

# Amulet Motion Controller

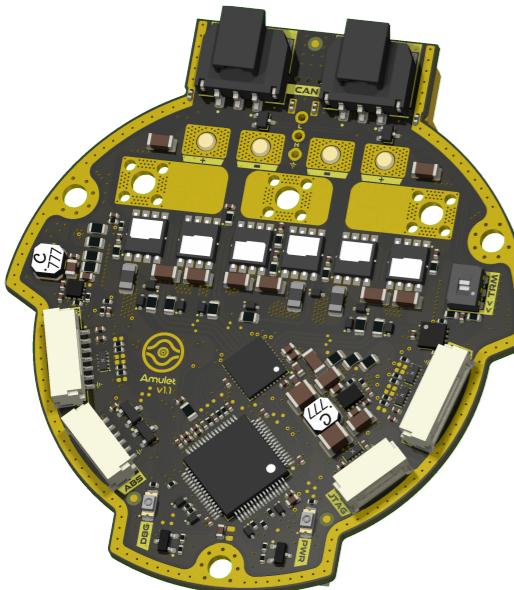
Variant: DRAFT

2024-11-25

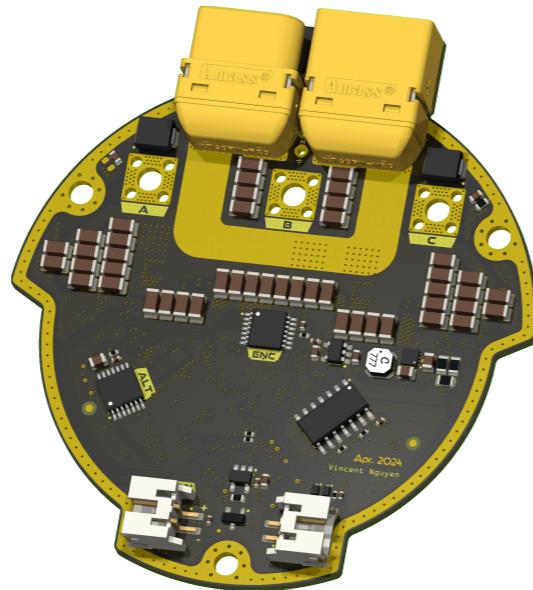
Rev 1.2+ (Unreleased)

Page	Index	Page	Index	Page	Index	Page	Index
1	Cover Page	11	User - LED Indicators	21	Revision History	31	.....
2	Block Diagram	12	Sensing - Temperature	22	.....	32	.....
3	Project Architecture	13	Sensing - Battery	23	.....	33	.....
4	MCU - Power	14	Sensing - Position	24	.....	34	.....
5	MCU - I/Os	15	Interface - RS-422	25	.....	35	.....
6	Power - Generation	16	Interface - FD-CAN	26	.....	36	.....
7	Power - Connectors	17	Interface - Fan Control	27	.....	37	.....
8	Motor Control - Top Level	18	Interface - Interconnects	28	.....	38	.....
9	Motor Control - Inverter	19	Misc - Holes, Fiducials	29	.....	39	.....
10	Misc - Board Version, DAC	20	Power - Sequencing	30	.....	40	.....

## 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.

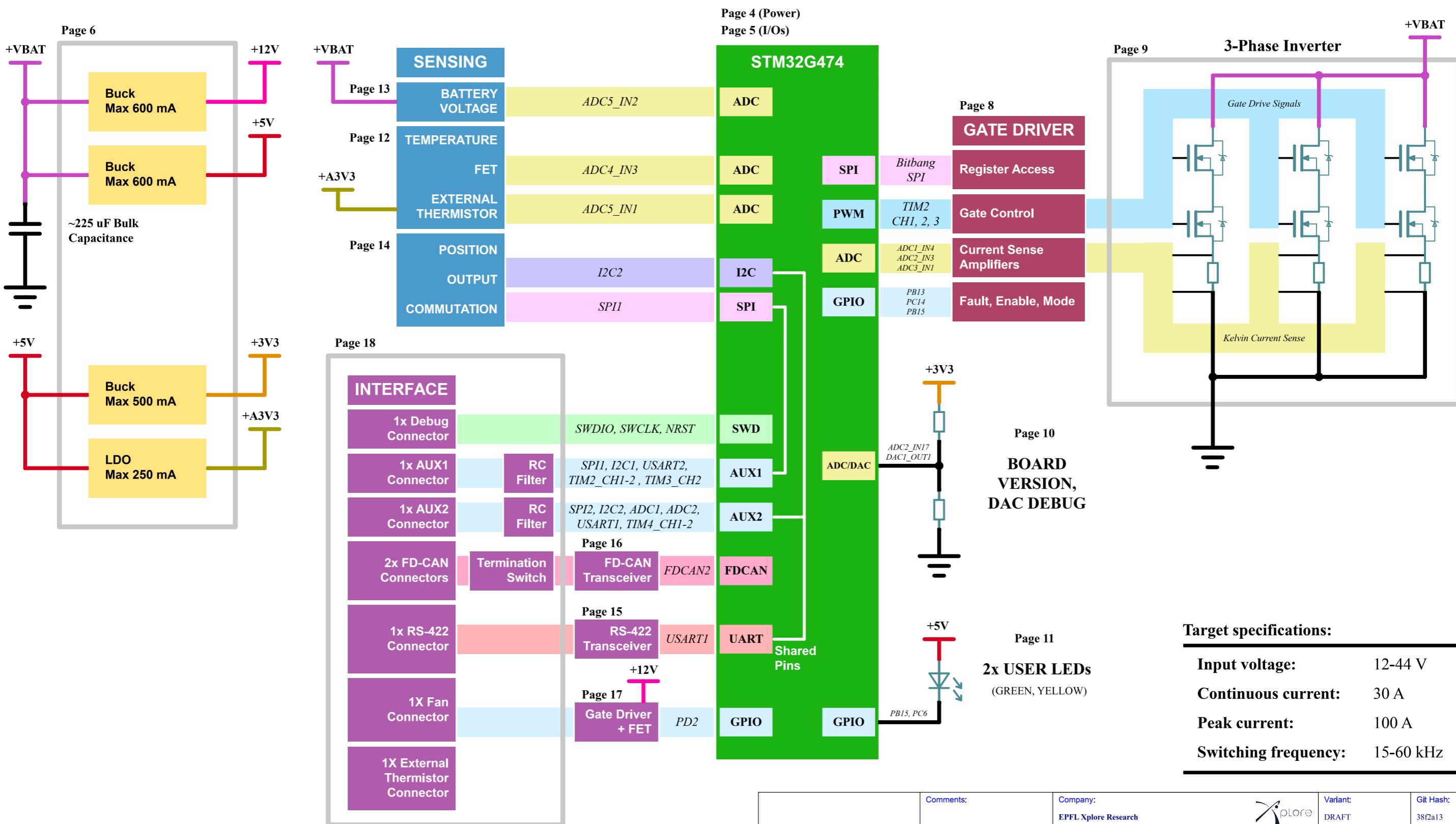
CHECKED - There shouldn't be any mistakes. Contact the engineer if you find any.

