Private Space Company

Nanosatellite platform «Orbicraft-Pro»

Nanosatellite Platform «Orbicraft-Pro» Interface control document

USER MANUAL

SXC ICD

Moscow 2021

ANNOTATION

This document is the source for the design and integration of onboard equipment or other payload into the Sputnix CubeSat (SXC) – Orbicraft-Pro nanosatellite platform of the CubeSat 1U (SXC1) and CubeSat 3U (SXC3) formats. The document specifies the technical requirements for the mechanical and electrical interfaces of the payloads being developed.

The following files are attached to the document

– SXC1 ICD.STEP – simplified three-dimensional model of the CubeSat 1U (SXC1) format platform.

– SXC3 ICD 2U – simplified three-dimensional model of the CubeSat 3U (SXC3) format platform.

– SXC3 ICD 1U – simplified three-dimensional model of the CubeSat 3U (SXC3-ADC) format platform with an installed orientation and stabilization system.

– SXC3 ICD 0.7U – simplified three-dimensional model of the CubeSat 3U format platform (SXC3-ADC-X) with an orientation and stabilization system installed, as well as a high-speed X-band transmitter (SXC-XTX-01).

– SXC1 PL ICD.STEP - three-dimensional model of the available payload volume for the CubeSat 1U platform

– SXC3 PL 0.7U.STEP – three-dimensional model of the available payload volume for the CubeSat 3U platform with an orientation and stabilization system installed, as well as a high-speed X-band transmitter (art. SXC XTX 01).

– SXC3 PL 1U.STEP – three-dimensional model of the available payload volume for the CubeSat 3U platform with an installed orientation and stabilization system.

– SXC3 PL 2U.STEP – three-dimensional model of the available payload volume for the CubeSat 3U platform.

VERSION HISTORY

Version Number	Date	Description
1	19.08.2021	Eletskaya: – source document
2	20.08.2021	Eletskaya: – updated to last version

TERMINOLOGY

Term	Description
SC	Spacecraft
CAN	Controller Area Network
I2C	Inter-Integrated Circuit
PSU	Power supply unit
SPI	Interface for synchronous data exchange between chips
UART	Universal Asynchronous Receiver-Transmitter

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INTRODUCTION

Name and model

Item name: Nanosatellite Platform «Orbicraft-Pro» Interface control document

Part Number: SXC IDC

The purpose and scope of the manual

The interface control document contains the information necessary for the user to develop their own payload, integrated into the product.

This document contains a description, technical characteristics of the product and the main restrictions for the equipment installed in the product.

Also, this document can be used in the development of on-board equipment compatible with the engineering solutions of Sputnix LLC.

This document is of a recommendatory nature and is not an exhaustive guide to the development of space technology.

1. RECOMMENDATION

1.1. CubeSat specification

The SXC 1 and SXC3 nanosatellite platforms are designed in accordance with the CubeSat Design Specification rev. 13 (http://emits.sso.esa.int/emits-doc/ESA_HQ/AD3_cds_rev13_final.pdf).

When designing any devices for these platforms, it is necessary to study this document and take into account the requirements.

1.2. Final characteristics of the spacecraft

The information provided in this document allows to develop devices compatible with the SXC platform, however, it is necessary to understand that they cannot completely determine the characteristics of any end spacecraft. To determine the capabilities and limitations of each specific spacecraft assembled on the SXC platform, it is necessary to conduct a comprehensive system analysis of the space system, taking into account the parameters of the orbit, the full composition of the spacecraft, the flight cyclogram and other factors.

