CZECH TECHNICAL
UNIVERSITY
IN PRAGUE

F3

Faculty of Electrical Engineering
Department of Measurement

Bachelor's Thesis

On-board computer for PC104 format CubeSats

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Cybernetics and Robotics

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https://github.com/visionspacetec/VST104
Supervisor: Ing. Vojtěch Petrucha, Ph.D.

Draft: 20. 5. 2021

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Acknowledgement / Declaration

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In Prague on May 21, 2021

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Abstrakt / Abstract

Kľúčové slová: CubeSat; PC104; OBC; hardvér; PCB dizajn; schémy.

Preklad titulu: Palubný počítač pre CubeSaty formátu PC104

Keywords: CubeSat; PC104; OBC; hardware; PCB design; schematics.

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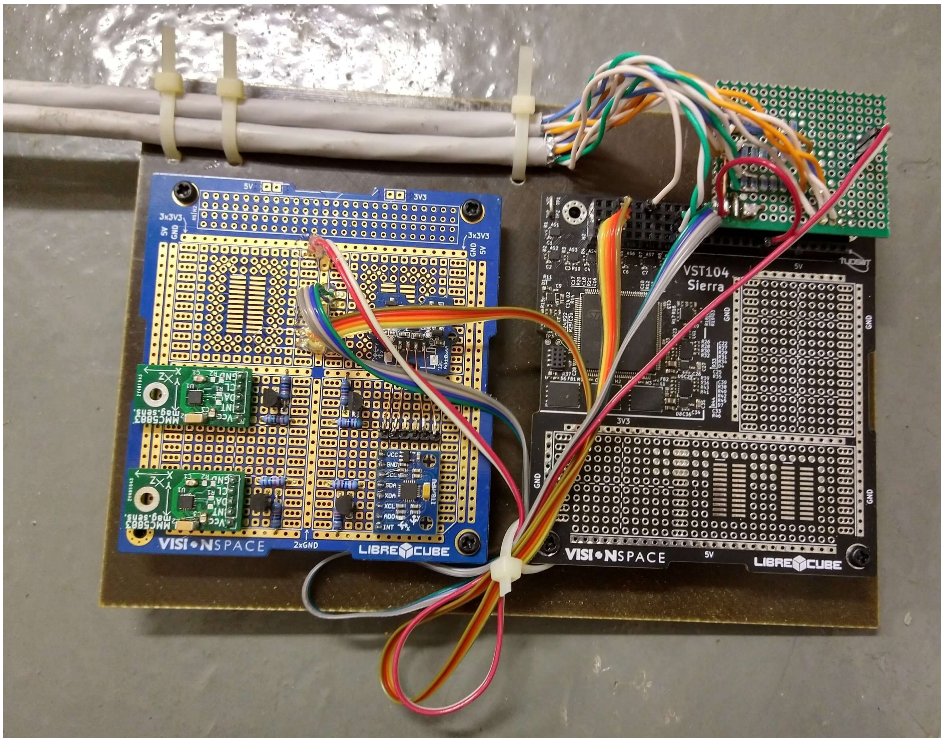
Chapter 1
Board Sierra - testing

1.1 Testing software

1.2 Radiation testing

1.2.1 Experiment setup

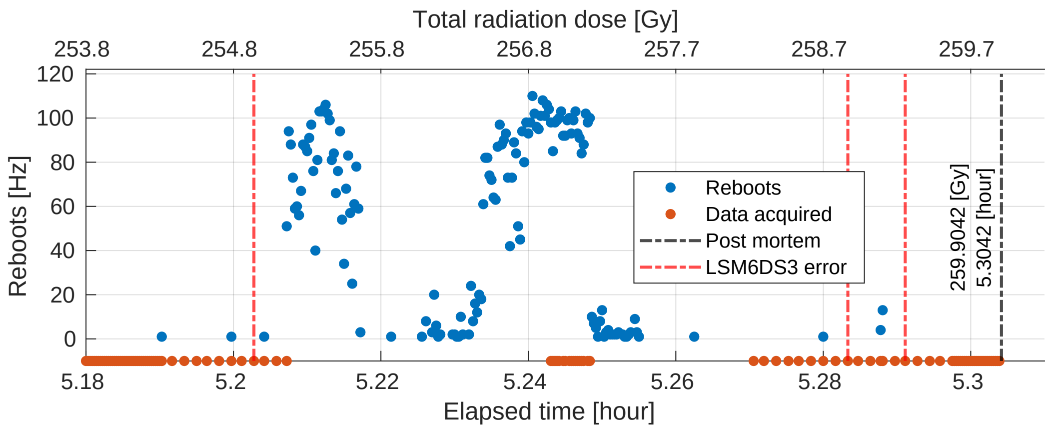
For the purpose of the radiation testing, the Board Sierra was extended with a couple of electronic sensors: i) an always-on 3D accelerometer and 3D gyroscope LSM6DS3, ii) a high-performance 3-axis magnetic sensors MMC5983MA (two devices), and iii) an integrated 6-axis motion processor with gyroscope and accelerometer MPU6050. All of these sensors were connected with the OBC using an I^{2}C data bus. Each sensor was powered through a separate high-base current PNP transistor controlled by the MCU. A proper power reset of each sensor could have been achieved by turning off this transistor and isolating the corresponding I^{2}C peripheral isolator. This feature was implemented in order to resolve a potential I^{2}C bus lockup or the sensor's latch-up.



[pho:rez_setup]
Figure 1.1.

1.2.2 Experiment results

Being a complex system of multiple semiconductor devices, the OBC was not expected to withstand the whole experiment. At 5.19[hour] after the start, the first unintentional reboot was logged. Until this point, the OBC performed normally without a single malfunction. The radiation dose at the time of this event was 254.32[Gy]. This reboot was the opening of 6.8 minutes long OBC's decay. Figure 1.2 shows timestamps of data and reboot logs received in this period. It is visible that the OBC entered a loop reaching up to 110 reboots per second. Despite this enormous frequency, some windows of inactivity and even a few data logs can be observed. At 5.27[hour], the OBC managed to start functioning again. Although, with visible delays between the acquired data. The very last log was received from the OBC at 5.30[hour], marking the end of its functionality. The overall radiation dose at this point was 259.90[Gy].



