

# Amulet Motion Controller

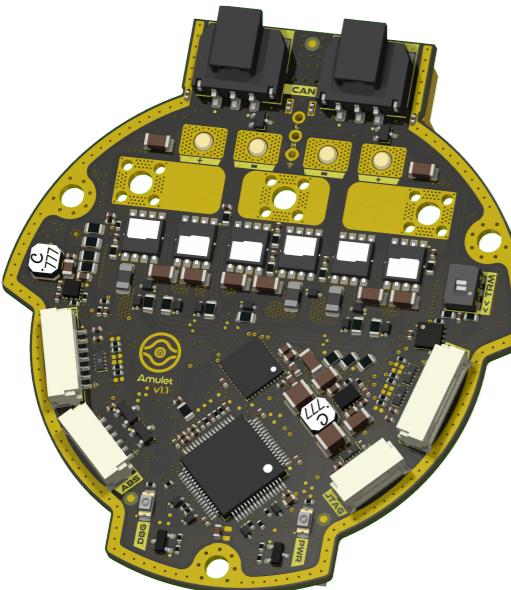
Variant: CHECKED

2025-01-18

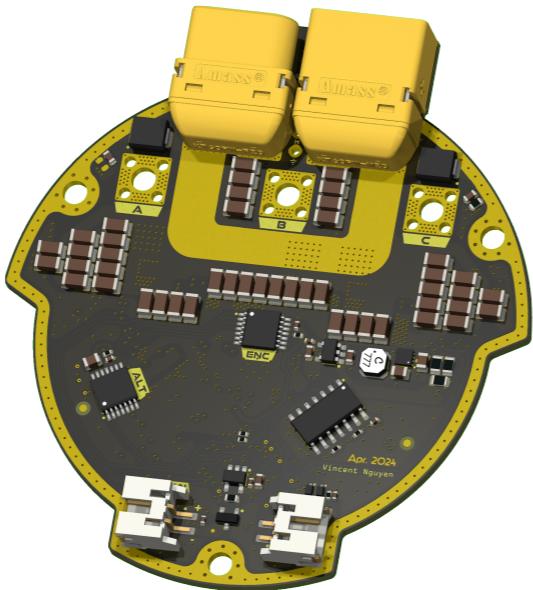
Rev 1.1.1+ (Unreleased)

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## TOP VIEW



## BOTTOM VIEW



## DESIGN CONSIDERATIONS

DESIGN NOTE:  
Example text for informational design notes.

DESIGN NOTE:  
Example text for debug notes.

DESIGN NOTE:  
Example text for cautionary design notes.

DESIGN NOTE:  
Example text for critical design notes.

LAYOUT NOTE:  
Example text for critical layout guidelines.

## NOTES

Schematic based off Josh Pieper's moteus controllers.

Not fitted components are marked as

DRAFT - Very early stage of schematic, ignore details.

PRELIMINARY - Close to final schematic.

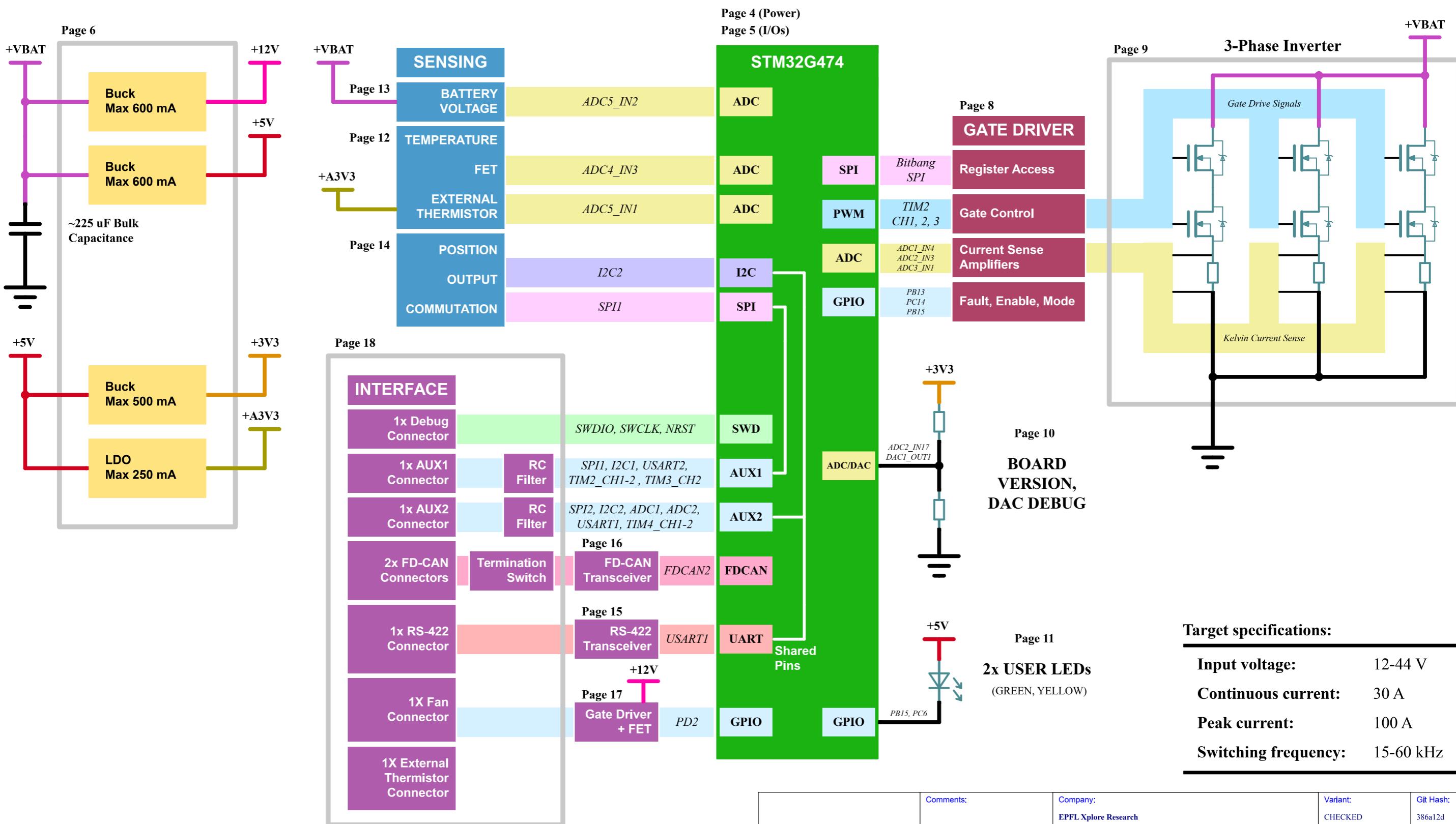
CHECKED - There shouldn't be any mistakes. Contact the engineer if you find any.

RELEASED - A board with this schematic has been sent to production.

Date: 18-Jan-2025

	Comments:	Company: EPFL Xplore Research	Variant: CHECKED	Git Hash: 386a12d
	Board Name: <b>Amulet Motion Controller</b>		Project Name: <b>Chienpanzé</b>	
	Sheet Title: Cover Page	File Name: amulet_controller.kicad_sch	Designer: Vincent Nguyen	Date: 2024-04-13
	Sheet Path: /		Reviewer:	Revision: 1.1.1+ (Unreleased)
			Size: <b>A3</b>	Sheet: <b>1 of 21</b>

