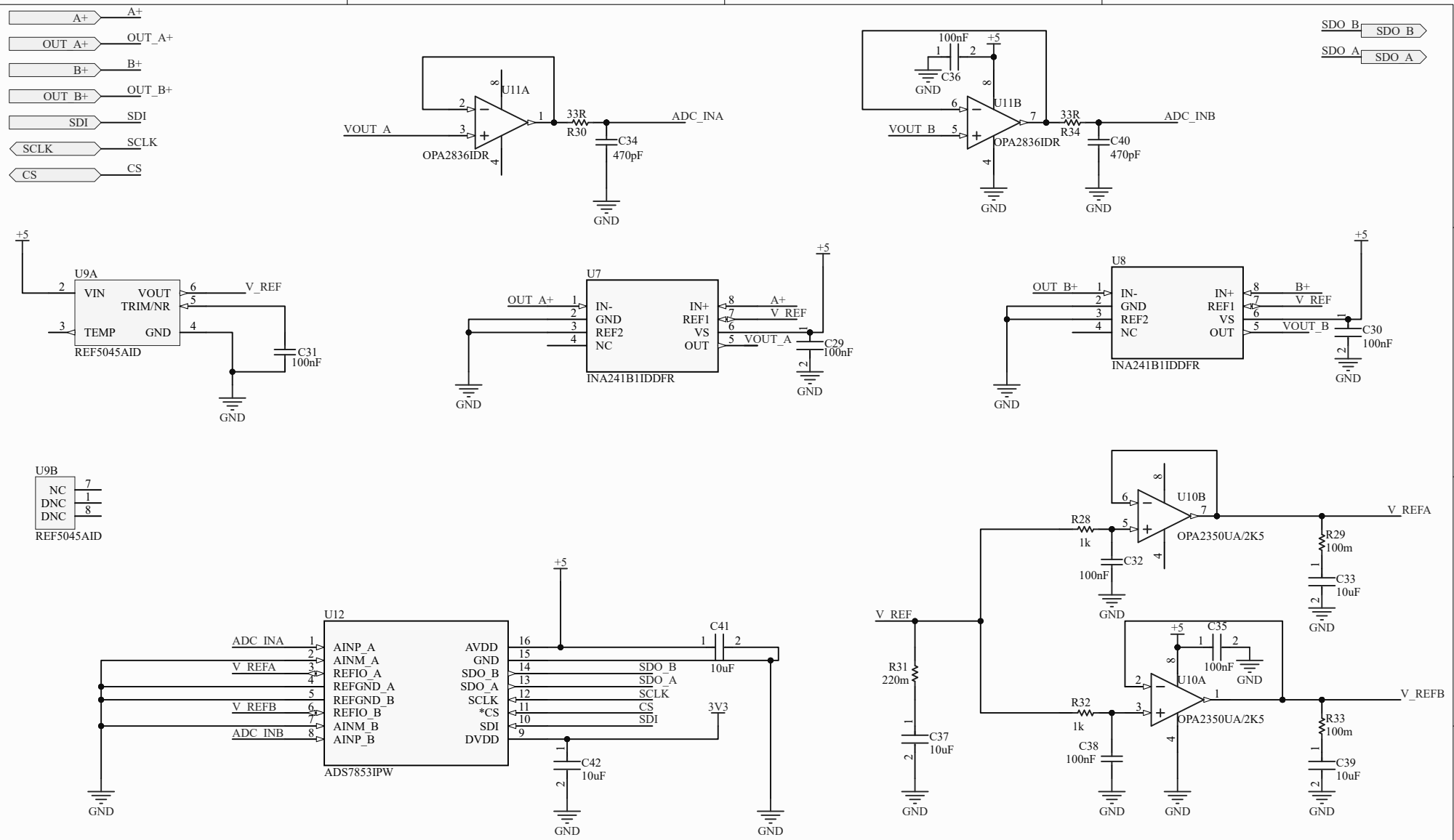

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Date: 5/21/2025		Sheet5 of 5
File: C:\Users\..\CurrentLoop.SchDoc		Drawn By: Fernando S.R.N.