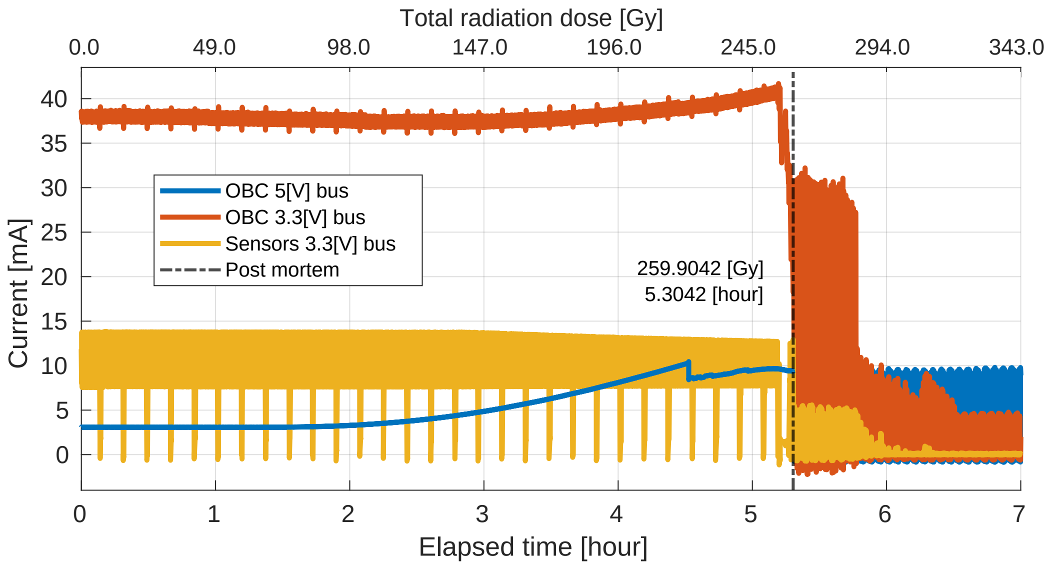
[plt:reboot]

Figure 1.2. Timestamps of logs received from the OBC during its last moments of activity.

The OBC's and the sensors' current consumptions, measured through the external shunt resistors, are shown in figure 1.3. The periodically repeating pattern on both 3.3[V] power busses was generated by the prevention power reset. As this feature has powered off the sensors and suspended some of the OBC's activity every ten minutes, the corresponding decrease in required power is visible. Another noticeable trend is the increasing current consumption by the OBC and slightly decreasing current consumption by the sensor board. However, this time we cannot provide it with an explanation. A significant current drop and oscillations follow the already described OBC failure. Some changes in the current consumption are also visible closely before this event.

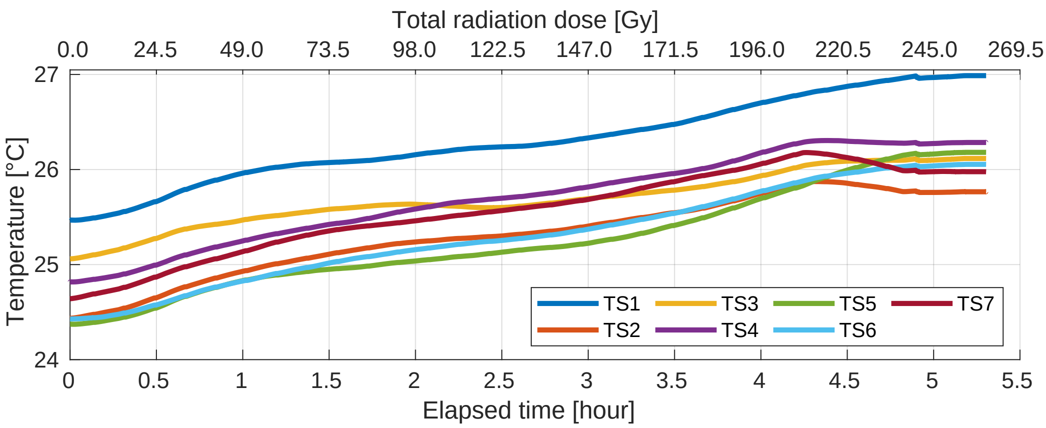
Temperature readings obtained from the OBC's inbuilt temperature sensors are shown in figure 1.4. No errors or failures of these sensors were recorded throughout the experiment. The acquired data also doesn't show any abnormality in the OBC's temperature or heat distribution. The slightly increased readings of the sensor T1 could be explained by its assignment to the Flash memory subsystem. Its continuous activity might have easily resulted in an increase of its temperature by roughly a 0.5[°C].

The LSM6DS3 was the only sensor that has experienced a total failure (actually seven of them). After being requested by the OBC, no response was obtained from the sensor, and the I^2C connection timeout was reached. The first failure occurred after exposure to a radiation dose of 196.90[Gy]. Timestamps of these failures, together with the obtained angular velocity, are shown in figure 1.5. A continuous malfunction/degradation of the sensor is visible from these data, as the Y and Z-axis readings are decreasing over time.



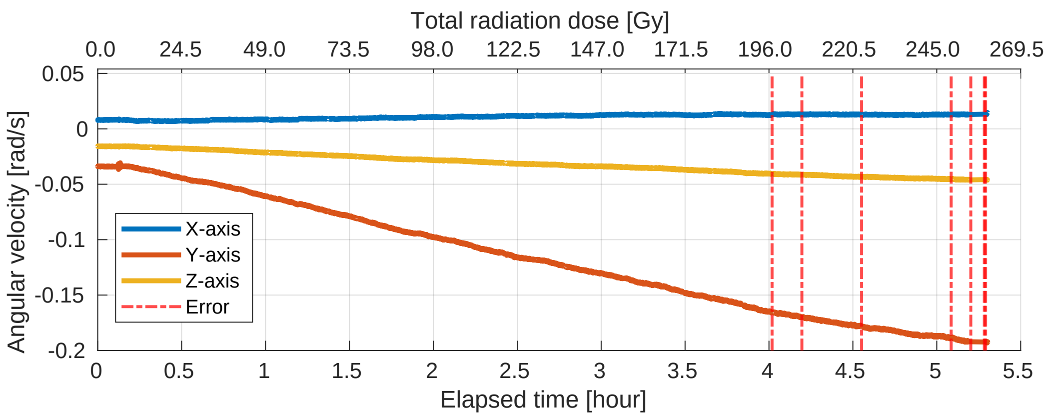
[plt:currents]

Figure 1.3. Current consumption measured throughout the experiment.