# [2] Block Diagram

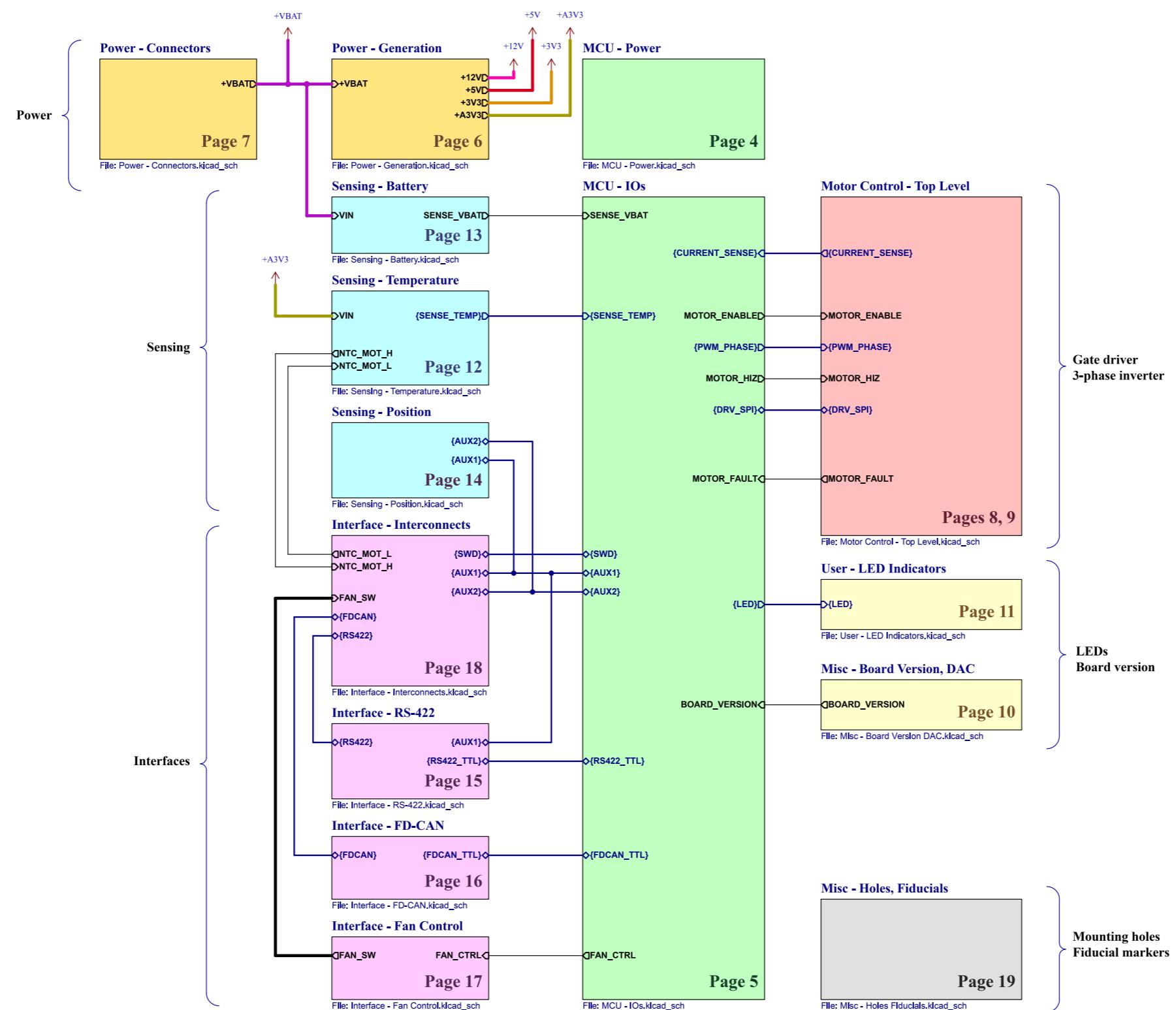


## Target specifications:

Input voltage:	12-44 V
Continuous current:	30 A
Peak current:	100 A
Switching frequency:	15-60 kHz

Comments:	Company: EPFL Xplore Research	Variant:	
		Checked	Git Hash: 386a12d
Board Name:	<b>Amulet Motion Controller</b>		Project Name: <b>Chienpanzé</b>
Sheet Title:	File Name:	Designer:	Date:
Block Diagram	Block Diagram.kicad_sch	Vincent Nguyen	2024-04-13
Sheet Path:	Reviewer:	Size:	Sheet:
/Block Diagram/		A3	2 of 21

# [3] Project Architecture



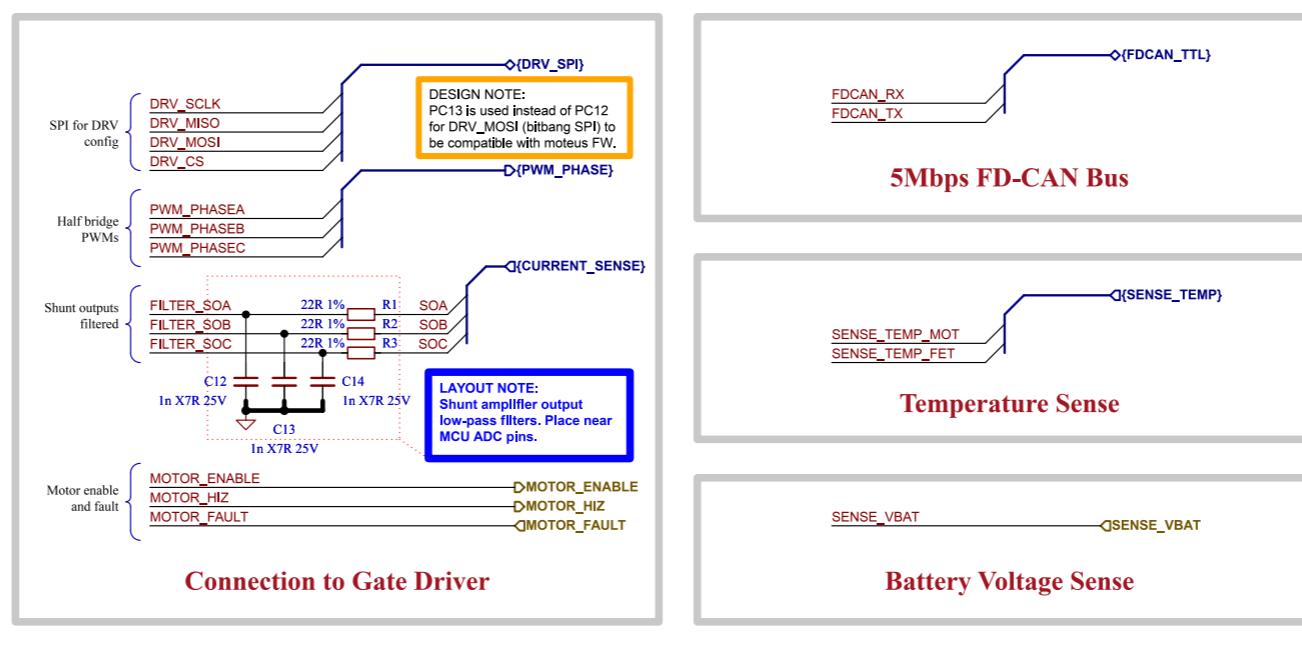
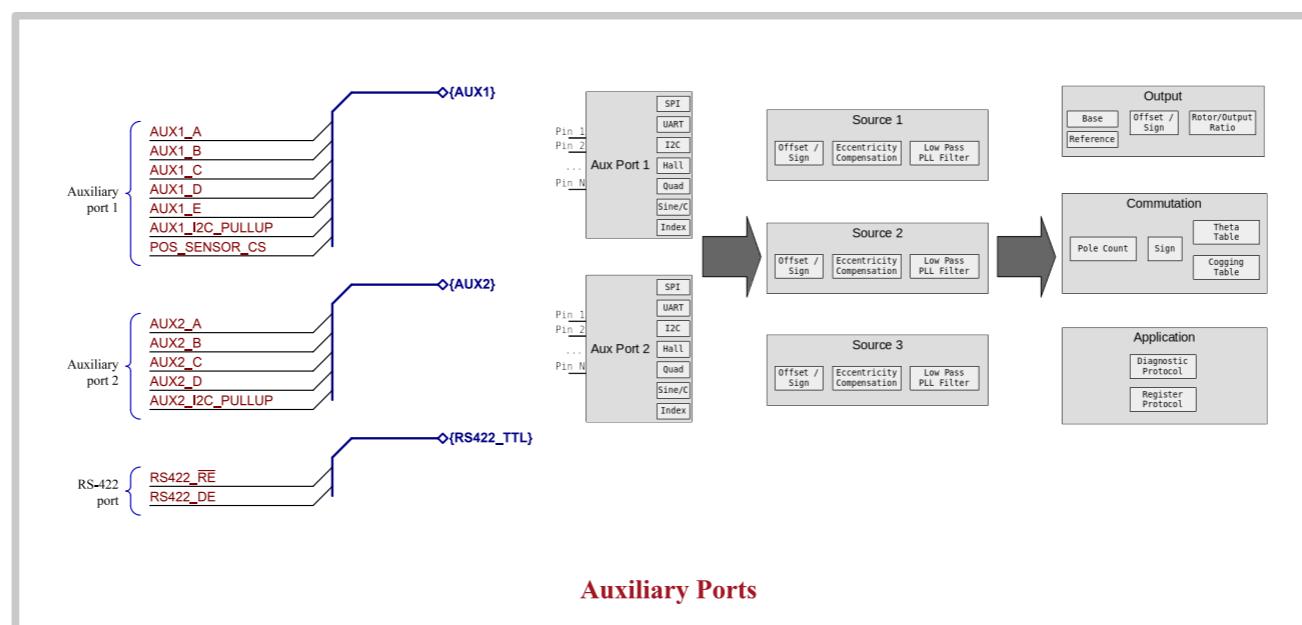
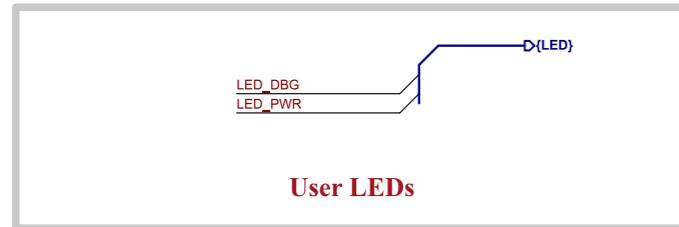
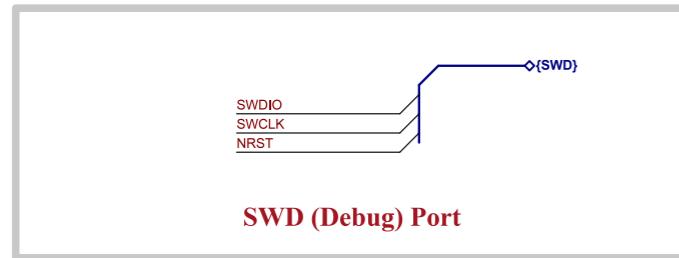
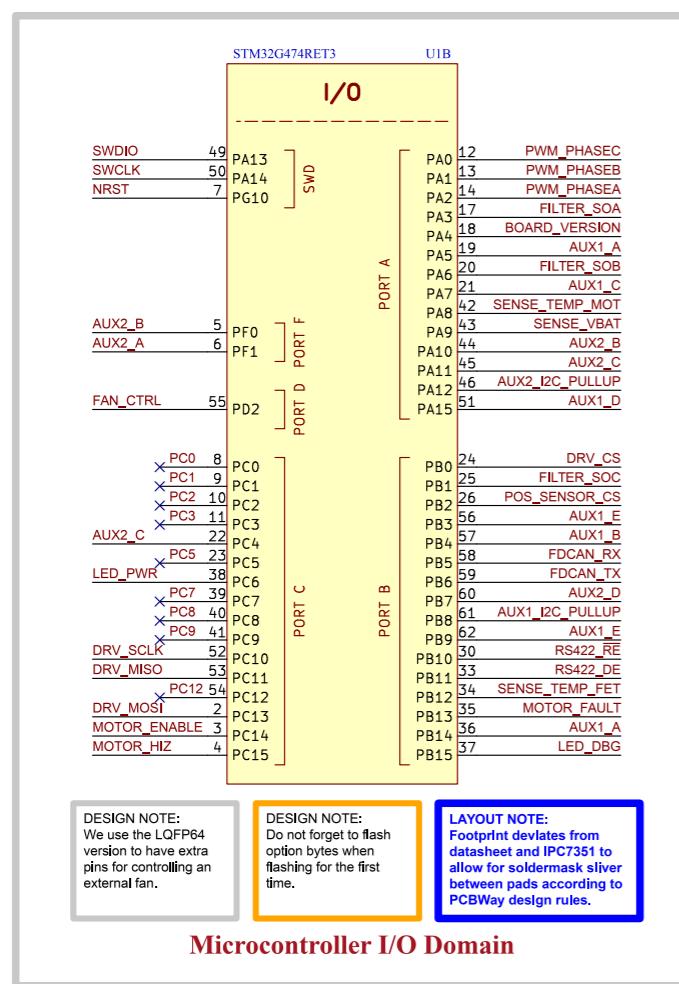
	Comments:	Company: EPFL Xplore Research	Variant: CHECKED	Git Hash: 386a12d
	Board Name: <b>Amulet Motion Controller</b>	Project Name: <b>Chienpanzé</b>		
	Sheet Title: Project Architecture	File Name: Project Architecture.kicad_sch	Designer: Vincent Nguyen	Date: 2023-12-22
	Sheet Path: /Project Architecture/		Reviewer:	Revision: 1.1.1+ (Unreleased)
			Size: <b>A3</b>	Sheet: <b>3 of 21</b>