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

Date: 25-Nov-2024

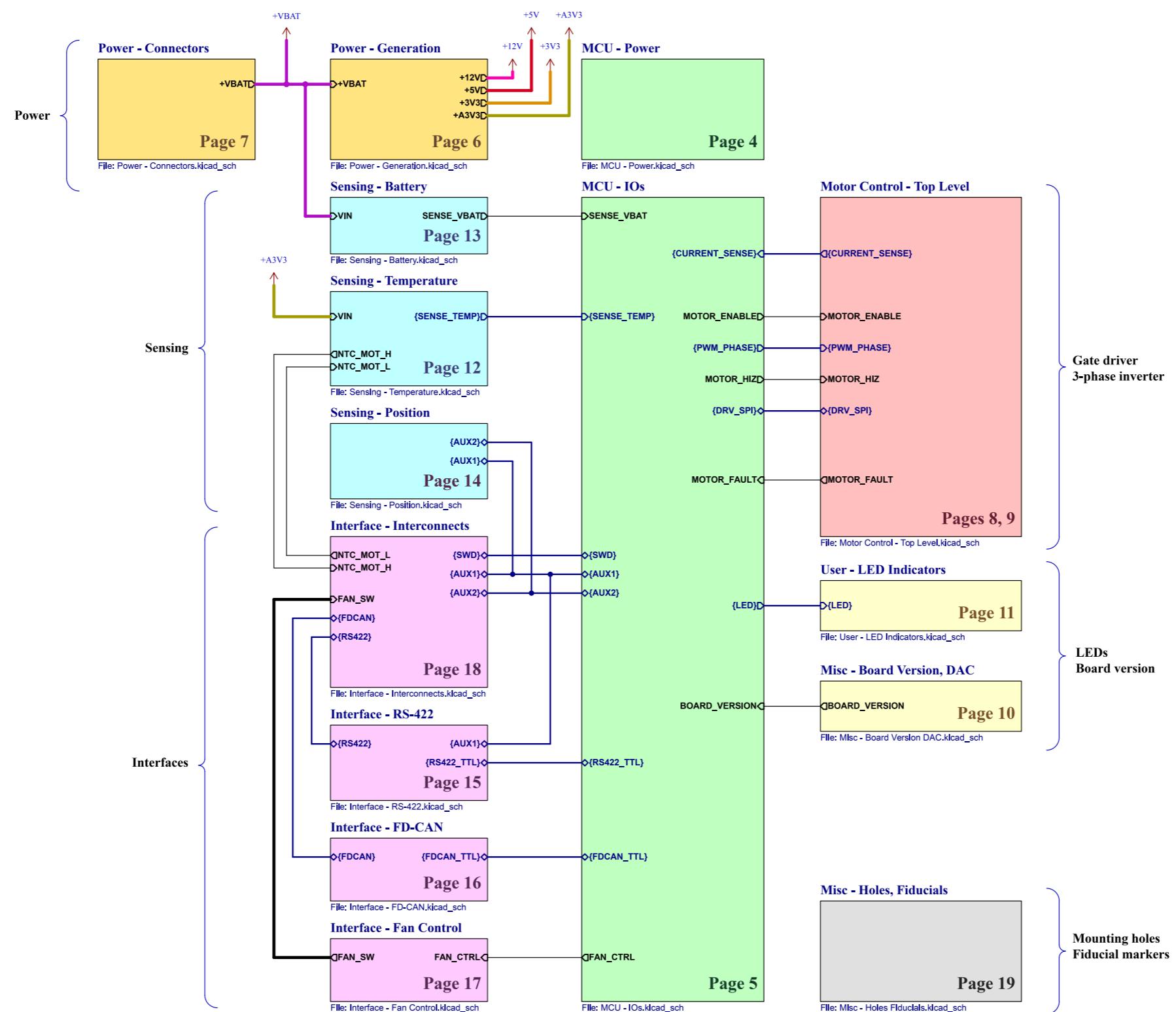
	Comments:	Company:	Xplore	
		EPFL Xplore Research	Variant: DRAFT	
	Board Name:	Amulet Motion Controller		Project Name: Chienpanzé
	Sheet Title:	File Name:	Designer:	Date: Revision:
	Cover Page	amulet_controller.kicad_sch	Vincent Nguyen	2024-04-13 1.2+ (Unreleased)
	Sheet Path:	Reviewer:		Size: Sheet:
	/			A3 1 of 21

# [2] Block Diagram



Comments:	Company: EPFL Xplore Research		Variant: DRAFT	Git Hash: 38f2a13
	Board Name: <b>Amulet Motion Controller</b>		Project Name: <b>Chienpanzé</b>	
Sheet Title: Block Diagram	File Name: Block Diagram.kicad_sch		Designer: Vincent Nguyen	Date: 2024-04-13
Sheet Path: /Block Diagram/	Reviewer:		Size: <b>A3</b>	Revision: 1.2+ (Unreleased)