[plt:mcp9884]

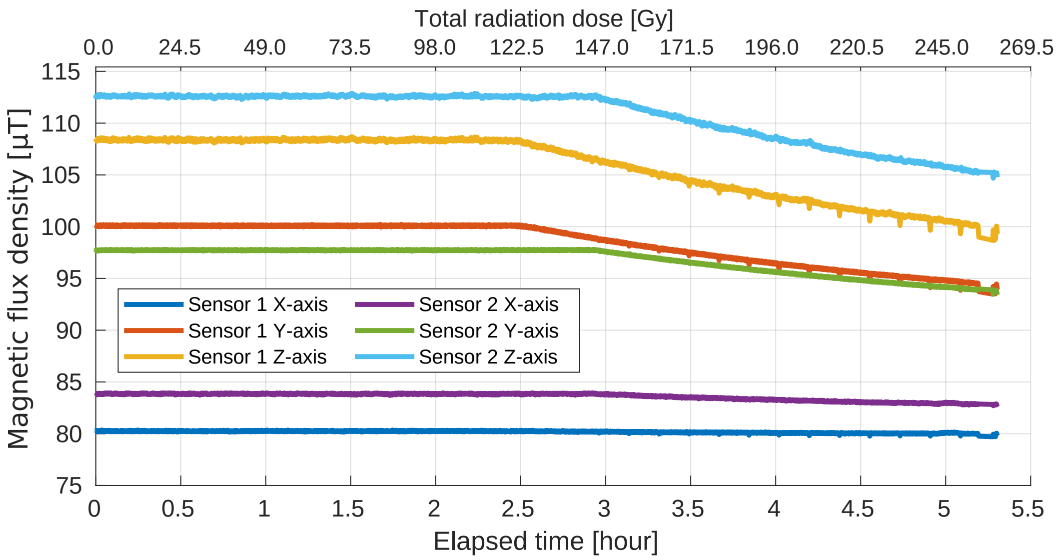
Figure 1.4. Readings of the OBC's inbuilt temperature sensors. The location and purpose of each sensor were described in section ??.



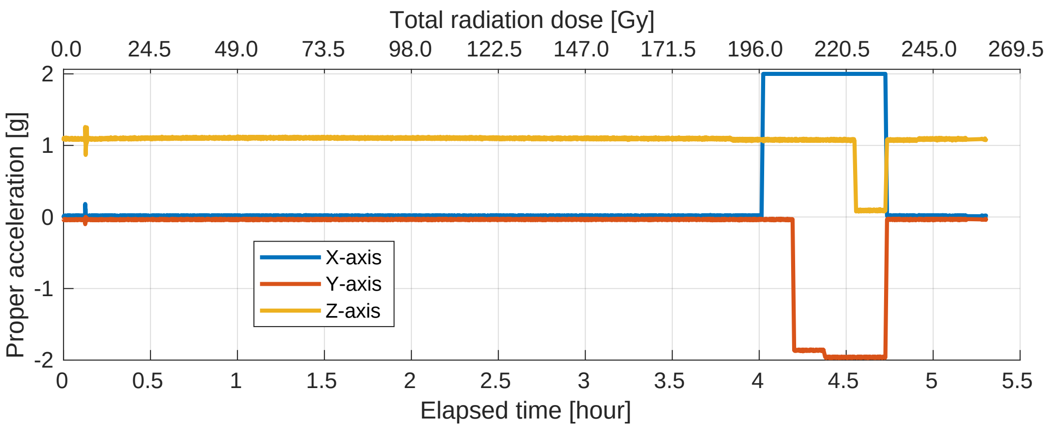
[plt:lsm6ds3g_gyr]

Figure 1.5. Angular velocity readings and occurred malfunctions of the LSM6DS3 sensor.

A real motion could not have caused these trends due to the sensor's stationary mount. Interestingly, the acceleration data acquired from this sensor are perfectly reasonable.



[plt:mmc5983]
Figure 1.6.



[plt:mpu6050_acc]
Figure 1.7.

Chapter 2
Conclusion

References

Appendix A
Thesis Assignment

CTU CZECH TECHNICAL UNIVERSITY IN PRAGUE

BACHELOR'S THESIS ASSIGNMENT

I. Personal and study details

Student's name: **Geib Filip** Personal ID number: **483567**

Faculty / Institute: **Faculty of Electrical Engineering**

Department / Institute: **Department of Measurement**

Study program: **Cybernetics and Robotics**

II. Bachelor's thesis details

Bachelor's thesis title in English:

On-board computer for PC104 format CubeSats

Bachelor's thesis title in Czech:

Palubní počítač pro CubeSaty formátu PC104

Guidelines:

- Design a concept of an STM32 based on-board computer for PC104 frame based CubeSats.
- Implement redundancy for the critical components to improve reliability of the design.
- Construct the device and conduct testing of the whole system, e.g. using a flatsat platform.
- Concentrate on providing detailed and accurate documentation of the system.

Bibliography / sources:

[1] Anil K. Maini et al.: "Satellite Technology: Principles and Applications", John Wiley & Sons, Incorporated, 2014
[2] Ahmet Bindal: "Electronics for Embedded Systems", Springer International Publishing, Switzerland 2017
[3] Report Concerning Space Data System Standards, Mission Operations Services Concept, CCSDS 520.0-G-3, Consultative Committee for Space Data Systems, Washington, DC, USA, 2020
[4] Dogan Ibrahim: "ARM-Based Microcontroller Projects Using Mbed", Elsevier Science & Technology, 2019

Name and workplace of bachelor's thesis supervisor:

Ing. Vojtěch Petrucha, Ph.D., 13138

Name and workplace of second bachelor's thesis supervisor or consultant:

Date of bachelor's thesis assignment: **13.01.2021** Deadline for bachelor thesis submission: ___________

Assignment valid until:
by the end of summer semester 2021/2022

Ing. Vojtěch Petrucha, Ph.D. Supervisor's signature	Head of department's signature	prof. Mgr. Petr Páta, Ph.D. Dean's signature

III. Assignment receipt

The student acknowledges that the bachelor's thesis is an individual work. The student must produce his thesis without the assistance of others, with the exception of provided consultations. Within the bachelor's thesis, the author must state the names of consultants and include a list of references.

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Date of assignment receipt	Student's signature

[app:thesisAssignment]

Figure 2.1. Assignment of this bachelor's thesis.

Appendix B
Glossary

I^2C	inter-integrated circuit
ADC	analog-to-digital converter
AEC	Automotive Electronics Council
ARM	advanced RISC machines
BGA	ball grid array
BOM	bill of materials
CAN	controller area network
CCSDS	Consultative Committee for Space Data Systems
COTS	commercial off-the-shelf
CPU	central processing unit
DAC	digital-to-analog converter
DCDC	direct current to direct current
DPDT	double pole double throw
DRC	design rule check
EECSS	European Cooperation for Space Standardization
eFuse	electronic fuse
EMI	electromagnetic interference
ESA	European Space Agency
ESD	electrostatic discharge
FFC	flat flexible cable
FPGA	field-programmable gate array
GND	ground
GPIO	general-purpose input/output pin
HSE	high speed external
IC	integrated circuit
JPL	Jet Propulsion Laboratory
LC	inductor-capacitor
LED	light emitting diode
LSE	low speed external
MCU	microcontroller unit
MEMS	microelectromechanical system
MOSFET	metal–oxide–semiconductor field-effect transistor
NA	not applicable
OBC	on board computer
PCB	printed circuit board
PDCU	power distribution and control unit
PDU	power distribution unit
PLL	phase-locked loop
PWM	pulse width modulation
QFN	quad-flat no-leads
QPI	quad peripheral interface