3.2 Components

Designator	Description	Manufacturer / Part Number
C1, C2	10pF, $\pm 5\%, 50V, 0603, NP0$	Yageo / CC0603JRNPO9BN100
C3	270pF, 50V, C0G/NP0, 0603	KEMET / C0603C271J5GACTU
C4, C12, C27, C28	100nF, 50V, X7R, 0603, Automotive	TDK / CGA3E2X7R1H104K080AA
C5	0.1uF, 50V, X7R, 0805	KEMET / C0805C104M5RACTM
C6	470pF, 50V, NP0, 0805	Murata / GQM2195C1H470JB01D
C7	6.8uF, 35V, X5R, 0805	TDK / C2012X5R1V685K125AC
C8	47uF, 16V, X5R, 1210	Murata / GRM32ER61C476KE15L
C9, C31, C32, C38	0.1uF, 50V, X7R, 0805	Kyocera AVX / C0805C105K4PACTU
C10	2.2uF, 100V, X7S, 1206	TDK / C3216X7S2A225K160AB
C11, C33, C37, C39, C41–C43	10uF, 6.3V, X5R, 0603	Murata / GRM188R60J106ME47D
C13–C26	22uF, 10V, X5R, 0603	Murata / GRM188R61A226ME15D
C29, C30, C35, C36	0.1uF, 100V, X7R, 1206	KEMET / C1206C104K1RACTU
C34, C40	470pF, 500V, 1206	Kyocera AVX / 12067A471JAT2A
DS1	Green Chip LED, 2.2V	Broadcom Avago / HSMG-C170
FB2	$60\Omega, 100MHz, 0402FerriteBead$	Murata / BLM15PD600SN1D
J1	CONN HEADER VERT 6POS 2.54MM	Molex / 22-28-4060
J2, J4–J6	Terminal Block, 3.50mm	Weidmuller / 1604490000
J3	2-pin Terminal Block	Wurth Electronics / 691709710302
L1	Inductor 10uH, 4.5A	Vishay Dale / IHLP2525EZER100M01

Designator	**Description**	**Manufacturer / Part Number**
P1	2-pin Header	Wurth Electronics / 691321100002
R1–R14	$100\text{k}\Omega, 1/16W, 0402$	Yageo / RC0402JR-07100KL
R9	$1\text{k}\Omega, 1\%, 0805$	Yageo / RC0805FR-071KL
R12	$3.3\text{k}\Omega, 1\%, 0805$	Vishay / CRCW08053K30FKEA
R15, R17	$0.51\Omega, 1\%, 2W, 2512$	Stackpole / CSRN2512FTR510
R16	$1\text{M}\Omega, 5\%, 0603$	Panasonic / ERJ-3GEYJ105V
R18	$2.2\text{k}\Omega, 1\%, 0603$	Vishay / CRCW06032K20FKEAHP
R19	$5.1\text{k}\Omega, 1\%, 0805$	Vishay / CRCW08055K10FKEA
R20	$10\text{k}\Omega, 1\%, 0805$	Yageo / RC0805FR-0710KL
R21, R22	$0.062\Omega, 1\%, 1W, 2512$	Rohm / MCR100JZHFSR062
R23	$100\text{k}\Omega, 1\%, 1206$	Bourns / CR1206-FX-1003ELF
R24	$11\text{k}\Omega, 1\%, 1206$	Vishay / CRCW120611K0FKEA
R25, R27	$120\Omega, 1\%, 1206$	Vishay / CRCW1206120RFKEA
R26	$56\Omega, 5\%, 0603$	Vishay Dale / CRCW060356R0JNEA
R28, R32	$1\text{k}\Omega, 1\%, 1206$	Yageo / RC1206FR-071KL
R29, R33	$100\text{m}\Omega, 1\%, 1206$	Vishay Dale / WSL1206R1000FEA
R30, R34	$33\Omega, 1\%, 1206$	Panasonic / ERJ-8ENF33R0V
R31	$0.22\Omega, 1\%, 1206$	Panasonic / ERJ-8RQFR22V
SW1	Tactile Switch SPST-NO, 0.05A 24V	TE Connectivity / 3-1825910-1
TP1–TP3	Test Point, Orange, THD	Keystone / 5003
U1	Piccolo Microcontroller, 80-pin HTQFP	TI / TMS320F28069PFPS
U2	Buck Regulator 3A, TSOT-23-6	TI / TPS54302DDCR