# [4] MCU - Power



	Comments: AN5346 STM32G474 Datasheet p.81 J. Pieper ADC investigation	Company: EPFL Xplore Research	Variant: CHECKED	Git Hash: 386a12d
	<b>Board Name:</b> <b>Amulet Motion Controller</b>			<b>Project Name:</b> <b>Chienpanzé</b>
	Sheet Title: MCU - Power	File Name: MCU - Power.kicad_sch	Designer: Vincent Nguyen	Date: 2023-12-18      Revision: 1.1.1+ (Unreleased)
	Sheet Path: /Project Architecture/MCU - Power/		Reviewer:	Size: <b>A4</b> Sheet: <b>4</b> of 21

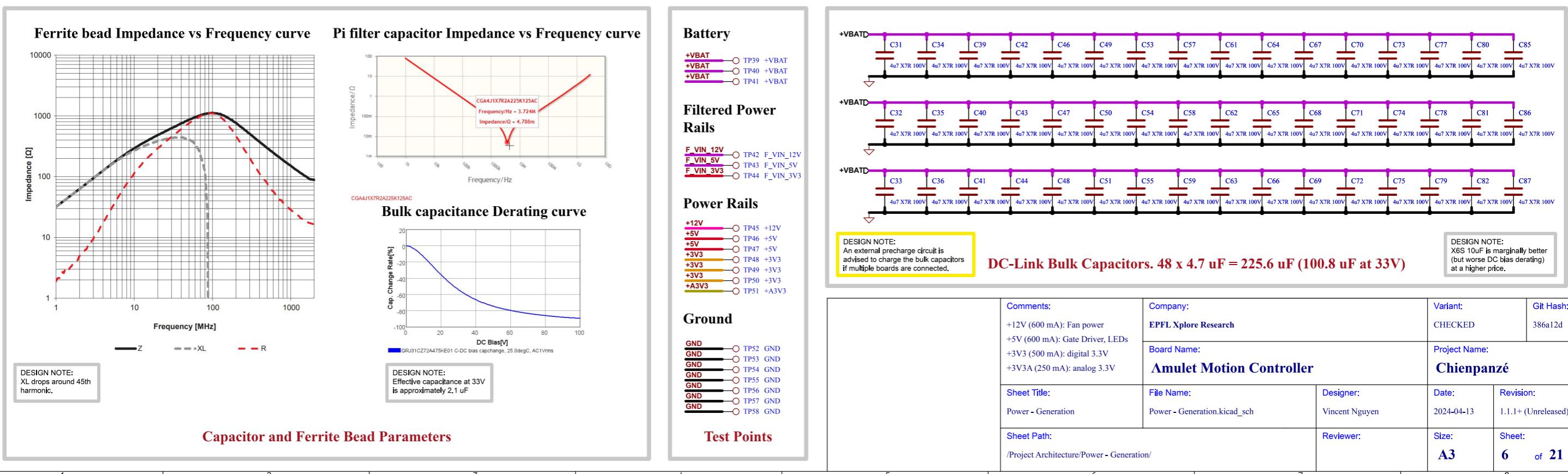
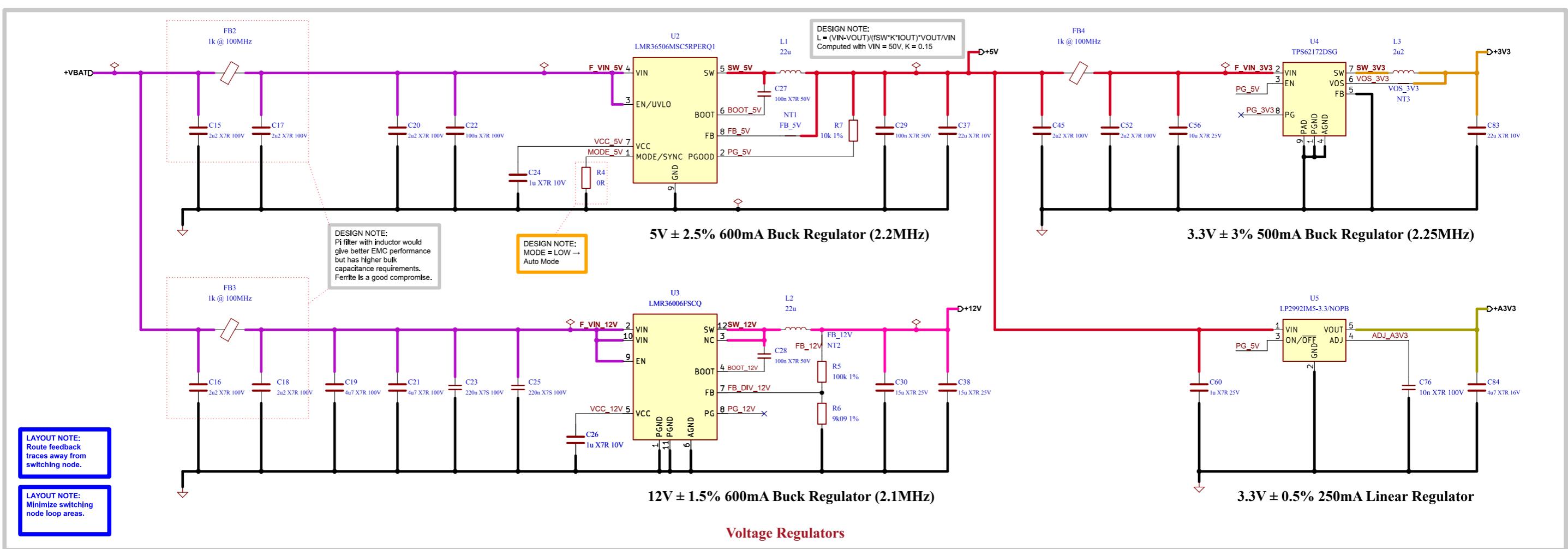
# [5] MCU - I/Os