RC	resistor-capacitor
RCS	radio communication subsystem
RTC	real time clock
RTD	resistance temperature detector
Rx/Tx	receive / transmit
SMD	surface mount device
SPI	serial peripheral interface
SPICE	simulation program with integrated circuit emphasis
SSOP	shrink small-outline package
SWD	serial wire debug
SWJ-DP	serial wire JTAG debug port
SWO	serial wire output
SWV	serial wire viewer
THT	through-hole technology
TVS	transient-voltage-suppression
UART	universal asynchronous receiver-transmitter
USB	universal serial bus
USB-C	universal serial bus type C
VST	Vision Space Technologies

Appendix C
VST104 pinout

Header H1

	1	2	
	3	4	
USER_1_1	5	6	USER_1_2
SPI_1_CS2	7	8	USER_1_4
SPI_1_CS1	9	10	SPI_1_MOSI
SPI_1_CLK	11	12	SPI_1_MISO
UART_1_TX	13	14	UART_1_CTS
UART_1_RX	15	16	UART_1_RST
UART_RCS_1_TX	17	18	UART_RCS_1_CTS
UART_RCS_1_RX	19	20	UART_RCS_1_RST
I2C_1_SCL	21	22	I2C_1_SDA
CAN_1_H	23	24	CAN_1_L
GLO_SYNC	25	26	GLO_FAULT
CPU_WD_1	27	28	CPU_WD_2
-	29	30	CPU_MODE
SUP_3V3_REF	31	32	SUP_5V_REF
GND	33	34	GND
GLO_KS_1	35	36	GLO_KS_2
-	37	38	-
USER_3_1	39	40	USER_3_2
USER_3_3	41	42	USER_3_4
USER_5_1	43	44	USER_5_2
USER_5_3	45	46	USER_5_4
	47	48	
	49	50	
	51	52	

Header H2

	1	2	
	3	4	
USER_2_1	5	6	USER_2_2
SPI_2_CS2	7	8	USER_2_4
SPI_2_CS1	9	10	SPI_2_MOSI
SPI_2_CLK	11	12	SPI_2_MISO
UART_2_TX	13	14	UART_2_CTS
UART_2_RX	15	16	UART_2_RST
UART_RCS_2_TX	17	18	UART_RCS_2_CTS
UART_RCS_2_RX	19	20	UART_RCS_2_RST
I2C_2_SCL	21	22	I2C_2_SDA
CAN_2_H	23	24	CAN_2_L
SUP_5V	25	26	SUP_5V
SUP_3V3	27	28	SUP_3V3
GND	29	30	GND
AGND	31	32	GND
-	33	34	-
-	35	36	-
-	37	38	-
USER_4_1	39	40	USER_4_2
USER_4_3	41	42	USER_4_4
USER_6_1	43	44	USER_6_2
-	45	46	-
USER_6_3	47	48	USER_6_4
	49	50	
	51	52	

p_vst:vst104_pinout]

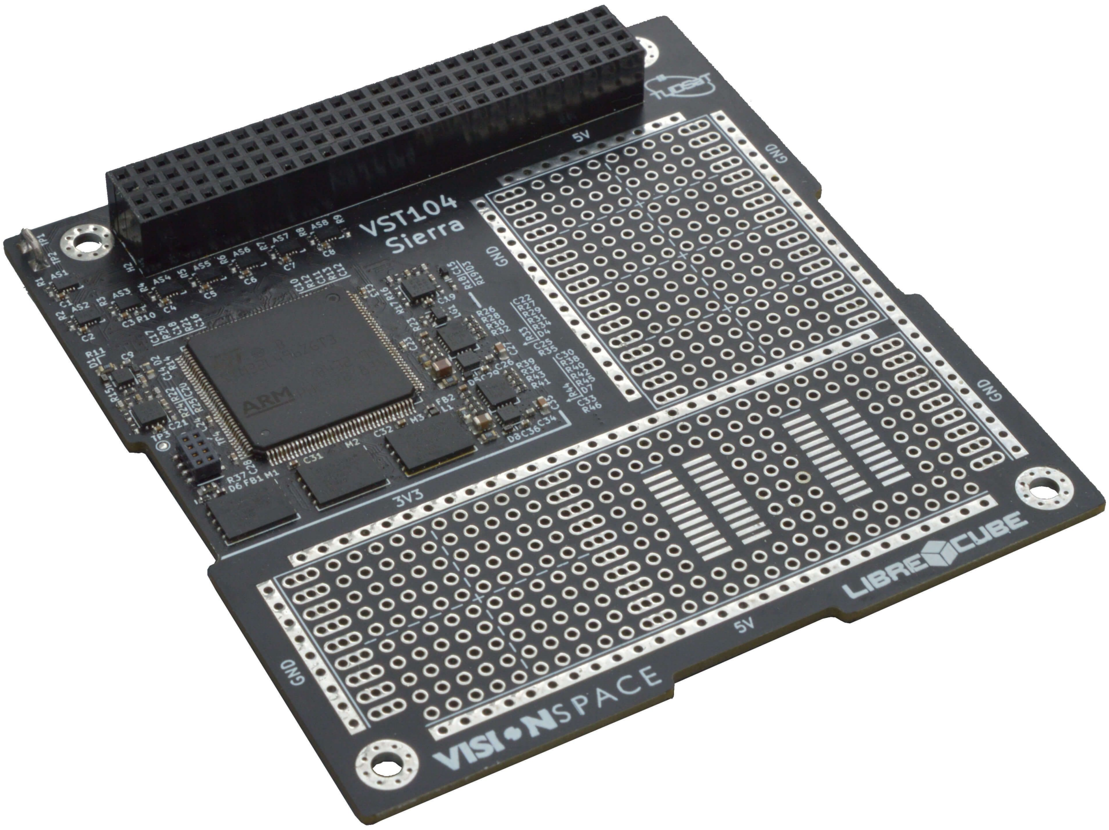
Figure 2.2. VST104 pinout: assignment of PC/104 header pins used in the VST104 project. Legend: red - mandatory, orange - optional, green - user defined, blue - legacy pins.

Signal name	Signal purpouse
`UART_RCS_`	UART used explicitly for the RCS*
`GLO_SYNC`	clock signal of global synchronization
`GLO_FAULT`	signal setting a global fault flag
`GLO_KS_`	standard kill switch signal (active high)
`CPU_WD_`	watchdog signal for each of the OBCs (CPUs)
`CPU_MODE`	OBC selection signal used in Board Delta

[tab:vst104_pinout]

Table 2.1. A brief explanation of selected signals from the VST104 pinout. A more specific definition will be proved ed by the VST in the future. *radio communication subsystem

Appendix D
Photo documentation



[app_photo:vst104_pinout]
Figure 2.3.