# [3] Project Architecture



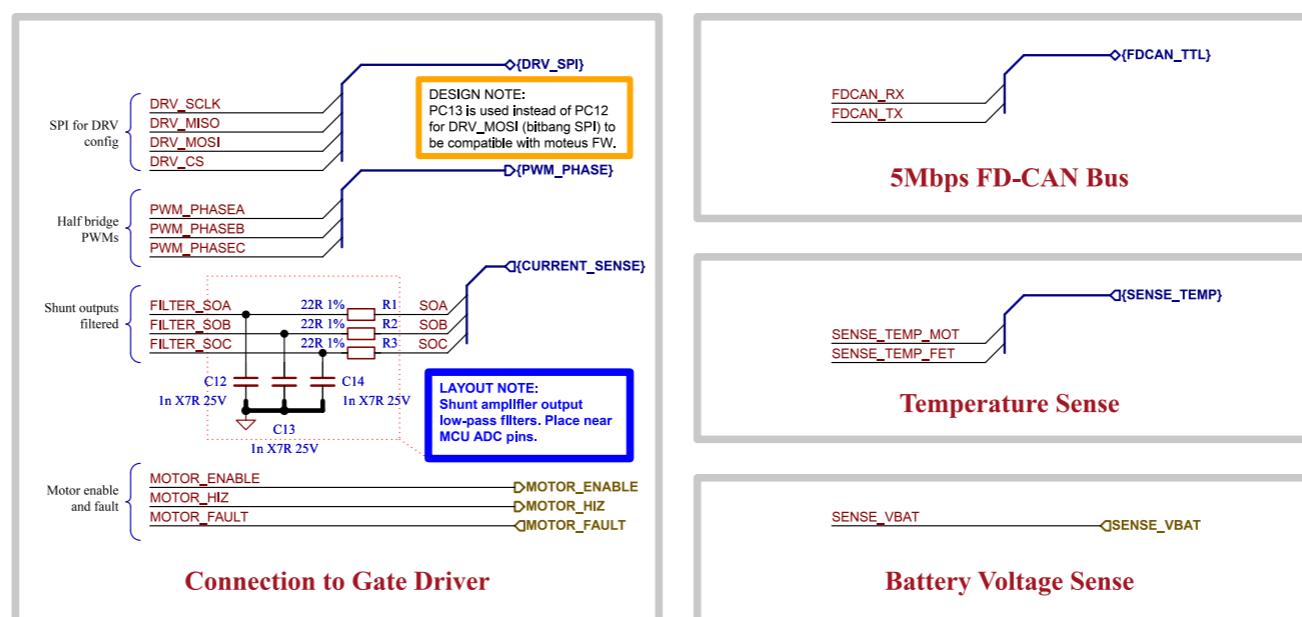
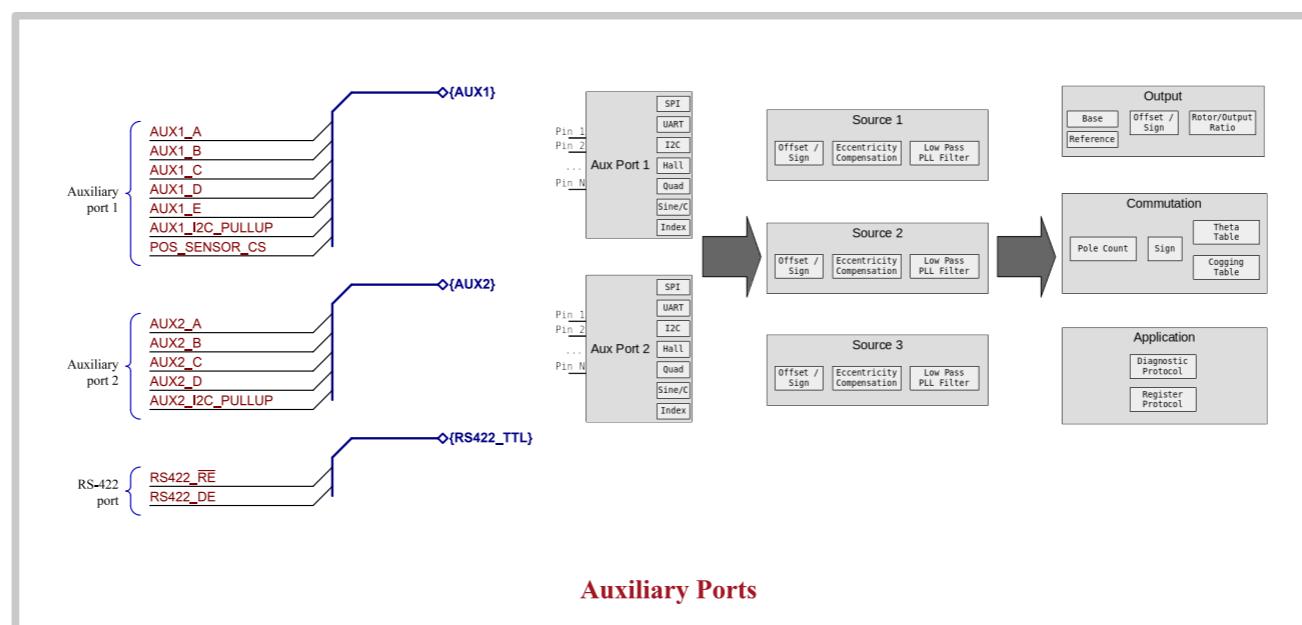
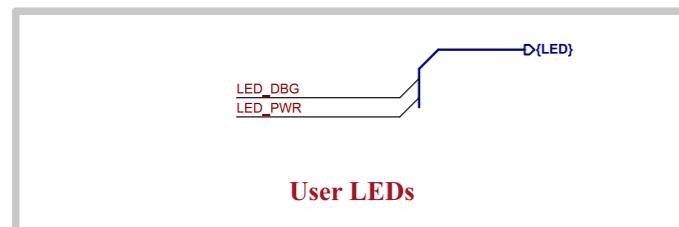
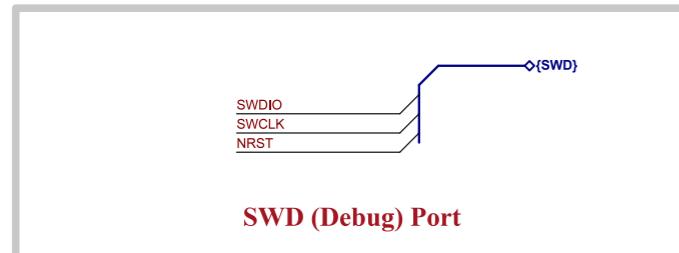
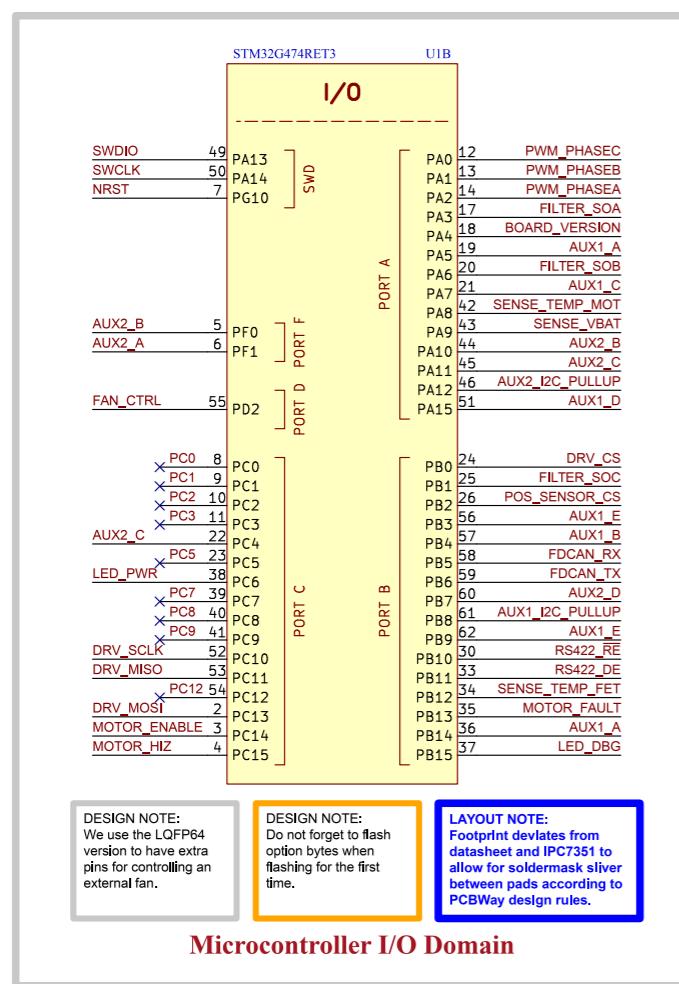
	Comments:	Company: EPFL Xplore Research	Variant: DRAFT	Git Hash: 38f2a13
	Board Name: <b>Amulet Motion Controller</b>	Project Name: <b>Chienpanzé</b>		
	Sheet Title: Project Architecture	File Name: Project Architecture.kicad_sch	Designer: Vincent Nguyen	Date: 2023-12-22
	Sheet Path: /Project Architecture/		Reviewer:	Revision: 1.2+ (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: DRAFT	Git Hash: 38f2a13
	<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
	Sheet Path: /Project Architecture/MCU - Power/	Reviewer:	Size: <b>A4</b>	Sheet: <b>4</b> of <b>21</b>