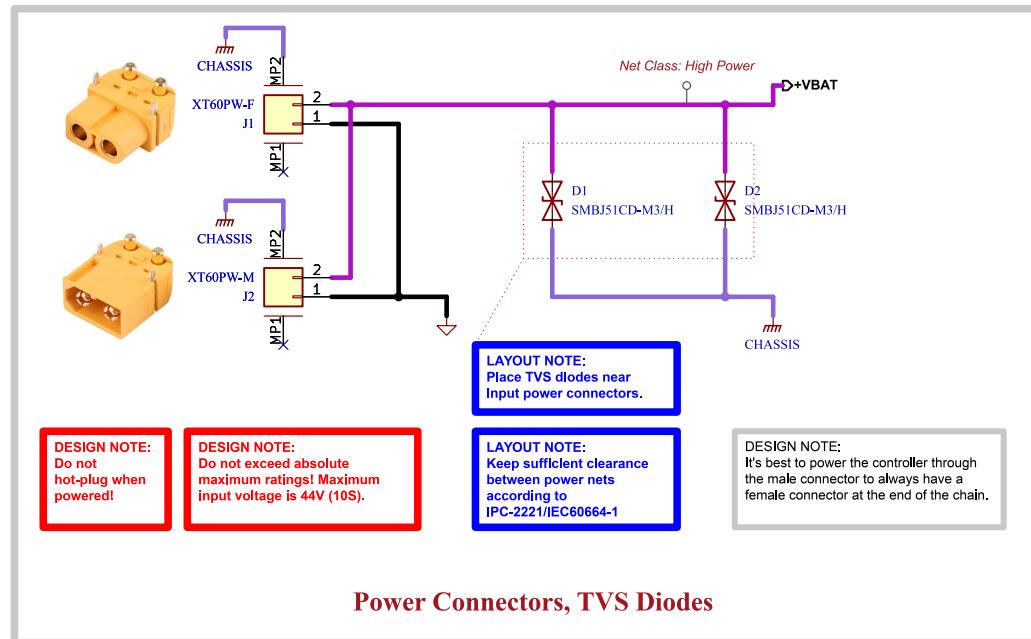
<b>Gate Driver</b>	
MOTOR_ENABLE	TP1
MOTOR_HIZ	TP2
MOTOR_FAULT	TP3
DRV_SCLK	TP4
DRV_MISO	TP5
DRV_MOSI	TP6
DRV_CS	TP7
PWM_PHASEA	TP8
PWM_PHASEB	TP9
PWM_PHASEC	TP10
SOA	TP11
SOB	TP12
SOC	TP13
<b>Debug</b>	
SWDIO	TP14
SWCLK	TP15
NRST	TP16
<b>Auxiliary pins 1</b>	
AUX1_A	TP17
AUX1_B	TP18
AUX1_C	TP19
AUX1_D	TP20
AUX1_E	TP21
AUX1_I2C_PULLUP	TP22
POS_SENSOR_CS	TP23
<b>Auxiliary pins 2</b>	
AUX2_A	TP24
AUX2_B	TP25
AUX2_C	TP26
AUX2_D	TP27
AUX2_I2C_PULLUP	TP28
<b>5Mbps FD-CAN Bus</b>	
FDCAN_RX	
FDCAN_TX	
<b>RS-422</b>	
RS422_RE	TP29
RS422_DE	TP30
<b>LEDs</b>	
LED_DBG	TP31
LED_PWR	TP32
<b>FD-CAN</b>	
FDCAN_RX	TP33
FDCAN_TX	TP34
<b>Fan</b>	
FAN_CTRL	TP35
<b>Sense</b>	
SENSE_TEMP_MOT	TP36
SENSE_TEMP_FET	TP37
SENSE_VBAT	TP38
<b>Test Points</b>	

Comments: References: Flexible I/O worked examples Flexible I/O source configuration	Company: EPFL Xplore Research		Variant: CHECKED	Git Hash: 386a12d
	Board Name: <b>Amulet Motion Controller</b>			
Sheet Title: MCU - I/Os	File Name: MCU - IOs.kicad_sch		Designer: Vincent Nguyen	Date: 2023-12-20
Sheet Path: /Project Architecture/MCU - IOs/	Reviewer:		Revision: 1.1.1+ (Unreleased)	
	Size: <b>A3</b>	Sheet: <b>5 of 21</b>		