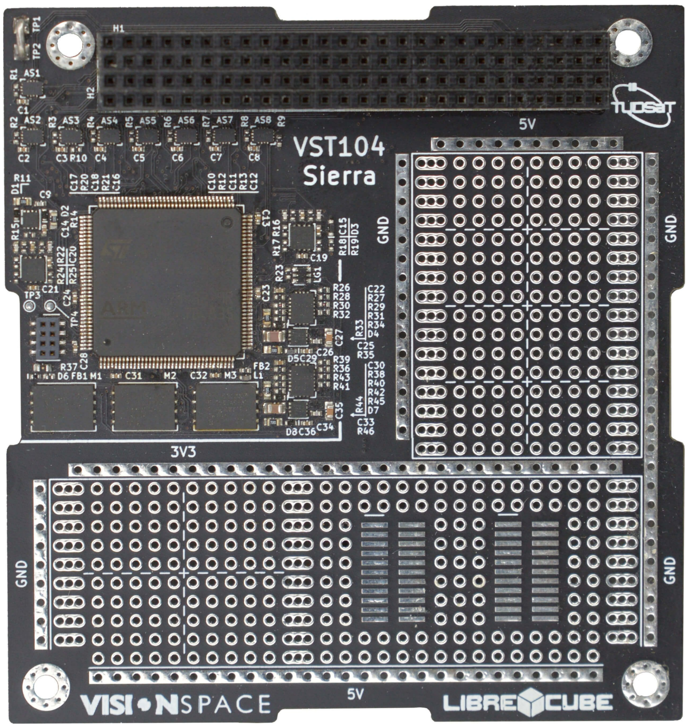


Figure 2.4.

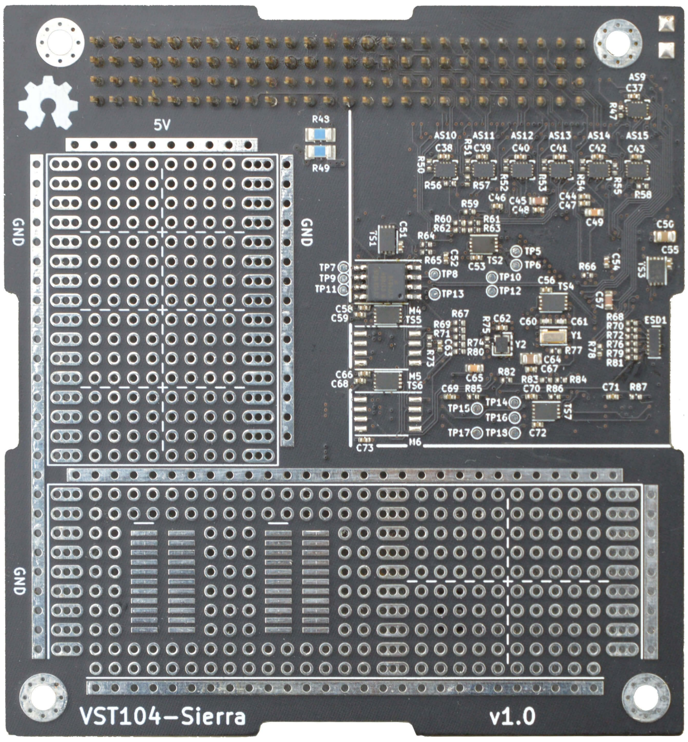


Figure 2.5.

Figure 2.6.

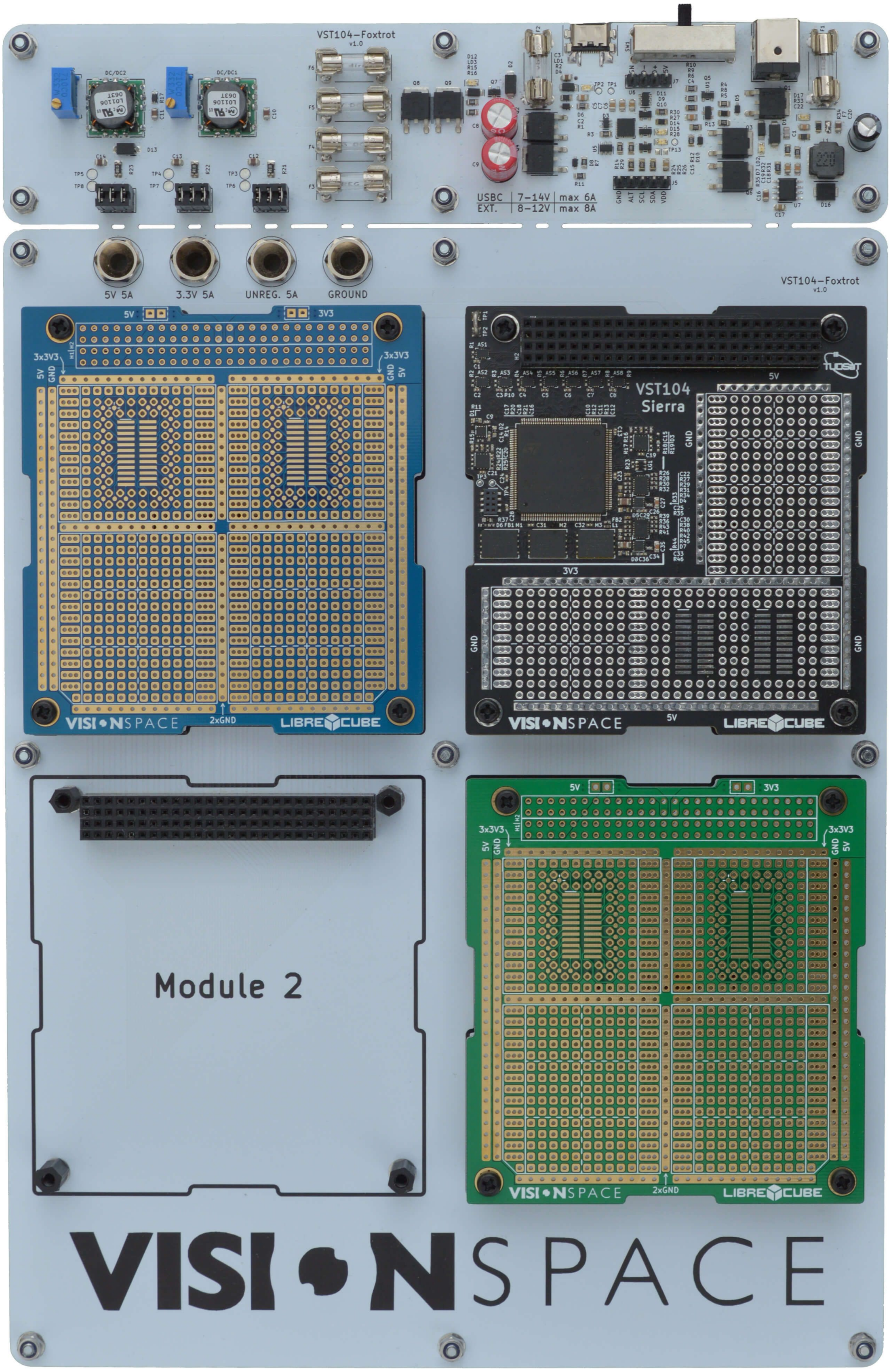
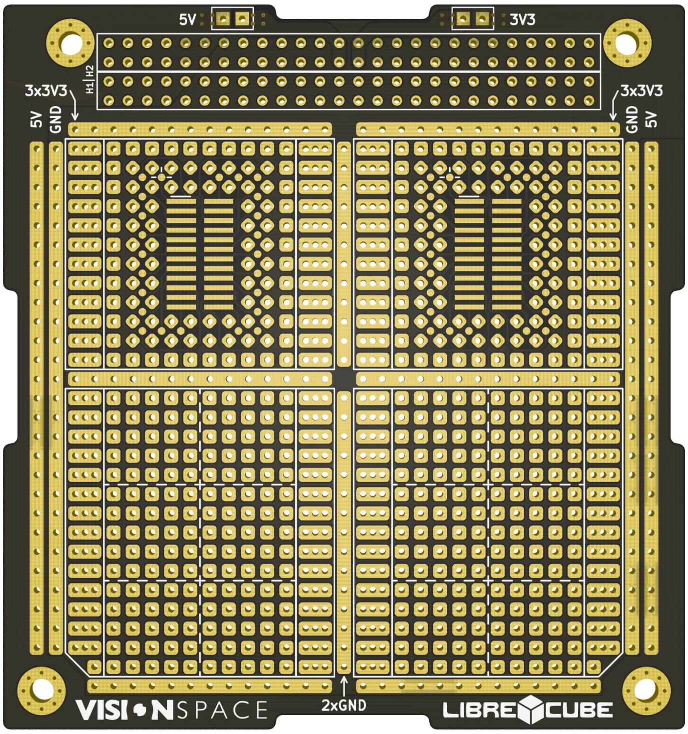