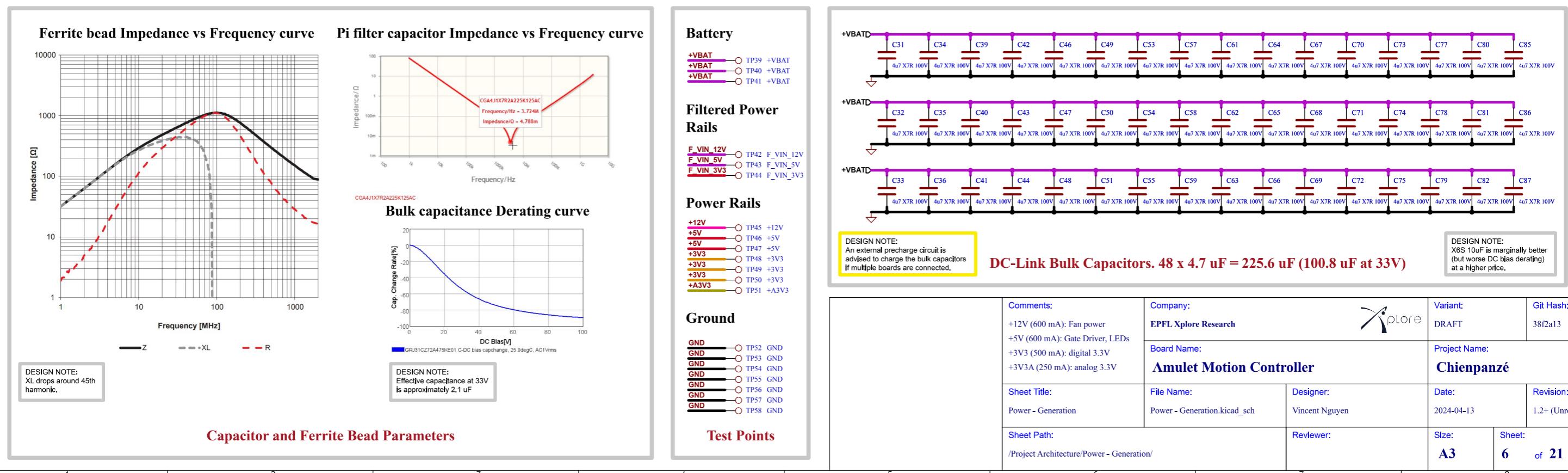
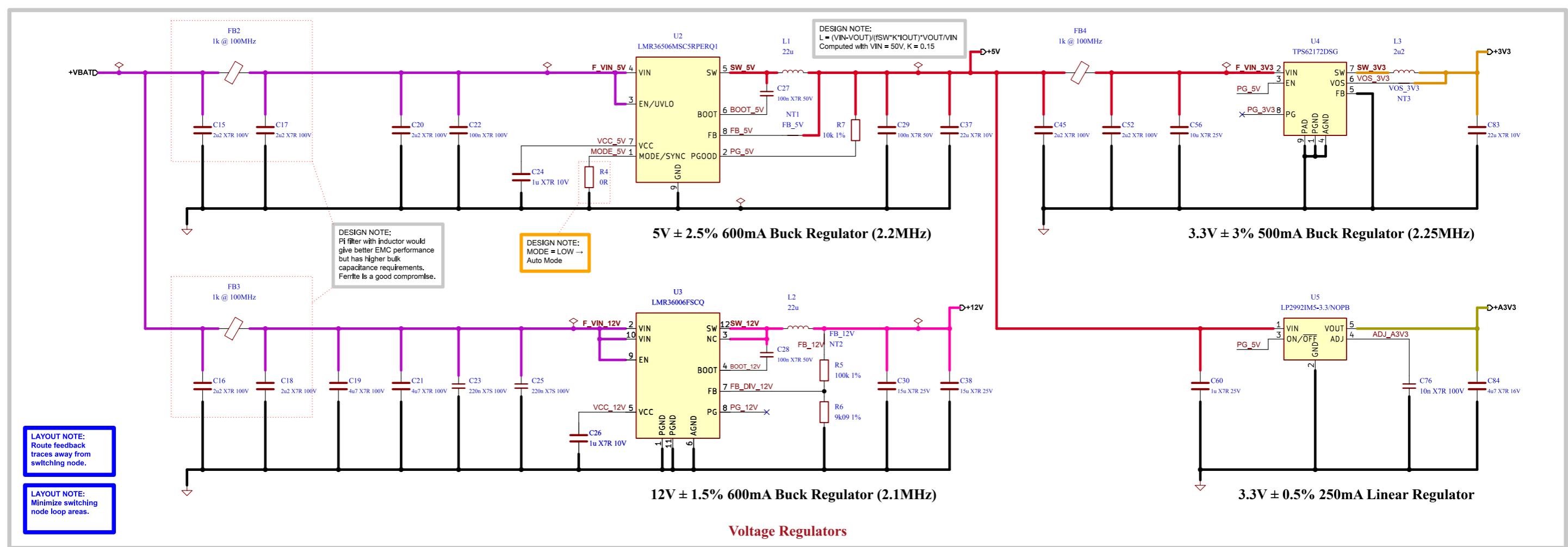
# [5] MCU - I/Os



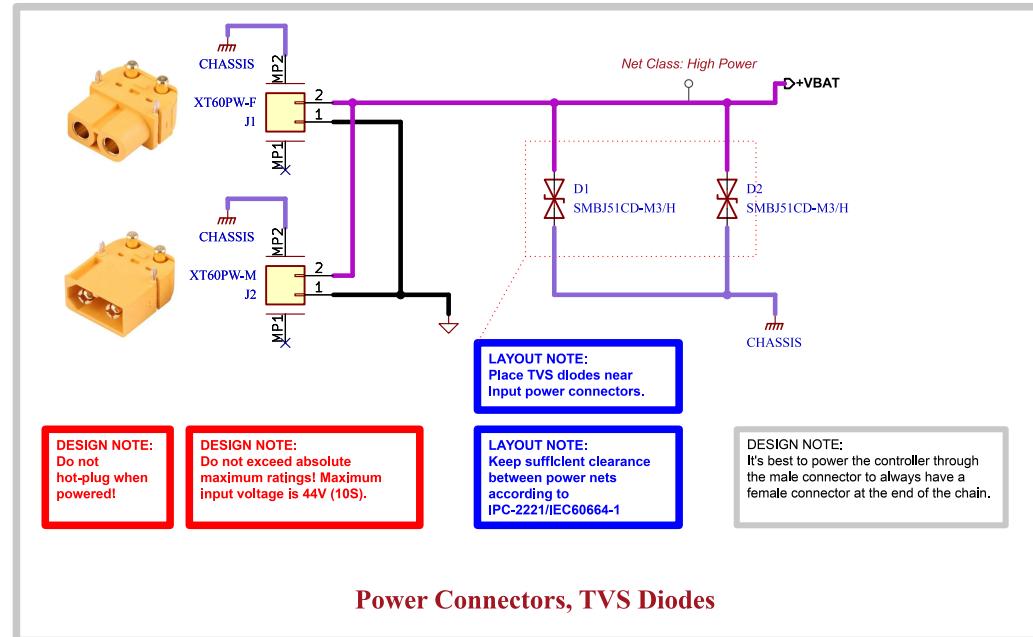
<b>Gate Driver</b>	
MOTOR_ENABLE	TP1
MOTOR_HIZ	TP2
MOTOR_FAULT	TP3
DRV_SCLK	TP4
DRV_MISO	TP5
DRV_MOSI	TP6
DRV_CS	TP7
PWM_PHASEA	TP8
PWM_PHASEB	TP9
PWM_PHASEC	TP10
SOA	TP11
SOB	TP12
SOC	TP13
<b>Debug</b>	
SWDIO	TP14
SWCLK	TP15
NRST	TP16
<b>Auxiliary pins 1</b>	
AUX1_A	TP17
AUX1_B	TP18
AUX1_C	TP19
AUX1_D	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>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: DRAFT	Git Hash: 38f2a13
	Board Name: <b>Amulet Motion Controller</b>	Project Name: <b>Chienpanzé</b>		
Sheet Title: MCU - I/Os	File Name: MCU - IOs.kicad_sch	Designer: Vincent Nguyen	Date: 2023-12-20	Revision: 1.2+ (Unreleased)
Sheet Path: /Project Architecture/MCU - IOs/	Reviewer:	Size: <b>A3</b>	Sheet: <b>5</b> of <b>21</b>	