Designator	Description	Manufacturer / Part Number
U3	1A Linear Regulator, 16V, SOT-223	TI / TLV76133DCYR
U4	500mA LDO Regulator, SOIC-8	Analog Devices / LT1763CS8-5TRPBF
U6	Line Receiver, 16-Pin SOIC	TI / AM26LS32ACDR
U9	Precision Voltage Ref, 8-Pin SOIC	TI / REF5045AID
U10	Rail-to-Rail Op Amp, SOIC-8	TI / OPA2350UA/2K5
U11	Dual Op Amp, SOIC-8	TI / OPA2836IDR

Table 1: Full Bill of Materials (BOM)

Component Designator	Price (USD)
C1, C2	0.20
C3	0.10
C4, C12, C27, C28	0.38
C5	0.10
C6	0.10
C7	0.60
C8	1.23
C9, C31, C32, C38	0.14
C10	0.53
C11, C33, C37, C39, C41–C43	0.46
C13–C26	0.56
C29, C30, C35, C36	0.64
C34, C40	0.76
DS1	0.28
FB2	0.10
J1	0.12
J2, J4–J6	8.32
J3	2.68
L1	1.72
P1	0.40
R1–R14	0.07
R9	0.10
R12	0.03
R15, R17	0.74
R16	0.10
R18	0.02
R19	0.02
R20	0.10

Component Designator	Price (USD)
R21, R22	0.02
R23	0.01
R24	0.02
R25, R27	0.03
R26	0.03
R28, R32	0.20
R29, R33	0.46
R30, R34	0.32
R31	0.22
SW1	0.08
TP1–TP3	0.84
U1	18.05
U2	0.80
U3	0.41
U4	6.71
U6	0.55
U9	4.00
U10	4.54
U11	3.82
Total Component Cost	**58.58**

Table 2: Component Prices and Total Cost

3.3 PCB Layer Stackup

#	Name	Material	Type	Weight	Thickness	Dk
	Top Overlay		Overlay			
	Top Solder	Solder Resist	Solder Mask		0.0127mm	3.8
1	Top Layer		Signal	1oz	0.035mm	
	Dielectric 1	2313	Prepreg		0.1mm	4.05
2	Mid Layer 1		Signal	1/2oz	0.0175mm	
	Core	FR-4	Core		1.265mm	4.5
3	Mid Layer 2		Signal	1/2oz	0.0175mm	
	Dielectric 2	2313	Prepreg		0.1mm	4.05
4	Bottom Layer		Signal	1oz	0.035mm	
	Bottom Solder	Solder Resist	Solder Mask		0.0127mm	3.8