VST104–Foxtrot
v1.0
USBC 7–14V max 6A
EXT. 8–12V max 8A
5V 5A
3.3V 5A
UNREG. 5A
GROUND
VST104–Foxtrot
v1.0
VST104
Sierra
Module 2
VISIONSPACE

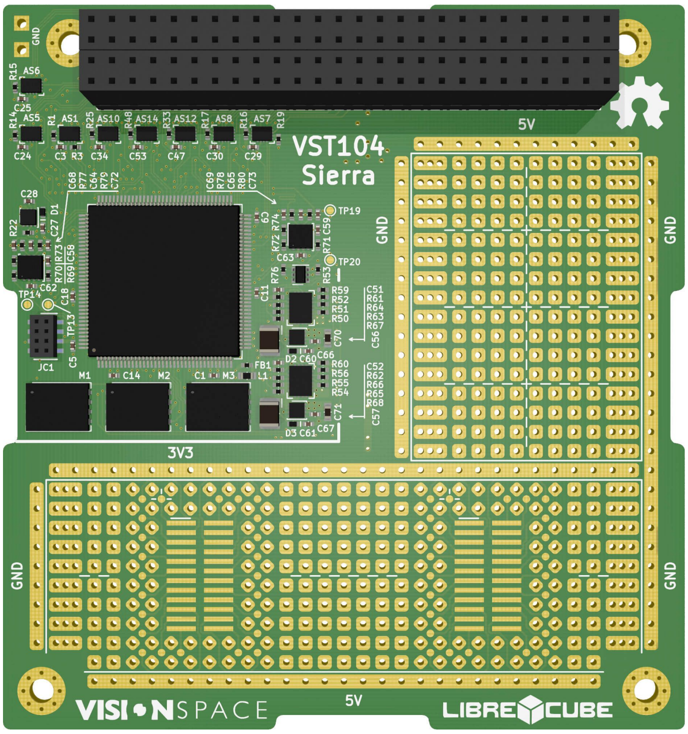
Figure 2.7.

Appendix E
Over-sized figures



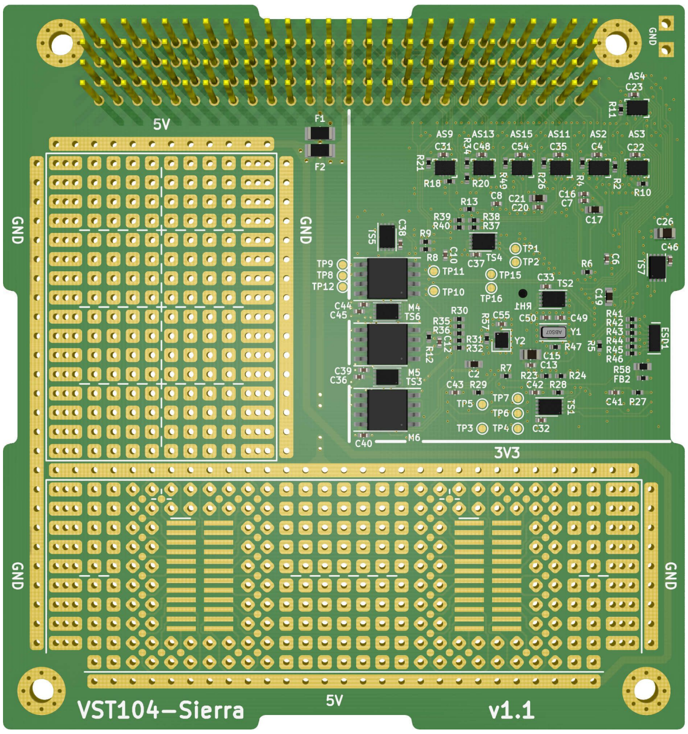
[app_vis:zeroTop]

Figure 2.8. Visualization of the Board Zero captured from its top side. The dimensions of this 3D render match the actual size of the board 1:1.