# [6] Power - Generation



# [7] Power - Connectors



A

B

C

D

A

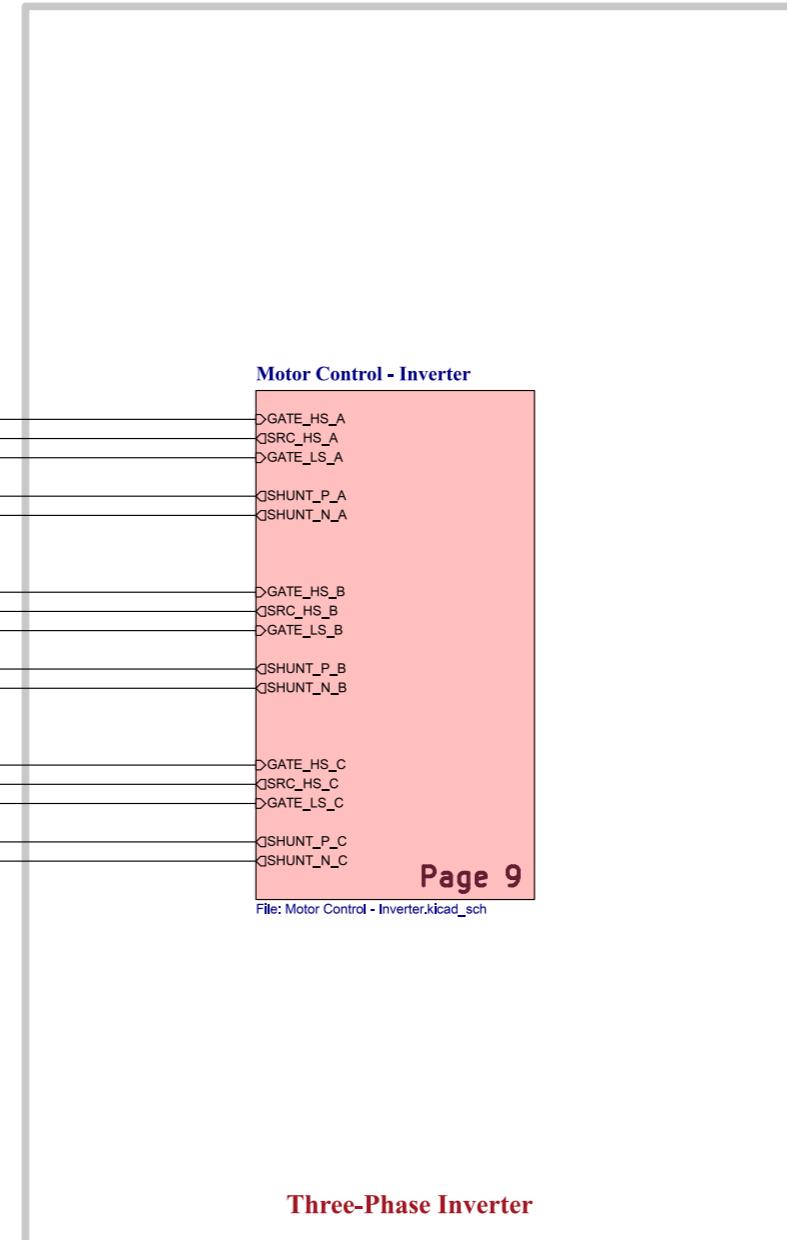
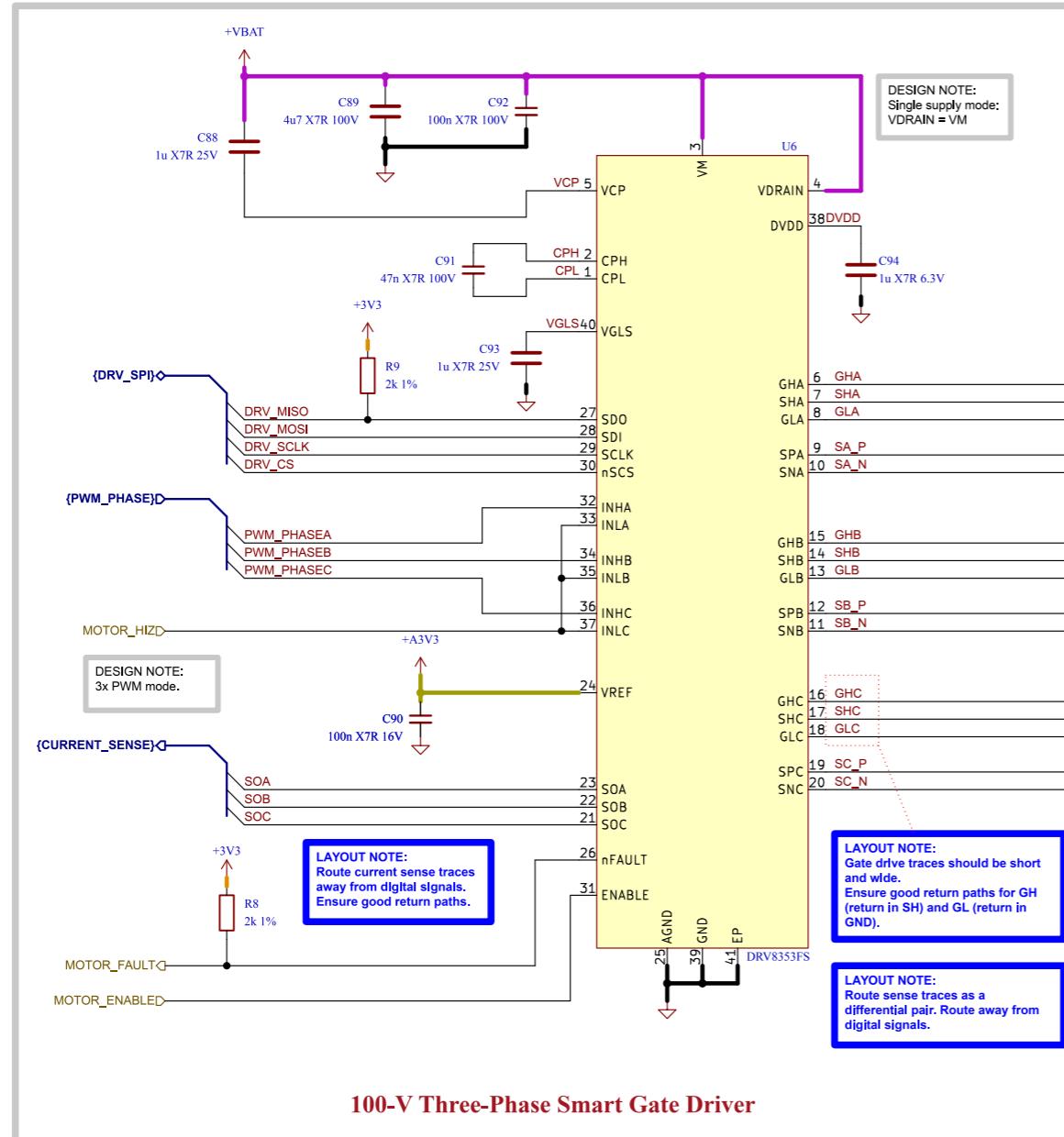
B

C

D

	Comments:	Company: EPFL Xplore Research	Variant: DRAFT	Git Hash: 38f2a13
	Board Name: <b>Amulet Motion Controller</b>			Project Name: <b>Chienpanzé</b>
	Sheet Title: Power - Connectors	File Name: Power - Connectors.kicad_sch	Designer: Vincent Nguyen	Date: 2023-12-31
	Sheet Path: /Project Architecture/Power - Connectors/		Reviewer:	Size: <b>A4</b> Sheet: <b>7</b> of <b>21</b>