Figure 2: PCB Layer Stackup

3.4 PCB Layout

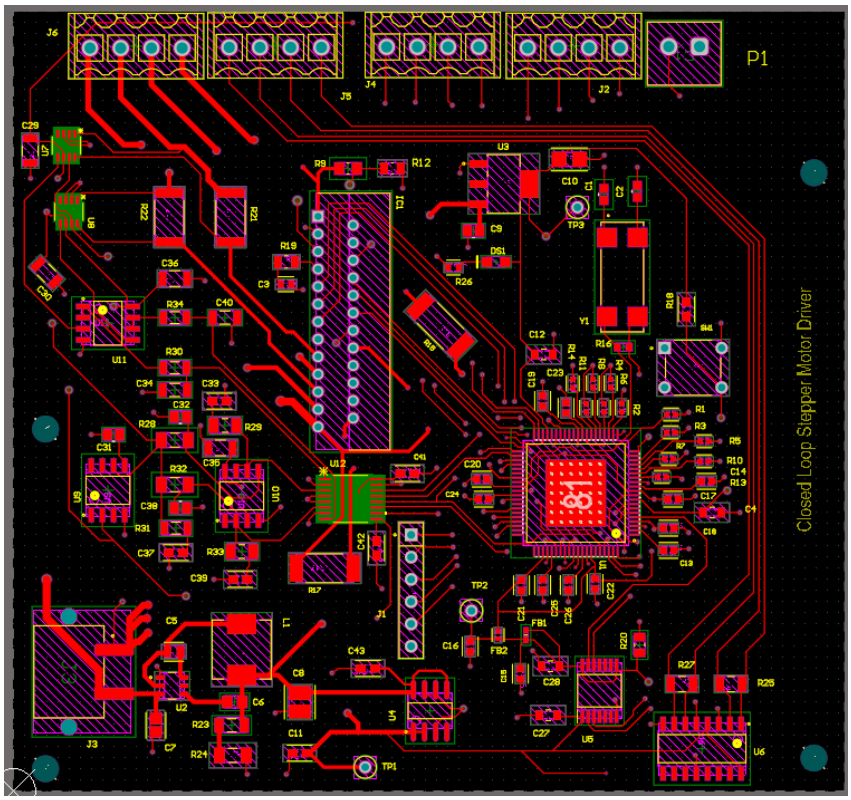


Figure 3: Component Layout

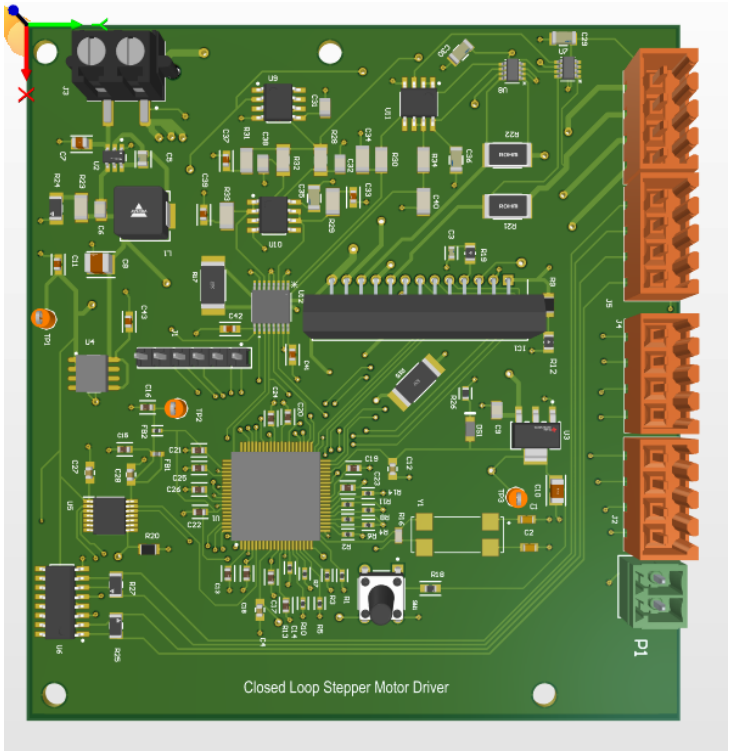


Figure 4: 3D view

PCB design documents can be accessed from this link: https://github.com/Rashane02/Closed-Loop-Stepper-Motor