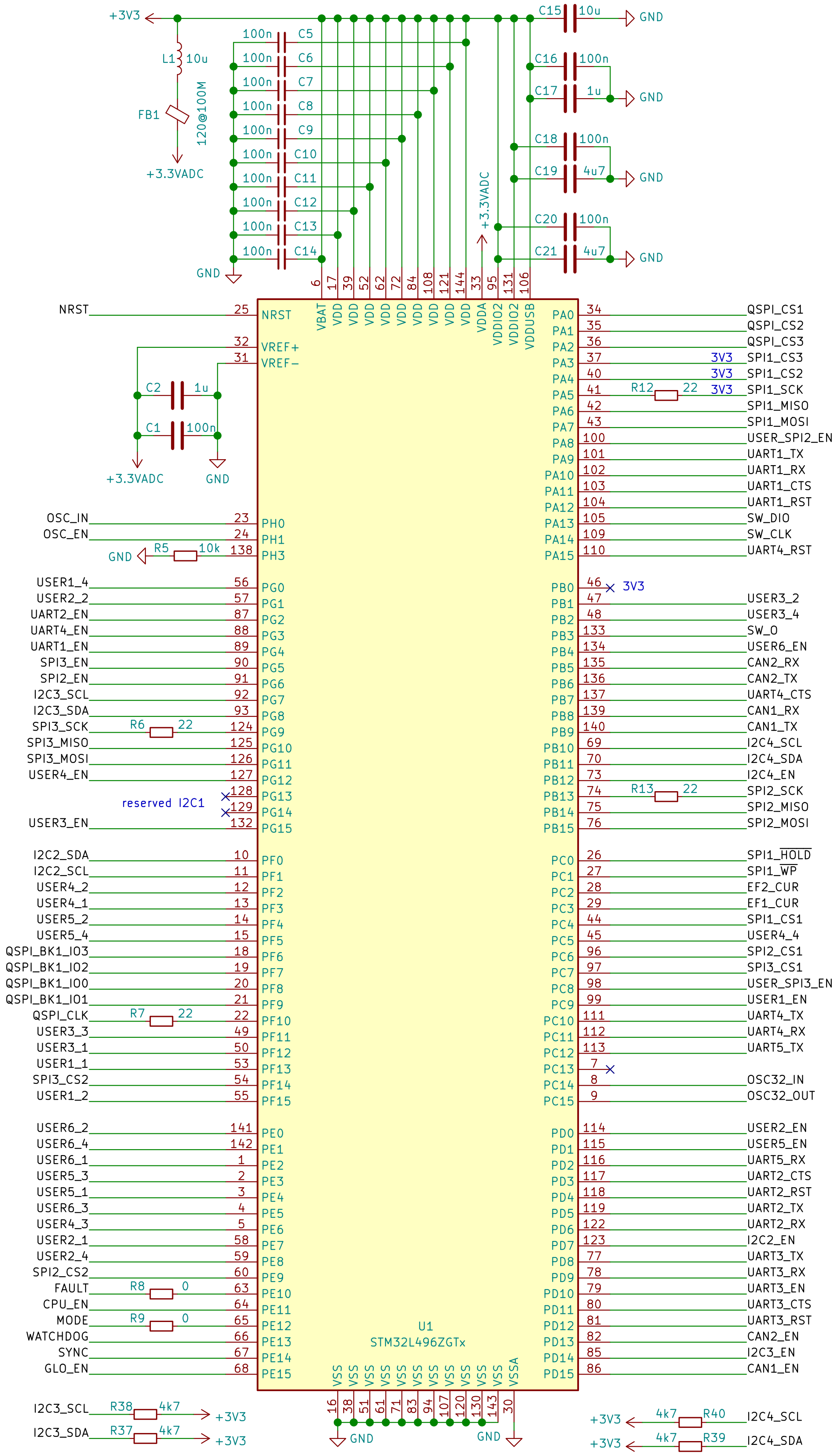
[app_vis:sierraTop]

Figure 2.9. Visualization of the Board Sierra captured from its top side. The dimensions of this 3D render match the actual size of the board 1:1.



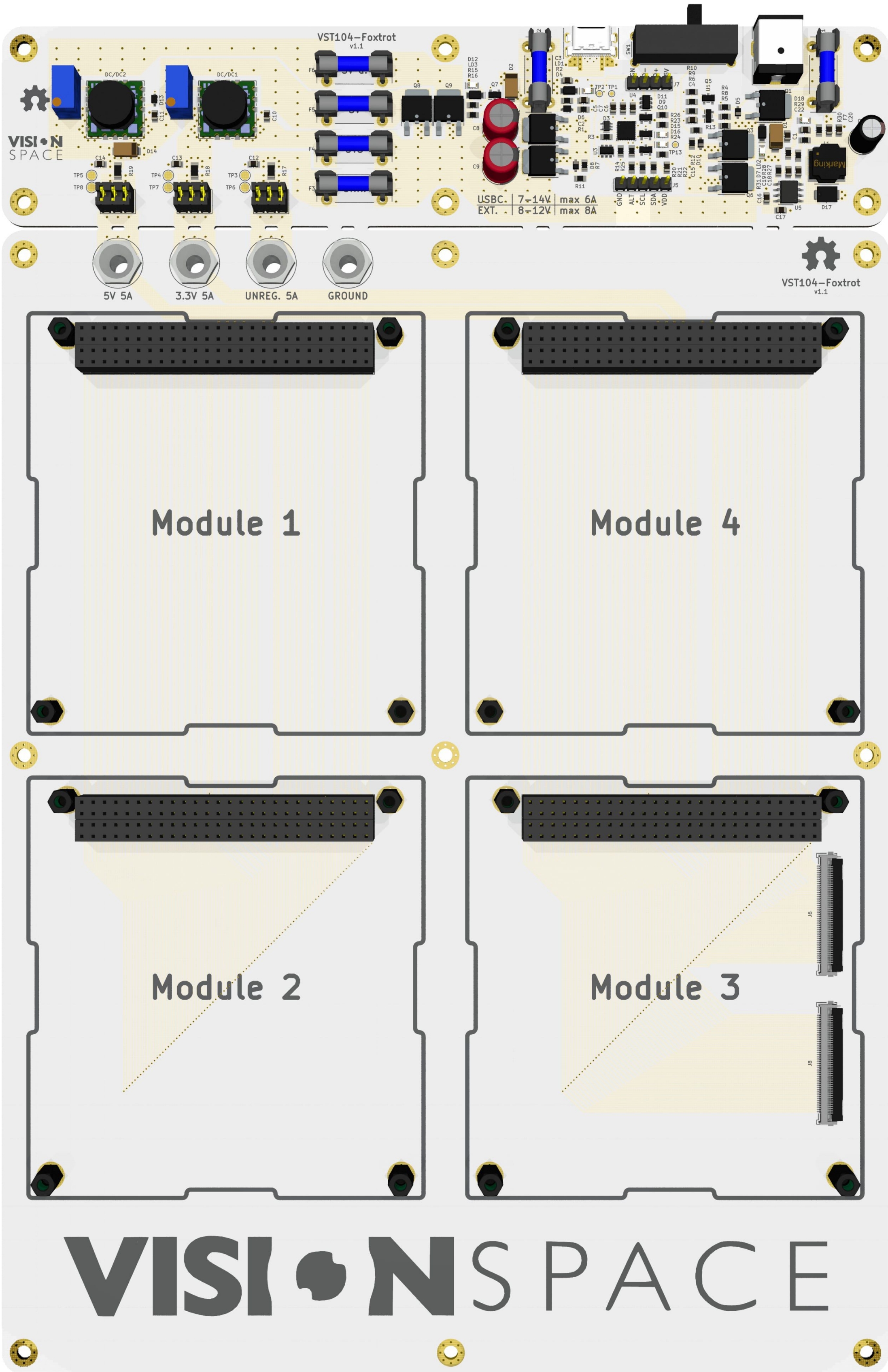
pp_vis:sierraBottom]

Figure 2.10. Visualization of the Board Sierra captured from its bottom side. The dimensions of this 3D render match the actual size of the board 1:1.