# [6] Power - Generation

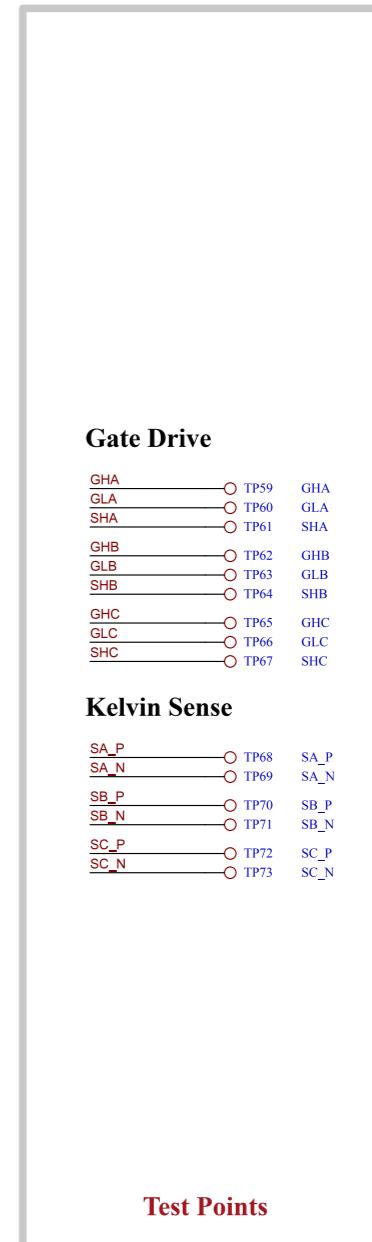
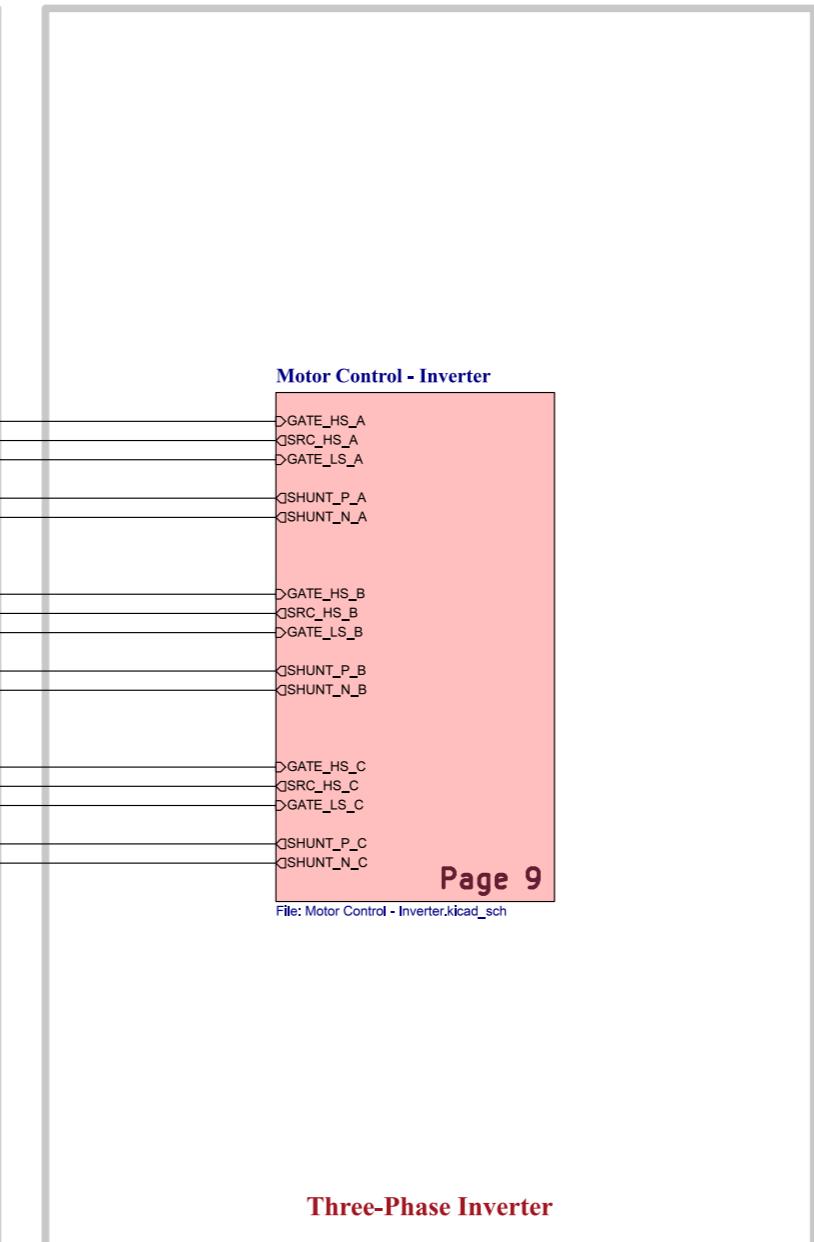
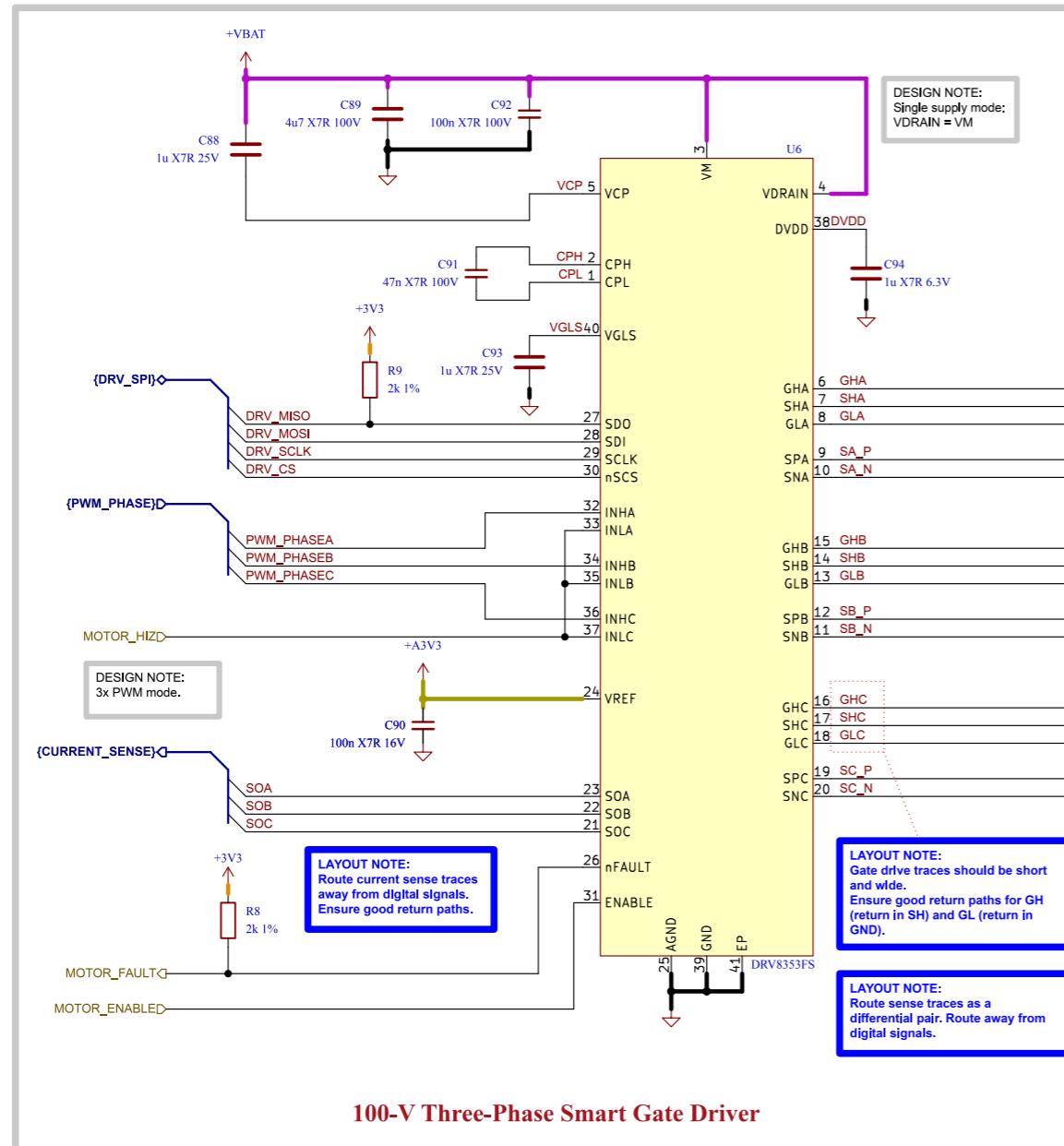


# [7] Power - Connectors



	Comments:	Company: EPFL Xplore Research	Variant: CHECKED	Git Hash: 386a12d
	<b>Board Name:</b> <b>Amulet Motion Controller</b>			<b>Project Name:</b> <b>Chienpanzé</b>
	Sheet Title: Power - Connectors	File Name: Power - Connectors.kicad_sch	Designer: Vincent Nguyen	Date: 2023-12-31    Revision: 1.1.1+ (Unreleased)
	Sheet Path: <a href="#">/Project Architecture/Power - Connectors/</a>		Reviewer:	Size: <b>A4</b> Sheet: <b>7</b> of <b>21</b>

# [8] Motor Control - Top Level



	Comments:	Company:	Variant:	Git Hash:
		EPFL Xplore Research	CHECKED	386a12d
	Board Name:	Project Name:		
	<b>Amulet Motion Controller</b>	<b>Chienpanzé</b>		
	Sheet Title:	File Name:	Designer:	Date: Revision:
	Motor Control - Top Level	Motor Control - Top Level.kicad_sch	Vincent Nguyen	2023-12-20 1.1.1+ (Unreleased)
	Sheet Path:	/Project Architecture/Motor Control - Top Level/	Reviewer:	Size: Sheet:
				A3 8 of 21

# [9] Motor Control - Inverter



**LAYOUT NOTE:**  
High current traces must be carefully designed. Ensure ground return path does not cross sensitive parts of the board. Use multiple planes for higher current carrying capacity.

**LAYOUT NOTE:**  
Keep sufficient clearance between power nets according to IPC-2221/IEC60664-1.

**DESIGN NOTE:**  
A gate drive current that is too large can damage the FETs!

**Comments:**  
System Design Considerations for High-Power Motor Driver Applications  
Best Practices for Board Layout of Motor Drivers  
Proper RC Snubber Design for Motor Drivers