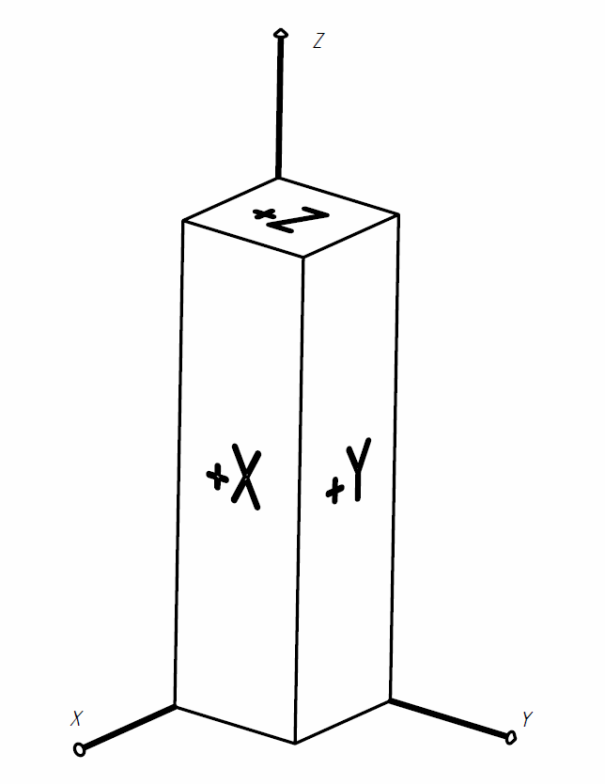


Figure 1 – Direction of the SC axes

2. INTERFACES OF THE SXC PLATFORM

2.1 SXC3 Mechanical interfaces

2.1.1 SXC3 general requirements

The payload must meet the following conditions:

1. Represent a device geometrically limited by the size of the model of the payload placement zone, depending on the configuration of the platform with service systems.

2. Have a PC104 connector for integration into the common bus of the on-board platform systems (except for cameras connected via cable).

3. The payload mass should not exceed:

– for the SXC3 modification – no more than 2200 g;

– for the SXC3-ADC modification – no more than 1700 g;

– for modification of SXC3-ADC-X – no more than 1400 g;

– for any modifications – the mass of the spacecraft assembly should not exceed 4000 g.

4. Have threaded holes M3 ensuring the installation of screws with a length of at least 4 mm. The location of the threaded holes in accordance with the corresponding models.

5. Comply with the requirements for mechanical loading given in Appendix A.

Notice – if necessary, the maximum overall dimensions of the payload can be changed in agreement with the platform developer.

2.1.2 Placement of the SXC3 payload

The payload can be placed in a volume free of service systems that do not interfere with their deployment and operation, an example of an assembled SXC3 platform with a volume for placing the payload is shown in the figure 2, solar panels and sun sensors are not shown.