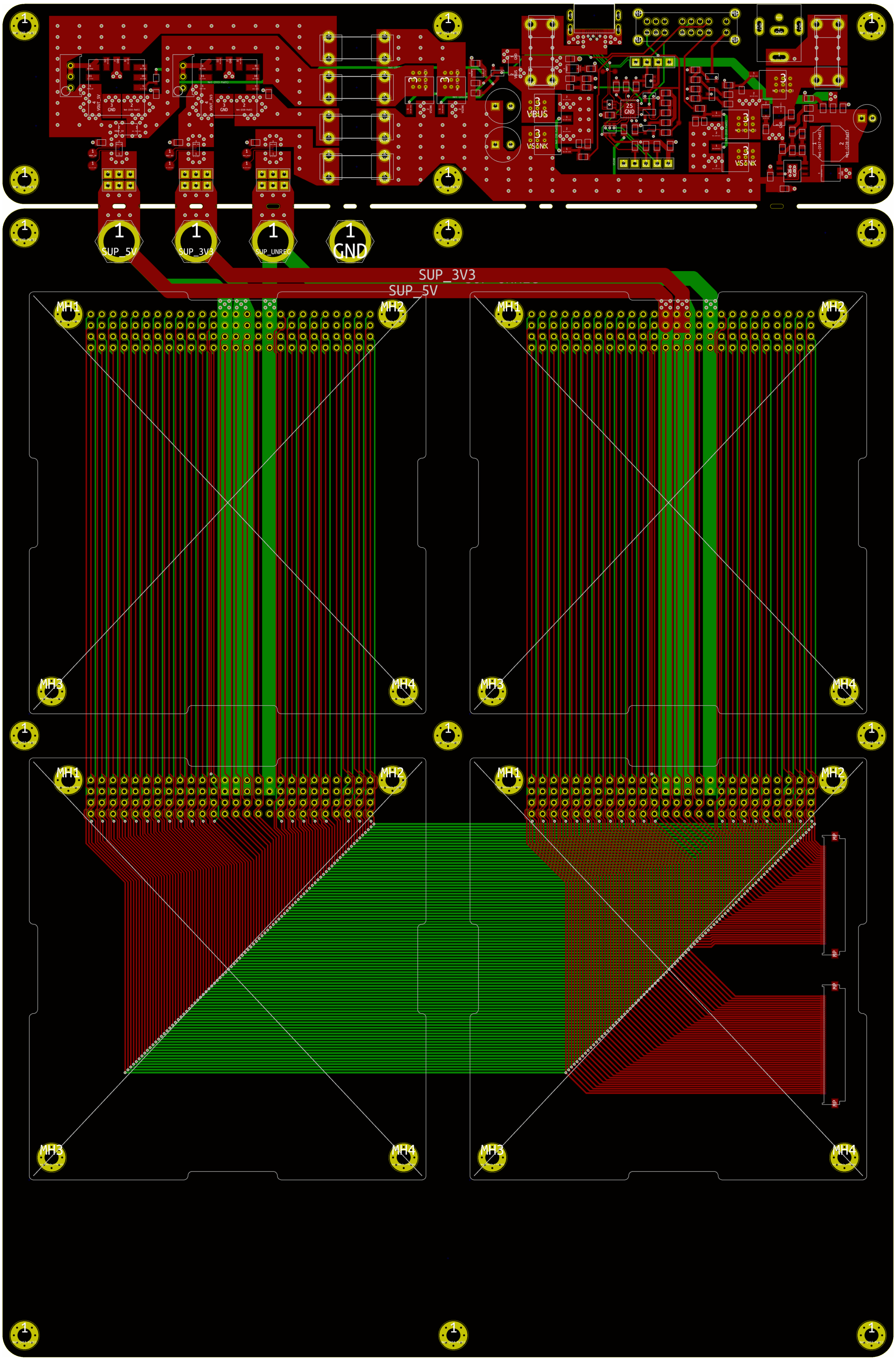
[app_sch:microcontroller]

Figure 2.11. Schematic diagram of the microcontroller and its auxiliaries.



[app_vis:foxtrotTop]

Figure 2.12. Visualization of the Element Foxtrot captured from its top side. The dimensions of this 3D render match the actual size of the board 1:1.4.



p_vis:foxtrotKicad]

Figure 2.13. PCB design of the Element Foxtrot captured directly in the KiCad environment. The dimensions of this render match the actual size of the board 1:1.4.

Appendix F
Additional materials

Designator	Power bus [V]	Current consumption [mA]		
		Min.	Typ.	Max.
AS[1-15]	5	-	0.02	0.06
EF[1,2]	3.3, 5	0.14	0.21	0.30
LG1	3.3	-	0.1	4
M[1-3]	3.3	10	25	40
M[4-6]	3.3	-	5	5
TS[1-7]	3.3	-	0.20	0.40
U[2,3]	5	-	40	70
Y2	3.3	-	4.0	4.8

mponentsConsumption]

Table 2.2. Listing of electronic components power consumption. The values were obtained from the datasheets, and correspond to the normal operation at room temperature.

Designator	Certified part no.	Uncertified part no.	Difference
LG1	74LVC1G11GW-Q100	74LVC1G11GW	auto.
M[1-3]	S25FL256LAGNFN	S25FL256LAGNFI S25FL256LDPNFI	temp. temp., speed
TS[1-7]	MCP9804x-E/MC	MCP9808x-E/MC	accuracy
Q[1-3]	TPS22965W-Q1	TPS22965-Q1 TPS22975	temp. temp., auto.

ab:uncertifiedParts]

Table 2.3. List of available uncertified variants to some of the OBCs electronic components. Legend: auto. - missing AEC certification, temp. - shrink operational temperature range, speed - decreased frequency, accuracy - decreased accuracy of measurements.

Requests for correction