3.5 Enclosure Design

External View

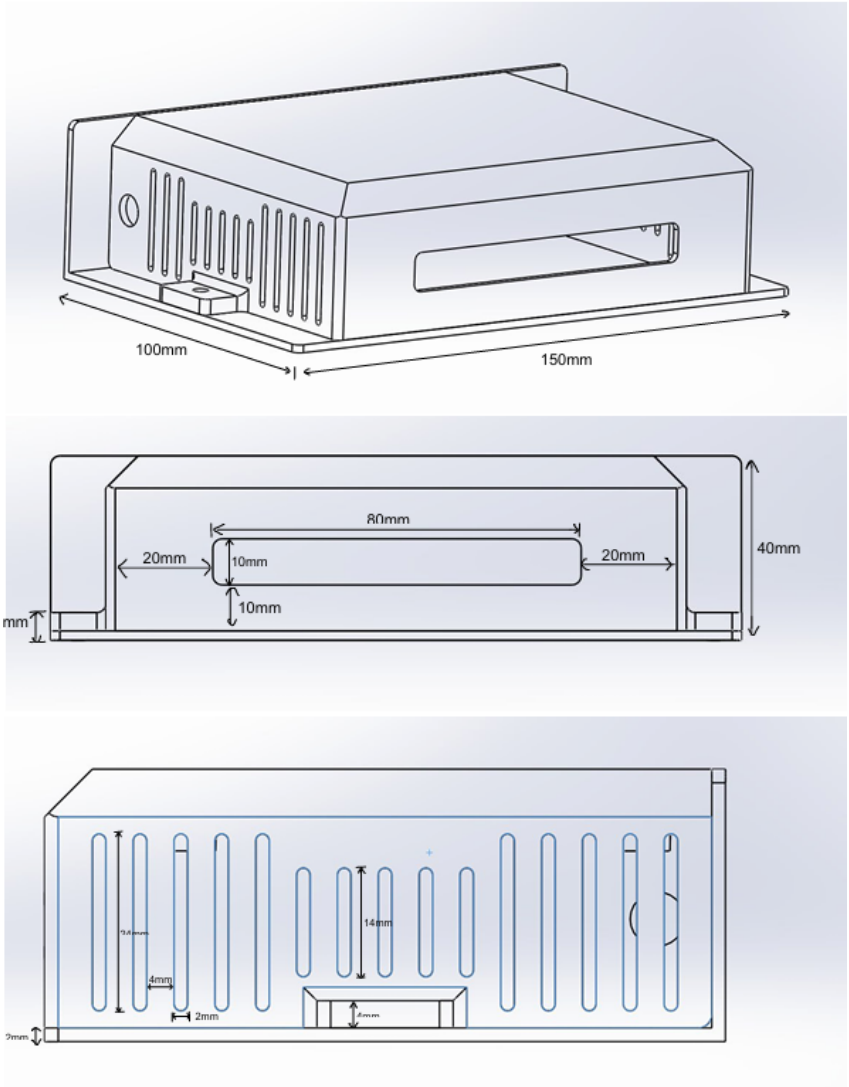


Figure 5: External Parameters

Internal View

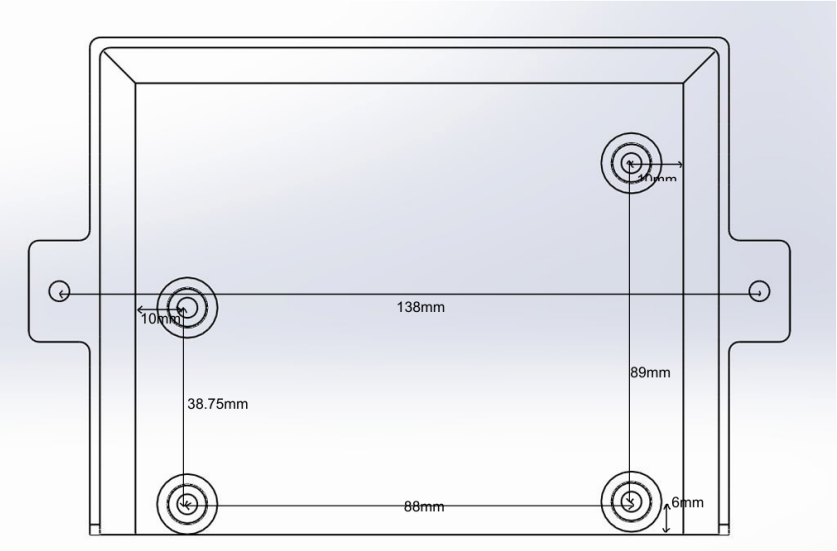


Figure 6: Internal Parameters

3D View

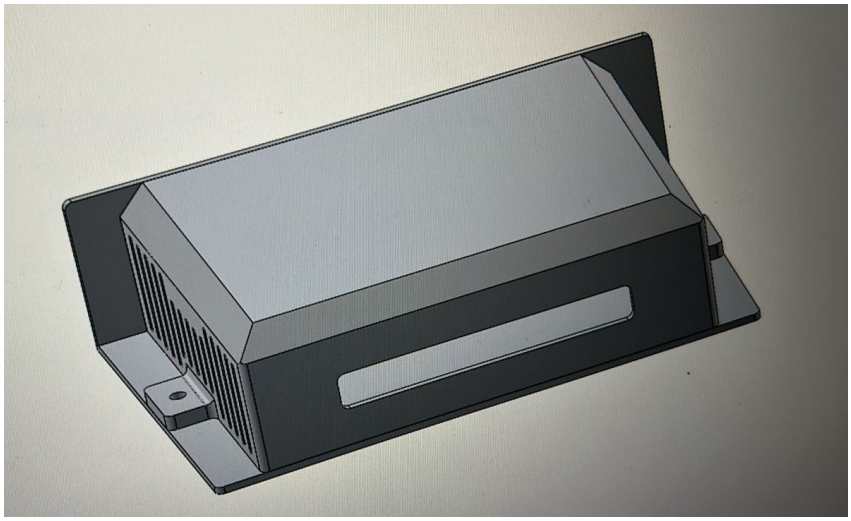
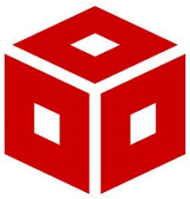
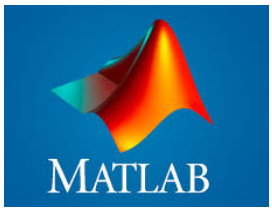


Figure 7: 3D View

Enclosure is manufactured as two parts. The bottom part is made out of metal while the top part is made out of thermoplastic polymer. PCB design documents can be accessed from this link: https://github.com/Rashane02/Closed-Loop-Stepper-Motor

4 Software Development





Software development tools used:

- CCS Studio by Texas Instruments
- MATLAB

Programming languages used: C/C++

Code used for programming can be accessed from the link below:
https://github.com/Rashane02/Closed-Loop-Stepper-Motor

5 Estimated Cost Per Unit

Category	**Cost (USD)**
Component Cost (refer table 2)	58.58
PCB Printing Cost	1.40
Enclosure Cost	10.00
Other Costs	10.00
Total Estimated Cost per Unit	**79.98**

Table 3: Estimated Cost per Unit (USD)

6 Component Datasheets

- TMS320F28069PFPS: https://www.ti.com/lit/gpn/TMS320F28069
- TBH67H400A: https://www.micro-semiconductor.nz/datasheet/de-TB67S149FTG-EL.pdf
- ADS7853: https://www.ti.com/lit/ds/symlink/ads7853.pdf
- INA241B: https://www.ti.com/lit/gpn/INA241B
- REF5045: https://www.ti.com/lit/gpn/ref50
- TLV76133DCYR: https://www.ti.com/lit/gpn/TLV761
- TPS54302DDCR: https://www.ti.com/lit/ds/symlink/tps54302.pdf
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