**Sheet Title:**  
Motor Control - Inverter

**Sheet Path:**  
/Project Architecture/Motor Control - Top Level/Motor Control - Inverter/

**Company:**  
EPFL Xplore Research

**Board Name:**  
**Amulet Motion Controller**

**File Name:**  
Motor Control - Inverter.kicad\_sch

**Designer:**  
Vincent Nguyen

**Reviewer:**

**Date:** 2024-01-25    **Revision:** 1.1.1+ (Unreleased)

**Variant:**  
CHECKED

**Git Hash:**  
386a12d

**Project Name:**  
**Chienpanzé**

**Size:**

**Sheet:**  
**A4**    **of 21**

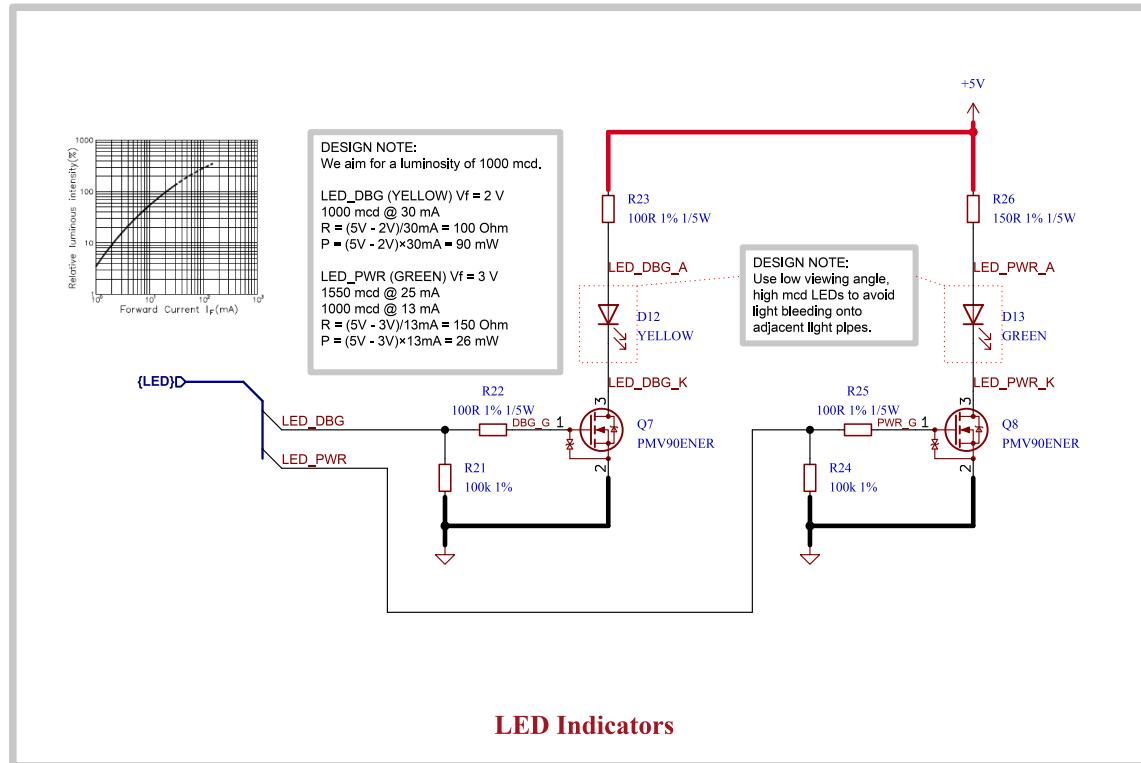
# [10] Misc - Board Version, DAC



	Comments:	Company: EPFL Xplore Research		Variant: CHECKED	Git Hash: 386a12d
D		Board Name: <b>Amulet Motion Controller</b>			Project Name: <b>Chienpanzé</b>
	Sheet Title: Misc - Board Version, DAC	File Name: Misc - Board Version DAC.kicad_sch	Designer: Vincent Nguyen	Date: 2024-04-13	Revision: 1.1.1+ (Unreleased)
	Sheet Path: <a href="#">/Project Architecture/Misc - Board Version, DAC/</a>			Reviewer:	Size: <b>A4</b> Sheet: <b>10</b> of <b>21</b>

# [11] User - LED Indicators

A



B

C

D

A

B

C

D

	Comments:  <b>User - LED Indicators</b>	Company:  <b>EPFL Xplore Research</b>	Variant:  <b>CHECKED</b>	Git Hash:  <b>386a12d</b>
	<b>Board Name:</b>  <b>Amulet Motion Controller</b>			<b>Project Name:</b>  <b>Chienpanzé</b>
	Sheet Title:  <b>User - LED Indicators</b>	File Name:  <b>User - LED Indicators.kicad_sch</b>	Designer:  <b>Vincent Nguyen</b>	Date:  <b>2023-12-19</b>
	Sheet Path:  <b>/Project Architecture/User - LED Indicators/</b>		Reviewer:  <b></b>	Size:  <b>A4</b>
			Sheet:  <b>11 of 21</b>	

# [12] Sensing - Temperature

A

B

C

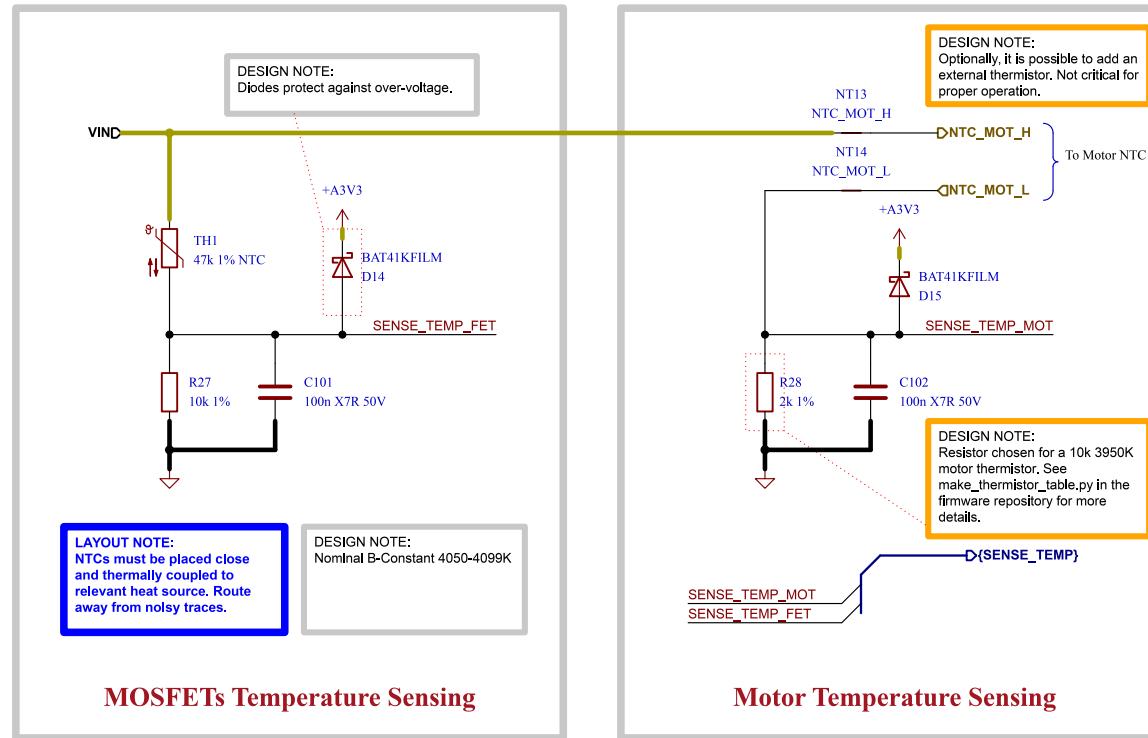
D

A

B

C

D



	Comments:	Company: EPFL Xplore Research	Variant: CHECKED	Git Hash: 386a12d
	Board Name: <b>Amulet Motion Controller</b>	Project Name: <b>Chienpanzé</b>		
	Sheet Title: Sensing - Temperature	File Name: Sensing - Temperature.kicad_sch	Designer: Vincent Nguyen	Date: 2024-04-13    Revision: 1.1.1+ (Unreleased)
	Sheet Path: /Project Architecture/Sensing - Temperature/		Reviewer:	Size: <b>A4</b> Sheet: <b>12 of 21</b>