# [8] Motor Control - Top Level



	Comments:	Company:	Xplore	Variant:	DRAFT
	Board Name:	EPFL Xplore Research		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	1.2+ (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



DRAFT

**Variant:**  
Git Hash:  
38f2a13

**Project Name:**  
**Chienpanzé**

**Date:**  
2024-01-25

**Revision:**  
1.2+ (Unreleased)

**Reviewer:**  
Size:  
**A4**

**Sheet:**  
**9** of 21

# [10] Misc - Board Version, DAC



	Comments:	Company: EPFL Xplore Research		Variant:	Git Hash:
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: 1.2+ (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



	Comments:	Company: EPFL Xplore Research	Variant: DRAFT	Git Hash: 38f2a13
	Board Name: <b>Amulet Motion Controller</b>	Project Name: <b>Chienpanzé</b>		
	Sheet Title: User - LED Indicators	File Name: User - LED Indicators.kicad_sch	Designer: Vincent Nguyen	Date: 2023-12-19
	Sheet Path: <a href="#">/Project Architecture/User - LED Indicators/</a>		Reviewer:	Size: <b>A4</b> Sheet: <b>11</b> of <b>21</b>

# [12] Sensing - Temperature

A

B

C

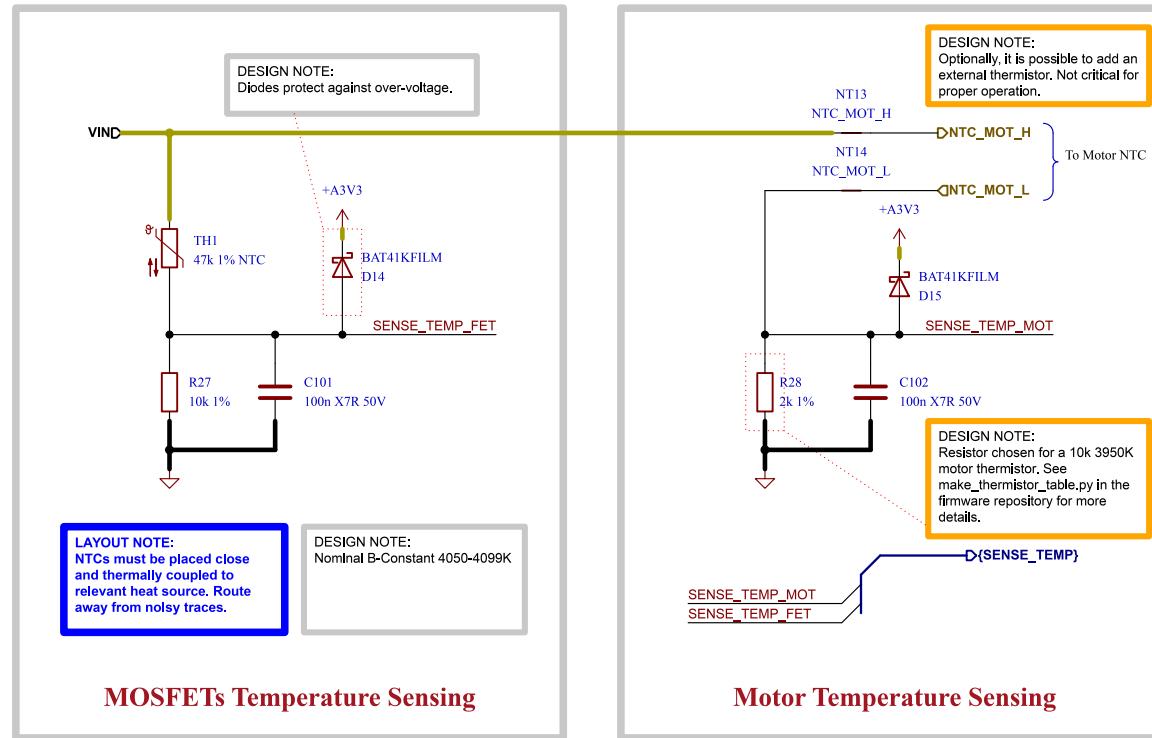
D

A

B

C

D



	Comments:	Company: EPFL Xplore Research	Variant: DRAFT	Git Hash: 38f2a13
	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
	Sheet Path: /Project Architecture/Sensing - Temperature/		Reviewer:	Size: <b>A4</b> Sheet: <b>12</b> of <b>21</b>

# [13] Sensing - Battery

A

A

B

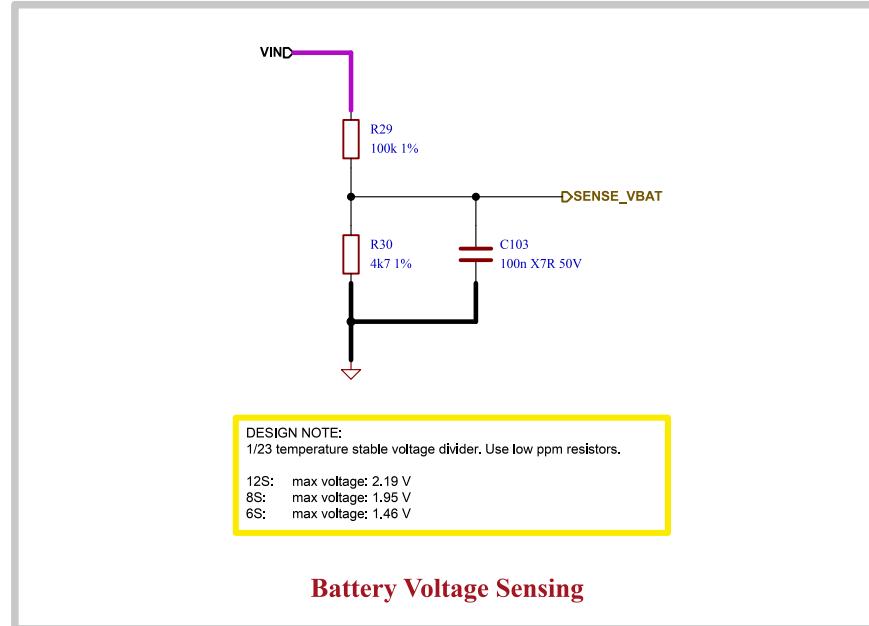
B

C

C

D

D



	Comments:	Company: EPFL Xplore Research	Variant: DRAFT	Git Hash: 38f2a13
	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
	Sheet Path: /Project Architecture/Sensing - Battery/		Reviewer:	Size: <b>A4</b> Sheet: <b>13</b> of <b>21</b>