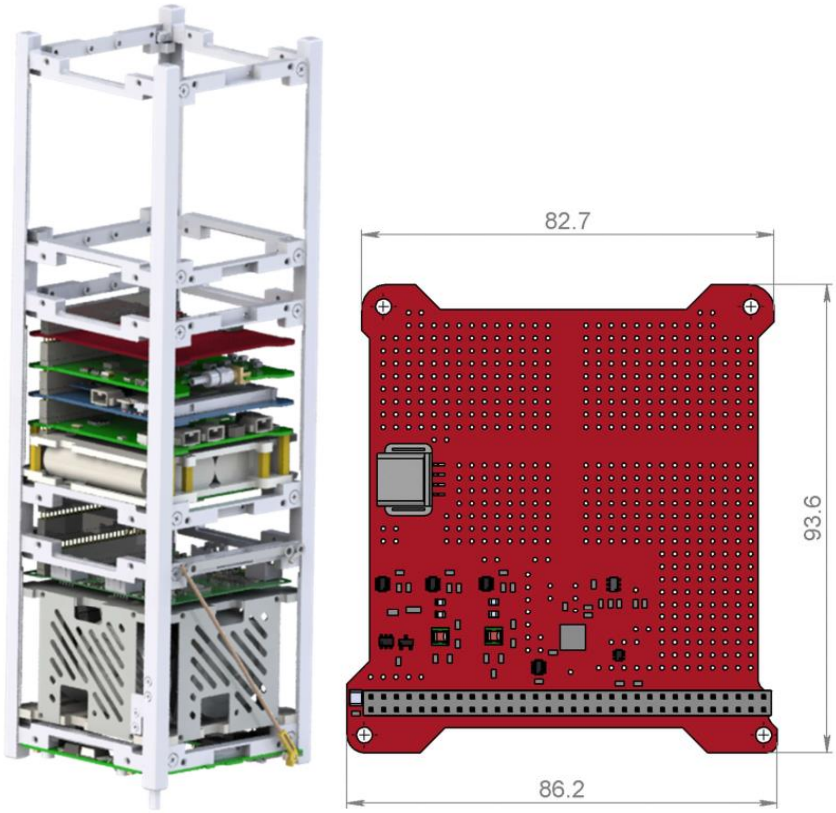


Figure 2 – Placement of the SXC3 payload

Depending on the configuration of the service systems, the volume available for the payload varies. Examples of the appearance for different configurations are shown in the figure **Ошибка! Источник ссылки не найден.**.

For each of the complete sets, a simplified 3D model of the platform and a 3D model of the available volume of the payload are attached. The developed payload should not exceed the dimensions of the model of the available volume and have landing holes and the location of the PC104 connector according to the platform model.

Table 1 – Compliance of documents with SXC3

Number	Name	3D model file	Model diagram
3	SXC3 (basic)	SXC3 PL 2U.STEP	SXC3 ICD 2U.STEP
2	SXC3-ADC (with ADCS)	SXC3 PL 1U.STEP	SXC3 ICD 1U.STEP
1	SXC3-ADC-X (witn ADCS and X-band)	SXC3 PL 0.7U.STEP	SXC3 ICD 0.7U.STEP

The platform body consists of two sidewalls (Figure **Ошибка! Источник ссылки не найден.** pos. 2) and a set of beams (Figure **Ошибка! Источник ссылки не найден.** pos. 1), designed for attaching the onboard equipment and payload to the sidewalls, that is, fixing them in the body of the SXC3 and SXC1 platforms.

Regardless of the height of a particular PN, the fixed ones should be carried out on the upper and lower landing holes, i.e. at 8 points.

It is not allowed to use magnetic fasteners as part of the payload. The following materials can be used for fasteners:

- Aluminum
- Stainless steel
- Brass
- Titanium

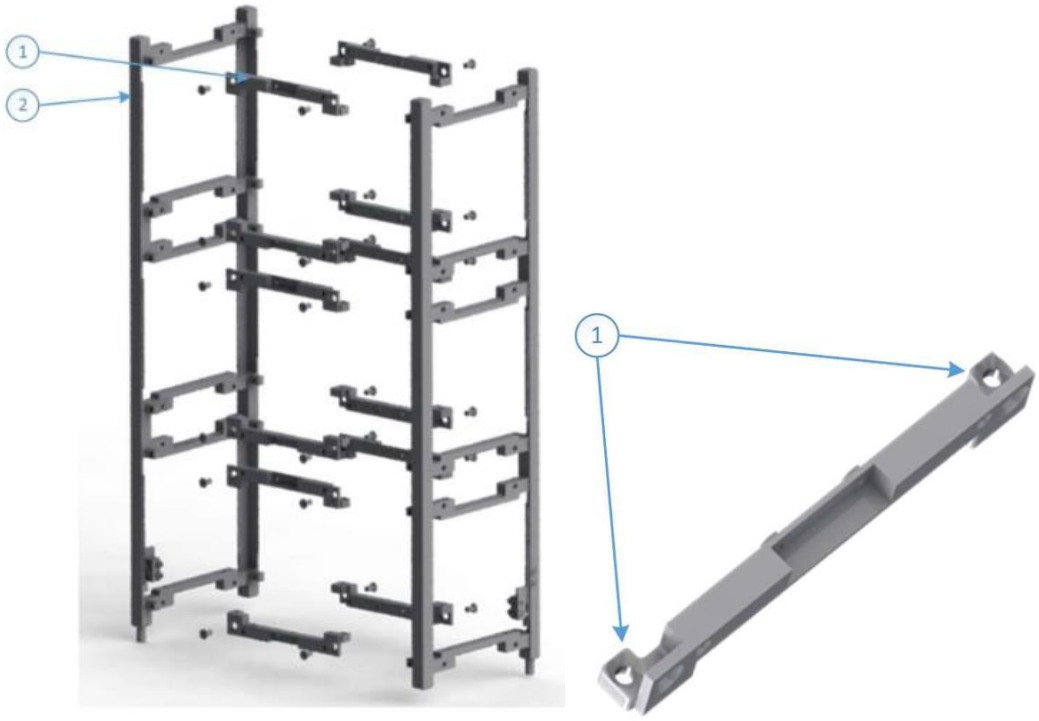


Figure 3 – Mounting the payload on the SXC3 platform

In the case when the payload is already developed and cannot be directly installed in the PC104 stack, it is necessary to develop a simple adapter board that is installed in the stack and contains a connector for connecting the payload, a quick way to develop such a board is to use the base board from the

manufacturer SXC – MBB-03, which includes the source code and the electrical circuit of the board. Mechanical fastening of non-standard payload can be provided by a transition bracket.

2.2 SXC1 mechanical interfaces

2.2.1 SXC1 general requirements

The payload must meet the following conditions:

1. Represent a device geometrically limited by the size of the model of the payload placement zone, depending on the configuration of the platform with service systems.

2. Have a PC104 connector for integration into the common bus of the on-board platform systems (except for cameras connected via cable).

3. The payload mass should not exceed 300 g.

4. Have non-threaded holes ⌀3,2 according to the model of the available payload volume for SXC1 .

Note: The payload can be performed not in the form of a board in agreement with the platform developer.

2.2.2 Placement of the SXC1 payload

The payload must meet the requirements of clause 2.2.1 and be placed in accordance with the model SX C 1 ID.STEP (Table 2).

Table 2 – Compliance of documents with SXC1

№	Name	3D model file	Model diagram
1	SXC1	SXC1 PL ICD.STEP	SXC1 ICD.STEP

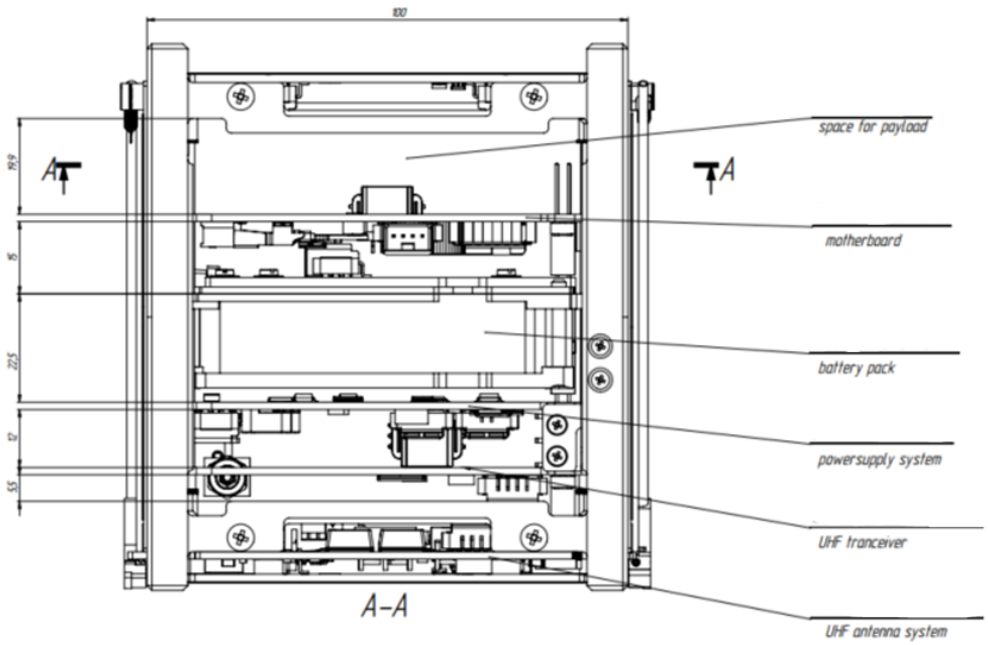


Figure 4 – Placement of the SXC1 payload

2.3 Electrical interface

The electrical connection of the payload is usually performed by installing its electronic board or adapter board into the on-board PC104 bus along with the service system boards. The pinout of the PC104 connector is shown in the Table 3. In this case, it is necessary to ensure the connection of the power supply and the data bus.