# [13] Sensing - Battery

A

A

B

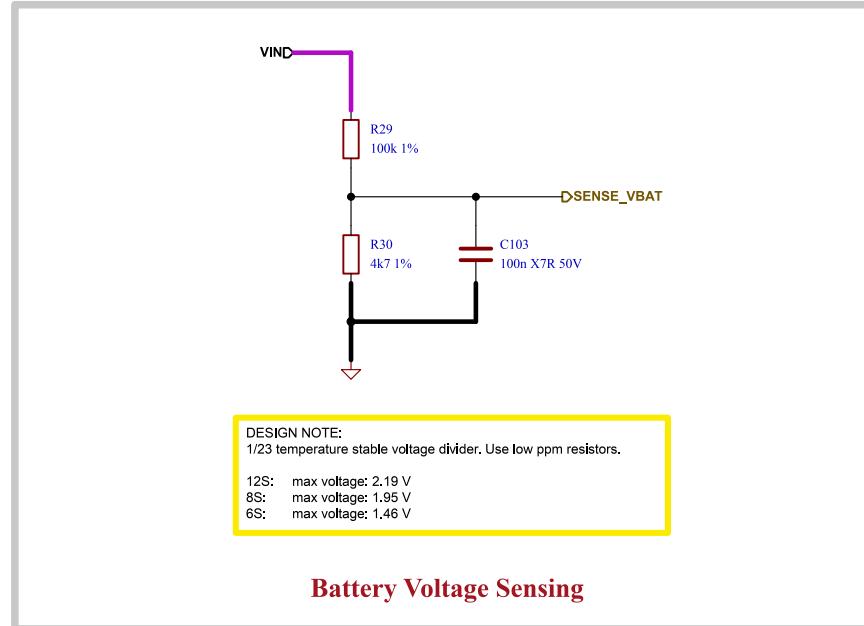
B

C

C

D

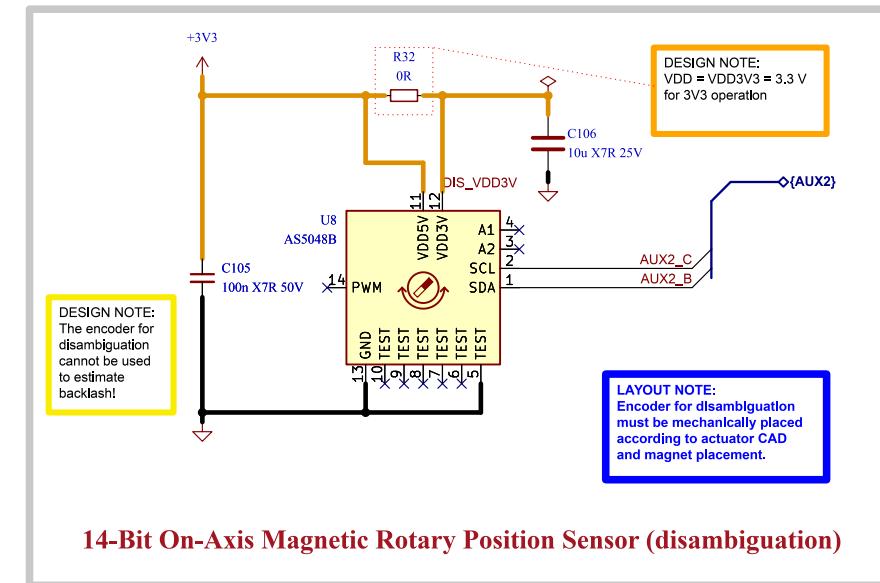
D



	Comments:	Company: EPFL Xplore Research	Variant: CHECKED	Git Hash: 386a12d
	Board Name: <b>Amulet Motion Controller</b>			Project Name: <b>Chienpanzé</b>
	Sheet Title: Sensing - Battery	File Name: Sensing - Battery.kicad_sch	Designer: Vincent Nguyen	Date: 2023-10-14      Revision: 1.1.1+ (Unreleased)
	Sheet Path: /Project Architecture/Sensing - Battery/		Reviewer:	Size: <b>A4</b> Sheet: <b>13</b> of <b>21</b>

# [14] Sensing - Position

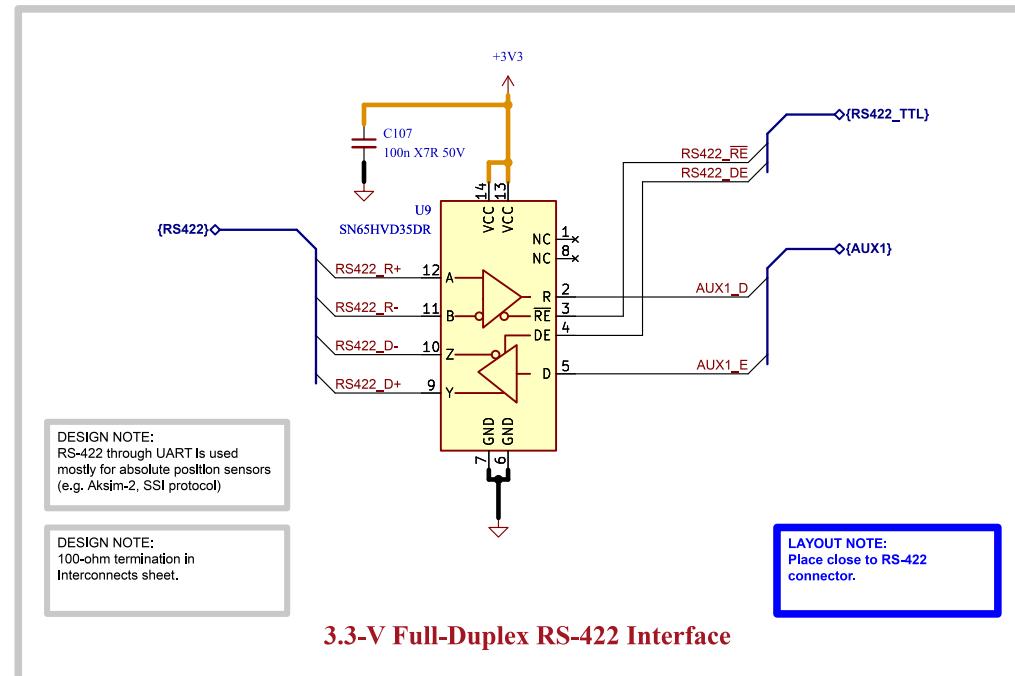
A



**DESIGN NOTE:**  
AS5047P senses magnet mounted on planetary sun gear, for commutation.  
AS5048B senses magnet mounted on shaft with same reduction factor as planetary gearbox for disambiguation.

Comments:	Company: EPFL Xplore Research		Variant: CHECKED	Git Hash: 386a12d
Board Name:	<b>Amulet Motion Controller</b>			Project Name: <b>Chienpanzé</b>
Sheet Title:	File Name: Sensing - Position.kicad_sch	Designer: Vincent Nguyen	Date: 2023-10-14	Revision: 1.1.1+ (Unreleased)
Sheet Path:	/Project Architecture/Sensing - Position/		Reviewer:	Size: <b>A4</b> Sheet: <b>14</b> of <b>21</b>

# [15] Interface - RS-422



	Comments:	Company: EPFL Xplore Research	Variant: CHECKED	Git Hash: 386a12d
	Board Name: <b>Amulette Motion Controller</b>	Project Name: <b>Chienpanzé</b>		
	Sheet Title: Interface - RS-422	File Name: Interface - RS-422.kicad_sch	Designer: Vincent Nguyen	Date: 2023-10-15    Revision: 1.1.1+ (Unreleased)
	Sheet Path: /Project Architecture/Interface - RS-422/		Reviewer:	Size: <b>A4</b> Sheet: <b>15</b> of <b>21</b>

# [16] Interface - FD-CAN



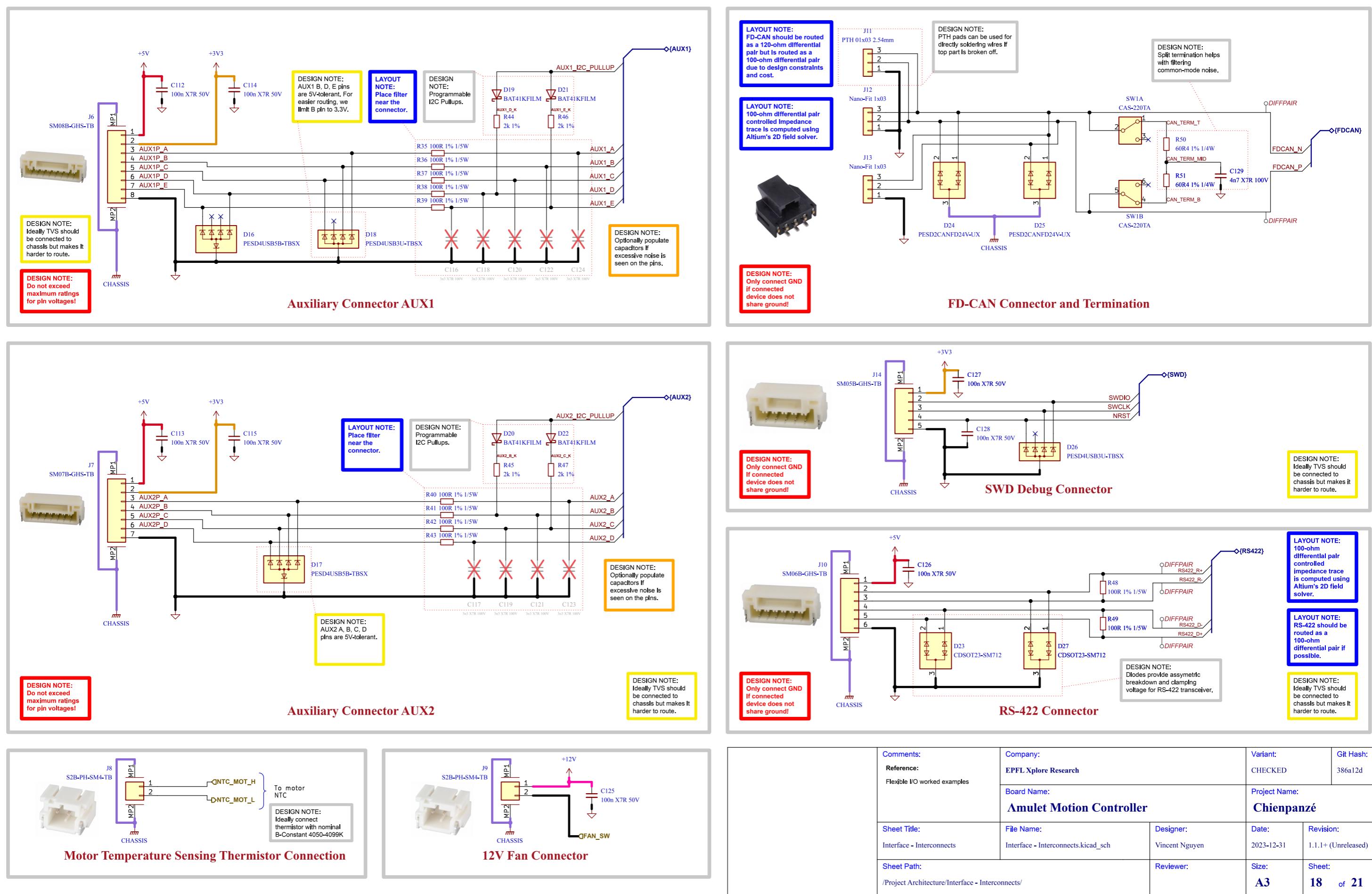
	Comments:	Company: EPFL Xplore Research	Variant: CHECKED	Git Hash: 386a12d
	Board Name: <b>Amulet Motion Controller</b>			Project Name: <b>Chienpanzé</b>
	Sheet Title: Interface - FD-CAN	File Name: Interface - FD-CAN.kicad_sch	Designer: Vincent Nguyen	Date: 2023-10-15    Revision: 1.1.1+ (Unreleased)
	Sheet Path: /Project Architecture/Interface - FD-CAN/		Reviewer:	Size: <b>A4</b> Sheet: <b>16</b> of <b>21</b>