# [14] Sensing - Position

A



B



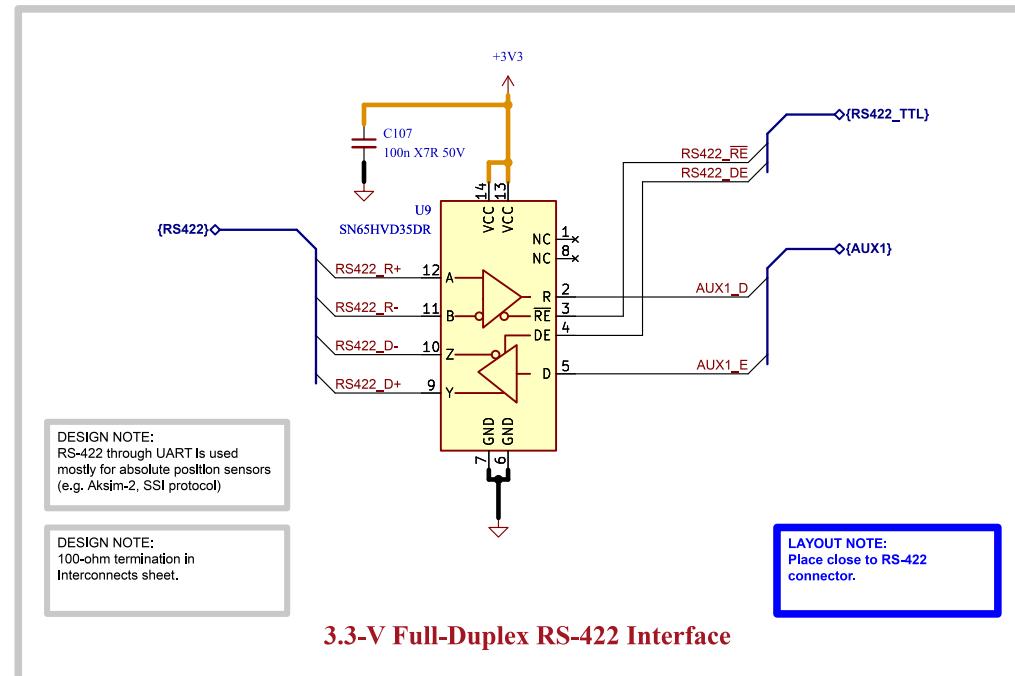
C

**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.

D

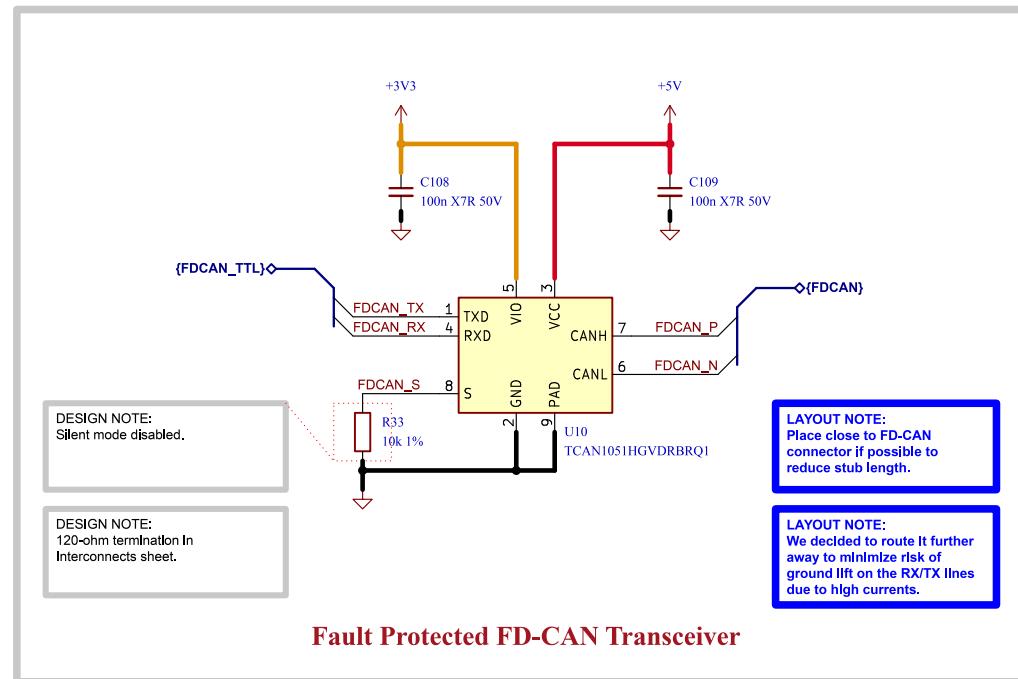
		Comments:	Company: EPFL Xplore Research	Variant: DRAFT	Git Hash: 38f2a13
		Board Name: <b>Amulet Motion Controller</b>	Project Name: <b>Chienpanzé</b>		
		Sheet Title: Sensing - Position	File Name: Sensing - Position.kicad_sch	Designer: Vincent Nguyen	Date: 2023-10-14
		Revision: 1.2+ (Unreleased)		Reviewer:	Size: <b>A4</b>
		Sheet Path: /Project Architecture/Sensing - Position/		Sheet: <b>14</b> of <b>21</b>	

# [15] Interface - RS-422



	Comments:	Company: EPFL Xplore Research 	Variant: DRAFT	Git Hash: 38f2a13
	Board Name: <b>Amulet 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
	Sheet Path: /Project Architecture/Interface - RS-422/		Reviewer:	Size: <b>A4</b> Sheet: <b>15</b> of <b>21</b>

# [16] Interface - FD-CAN



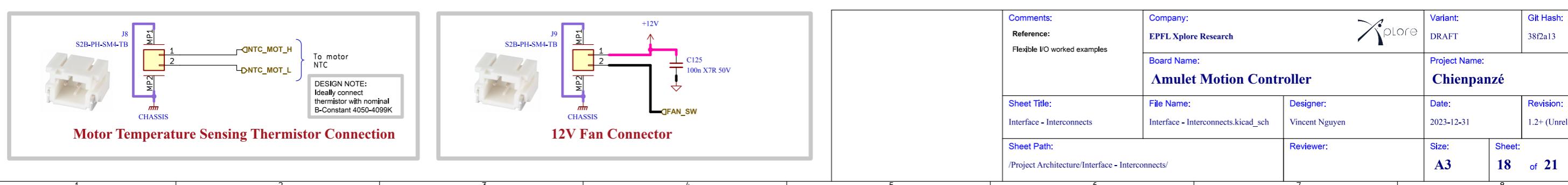
	Comments:	Company: EPFL Xplore Research 	Variant: DRAFT	Git Hash: 38f2a13
	Board Name: <b>Amulet Motion Controller</b>			Project Name: <b>Chienpanzé</b>
	Sheet Title: Interface - FD-CAN	File Name: Interface - FD-CAN.kicad_sch	Designer: Vincent Nguyen	Date: 2023-10-15
	Sheet Path: /Project Architecture/Interface - 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: DRAFT	Git Hash: 38f2a13
	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
	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