# [17] Interface - Fan Control



	Comments:	Company: EPFL Xplore Research	Variant: CHECKED	Git Hash: 386a12d
	Board Name: <b>Amulet Motion Controller</b>			Project Name: <b>Chienpanzé</b>
	Sheet Title: Interface - Fan Control	File Name: Interface - Fan Control.kicad_sch	Designer: Vincent Nguyen	Date: 2023-11-19      Revision: 1.1.1+ (Unreleased)
	Sheet Path: <a href="#">/Project Architecture/Interface - Fan Control/</a>		Reviewer:	Size: <b>A4</b> Sheet: <b>17</b> of <b>21</b>

# [18] Interface - Interconnects



# [19] Misc - Holes, Fiducials

A

A

B

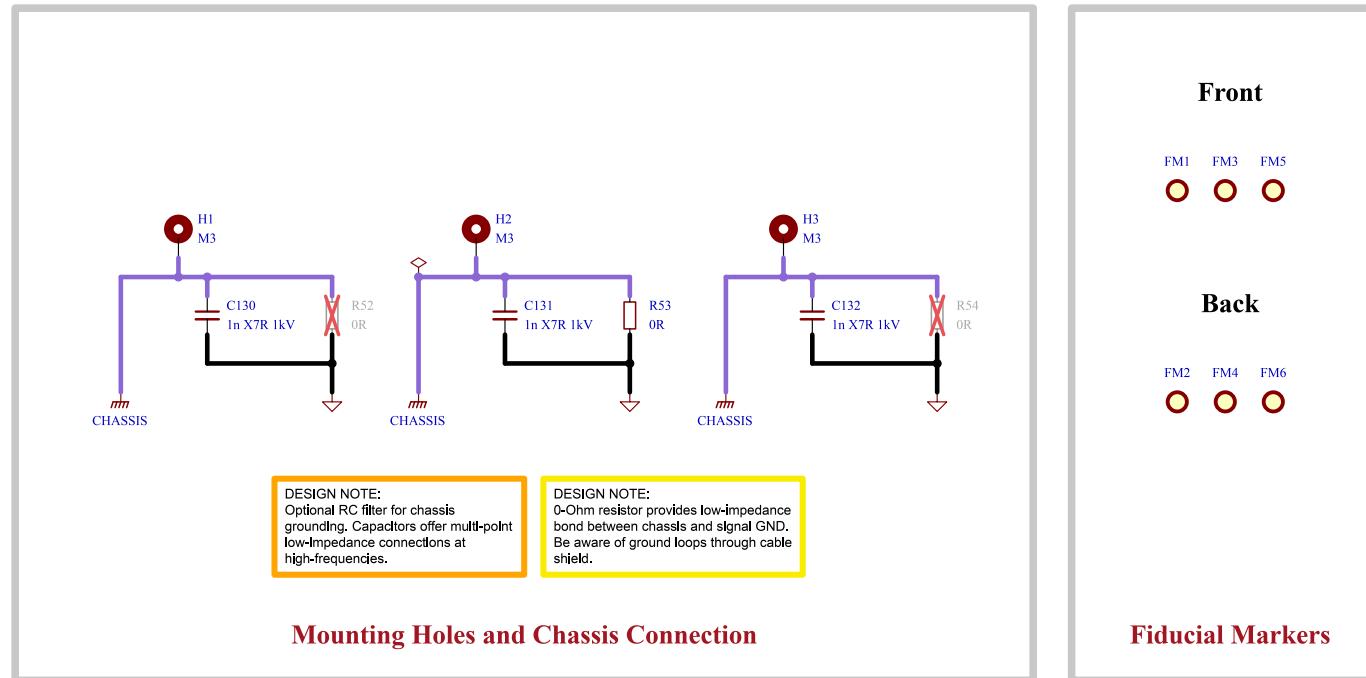
B

C

C

D

D



	Comments:	Company: EPFL Xplore Research	Variant: CHECKED	Git Hash: 386a12d
	Board Name: <b>Amulet Motion Controller</b>	Project Name: <b>Chienpanzé</b>		
	Sheet Title: Misc - Holes, Fiducials	File Name: Misc - Holes Fiducials.kicad_sch	Designer: Vincent Nguyen	Date: 2023-10-22      Revision: 1.1.1+ (Unreleased)
	Sheet Path: /Project Architecture/Misc - Holes, Fiducials/		Reviewer:	Size: <b>A4</b> Sheet: <b>19</b> of <b>21</b>

# [20] Power - Sequencing

A



C

D

	Comments:  <b>Amulet Motion Controller</b>	Company: EPFL Xplore Research		Variant: CHECKED	Git Hash: 386a12d
		Board Name: <b>Amulet Motion Controller</b>		Project Name: <b>Chienpanzé</b>	
		Sheet Title: Power - Sequencing	File Name: Power - Sequencing.kicad_sch	Designer: Vincent Nguyen	Date: 2024-03-12    Revision: 1.1.1+ (Unreleased)
		Sheet Path: <a href="#">/Power - Sequencing/</a>		Reviewer:	Size: <b>A4</b> Sheet: <b>20</b> of 21

# [21] Revision History

A

## Version 1.0.0 - 2023-12-12

- Added**
- TVS protection and termination switch to FD-CAN.
  - Low-side switched 12V 600 mA source for external fan.
  - LDO for analog supply.
  - One TVS diode per power connector.
  - Second on-board I2C magnetic encoder for disambiguation.
  - ESD protection to all interfaces.
  - Over-voltage protection on thermistor ADC inputs.
  - Pi filters to inputs of buck regulators and MCU analog supply.
  - Decoupling caps next to power pins of connectors.

B

## Changed

- CPH-CPL capacitor to 47 nF (gate driver).
- FD-CAN transceiver IC.
- FETs for top cooled variant.
- Input power TVS diode to bidirectional.
- Moved SOx low-pass filter to MCU section.
- PWM\_PHASEA with PWM\_PHASEC on STM32G474 pinout for easier routing.
- RS422 pinout on connector.
- Buck regulators to optimize for low noise.

## Version 1.0.1 - 2024-01-25

- Added**
- Controller target specifications.
  - Credits to moteus on cover page.
  - Optional RC-Snubber to power stage.

## Fixed

- Chassis guard ring to go around the board.
- CAN and power TVS diodes now go to chassis.
- Clearance between nets to respect IEC60664-1 where possible.
- Comment on precharge.
- Power TVS diode reference designator from "U" to "D".

## Changed

- 5V 300 mA buck converter with 600 mA version.
- Chassis-GND capacitor by 1nF 1kV.

## Version 1.0.2 - 2024-03-12

## Changed

- Power sequencing graph according to experimental data.

## Version 1.1.0 - 2024-04-13

## Added

- RC snubber passive values.

## Fixed

- More vias for VBUS and LMR36006 GND pads.
- Board version voltage reference from +3V3 to +A3V3.

## Changed

- Motor thermistor resistor divider to 2kOhm for a 10k 3950K thermistor.

## Version 1.1.1 - 2024-11-26

## Fixed

- Replace non-stocked components.

	Comments:	Company: EPFL Xplore Research	Variant: CHECKED	Git Hash: 386a12d
	Board Name: <b>Amulet Motion Controller</b>			Project Name: <b>Chienpanzé</b>
	Sheet Title: Revision History	File Name: Revision History.kicad_sch	Designer: Vincent Nguyen	Date: 2024-01-03
	Sheet Path: /Revision History/		Reviewer:	Size: <b>A4</b> Sheet: <b>21</b> of <b>21</b>