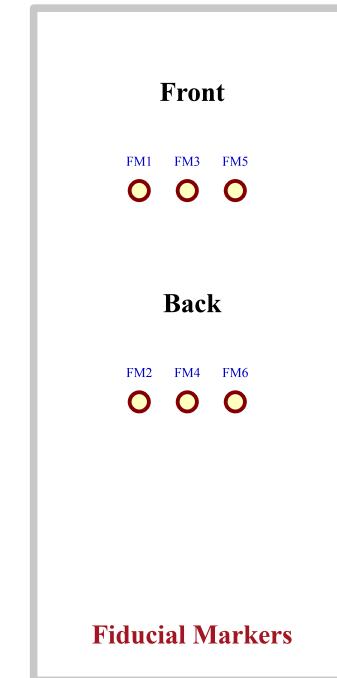
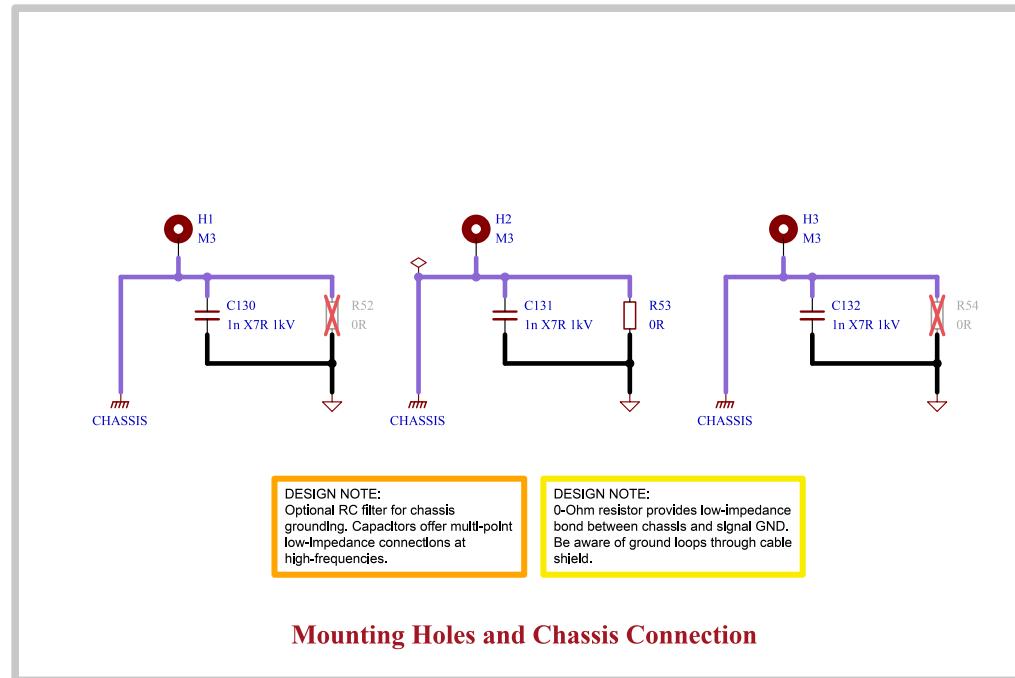
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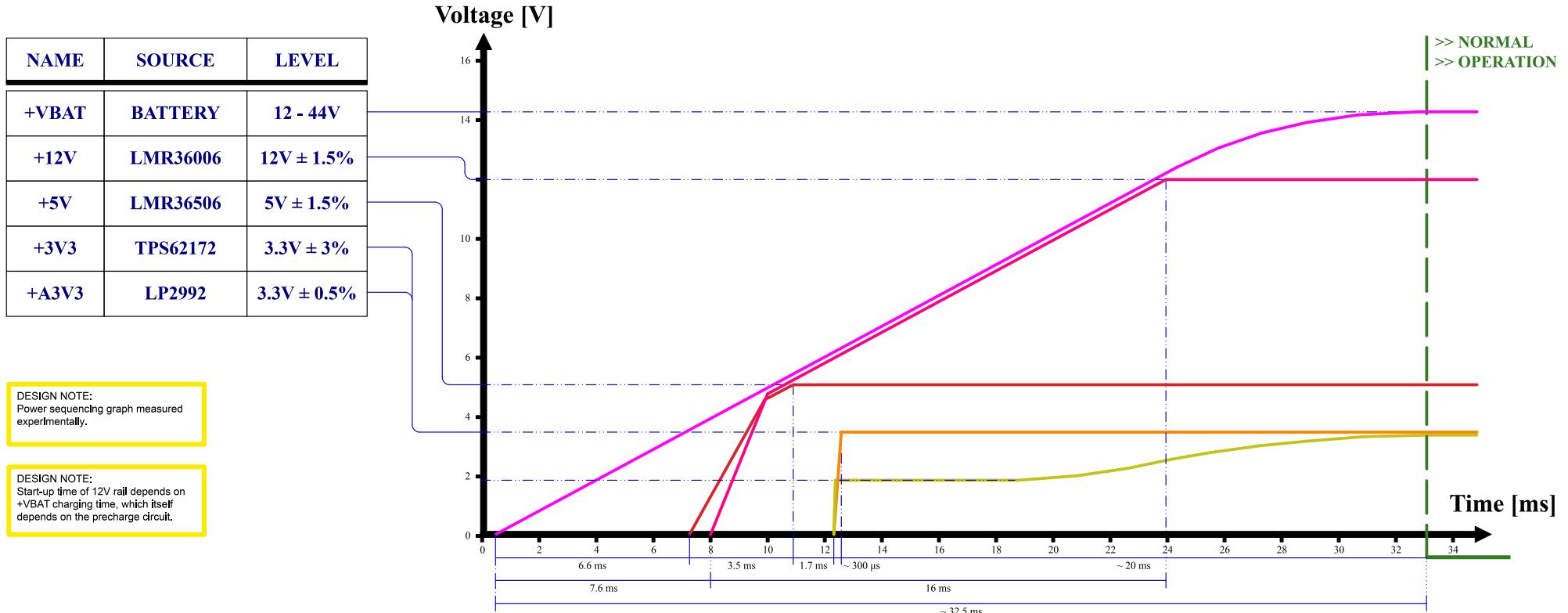
D



		Comments:	Company: EPFL Xplore Research	Variant: DRAFT	Git Hash: 38f2a13
		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
		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

	Comments:	Company: EPFL Xplore Research	Variant: DRAFT	Git Hash: 38f2a13
	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
	Sheet Path: <a href="#">/Power - Sequencing/</a>			Revision: 1.2+ (Unreleased)
	Reviewer:		Size: <b>A4</b>	Sheet: <b>20</b> of <b>21</b>

# [21] Revision History

A

**12-DEC-2023 - Initial Release**  
**Variant: v1.0 Preliminary**

- Changed CPH-CPL capacitor to 47nF (gate driver).
- Changed FD-CAN transceiver IC.
- Changed FETs for top cooled variant.
- Added TVS protection and termination switch to FD-CAN.
- Added low-side switched 12V 600mA source for external fan.
- Added LDO for analog supply.
- Changed input power TVS diode to bidirectional and added one diode per connector.
- Moved SOx low-pass filter to MCU section. Should be placed near MCU to avoid noise coupling into ADC lines.
- Added second onboard I2C magnetic encoder for disambiguation.
- Switched PWM\_PHASEA with PWM\_PHASEB on STM32G474 pinout for easier routing.
- Changed RS422 pinout on connector.
- Added ESD protection to all interfaces.
- Added overvoltage protection on thermistor ADC inputs.
- Changed buck regulators to optimize for low noise.
- Added Pi filters to inputs of buck regulators and MCU analog supply.
- Added decoupling caps next to power pins of connectors.

B

**25-JAN-2024 - First Revision**  
**Variant: v1.0 Checked**

- Added controller target specifications.
- Replaced 5V 300mA buck converter with 600mA version.
- Added credits to moteus on cover page.
- Added optional RC-Snubber to power stage.
- Increased chassis length to go around the board.
- CAN and power TVS diodes now go to chassis.
- Changed clearance between nets to respect IEC60664-1 where possible.
- Rectified comment on precharge.
- Changed power TVS diode reference designator from "U" to "D".
- Replaced chassis-GND capacitor by 1nF 1kV.

C

**12-MAR-2024 - First Revision**  
**Variant: v1.0 Released**

- Modified power sequencing graph according to experimental data.

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D

**13-APR-2024 - Second Revision**  
**Variant: v1.1 Released**

- Added RC snubber passive values.
- Added more vias for VBUS and LMR36006 GND pads.
- Changed board version voltage reference from +3V3 to +A3V3.
- Changed motor thermistor resistor divider to 2kOhm for a 10k 3950K thermistor.

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	Comments:	Company: EPFL Xplore Research	Variant:	Git Hash:
			DRAFT	38f2a13
			Project Name:	Chienpanzé
	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>