The power supply is connected via the PCH4 power channel on the PC104 connector (A9, B9), it is recommended to use both PCH4 contacts to increase the reliability of the connection. The common wire is connected at least through the PC104 GND pins-B10, A10, or through all the GND pins of the PC104 connector. The power supply of the payload with this connection will be turned on by turning on the 4th power supply channel of the PSS.

The data bus connection may differ for different types of payload:

1. The payload uses Raspberry as a data processor. In this case, the device can be connected both via a common CAN bus, and through direct connections to Raspberry, output to the PC104 connector (I2C, SPI, UART, GPIO-see the PC104

cap). After connecting and configuring the Raspbian OS, working with devices is performed using the standard OS tools.

2. The payload uses its own processor. In this case, it is sufficient for the payload to be connected only to the on-board CAN bus, however, the device must be compatible with the UniCAN exchange protocol. The simplest implementation of the protocol is the use of the source code of the basic software for a typical payload is provided when using the SXC-MBB-03 debugging product.

Special cases are the connection of a camera and USB devices. Such payload can only work with the use of Raspberry as a data processor.

To connect the camera, a special X6 «CAMERA» connector is used on the SXC-MB-04 board, which supports connecting Raspberry-compatible cameras, for example, Raspberry NoIR v2. The pinout of the X6 connector is shown in Table 5. Raspberry software is already configured to work with such a camera and standard tools for working with them, such as raspstill and raspicam, can be used. The camera is powered via the X6 connector on the OBCU.

To connect USB devices, a special X302 «USB» connector is used on the SXC-MB-04, which supports connecting USB 1.1 and USB 2.0 devices, including High-Speed connection (up to 480 Mbit/s). The pinout of the X302 connector is shown in Table 4. Through the X302 connector, the device is connected to the Raspberry, where the user can work with it using standard OS tools. The USB device can receive power via the X302 connector (100mA limit), or via the PC104 bus via the PCH4 power channel.

The combination of several payloads on one spacecraft is possible, provided that they do not interfere with the work of each other and service systems.

2.3.1Electrical parameters

The maximum input capacity of the зфндщфв on the power supply channel of the PSS is not more than 30 mF.

Signal pairing «GND» signal with the KA housing (mounting holes of the payload board) is via a parallel connection of a 10 MOhm resistor and a 3300 pF

2000V capacitor. The «GND» signal of the payload is connected directly to the GND pins of the PC/104 connector.

2.3.2Payload connectors

The connectors shown in the figure 5 can be used to connect the payload.



Figure 5 – The location of the payload connectors on the SXC3

1 – On-board PC104 bus on the service system boards, Samtec ESQ connector-132-38-G-D, used when installing boards in the main electronics stack, provides access to the Raspberry interfaces and the CAN-bus. The pinout is shown in the Table 3.

2 – Connector X302 «USB» on the SXC-MB-03 interface of the Raspberry USB module, connector type 62000411622 (Wurth Electronics), is used to connect standard USB devices, power is limited to 100 mA. The pinout is shown in the Table 4.

3 – X6 «CAMERA» connector on the SXC-MB-03 – Raspberry camera interface, SFW15R-1STE1LF (Amphenol) connector for a flat cable, used to

connect compatible cameras, for example, Raspberry Pi NoIR Camera Board, Version 2. The pinout is shown in the Table 5.

Table 3 – PC104 connector pinout

Description	Signal	Contact		Signal	Description
Reserve, do not connect	(NC)	B1	A1	(NC)	Reserve, do not connect
Positive terminal battery	VBAT+	B2	A2	VBAT+	Positive terminal battery
Negative terminal battery	VBAT-	B3	A3	VBAT-	Negative terminal battery
Channel 1 power switch	PCH1	B4	A4	PCH1	Channel 1 Power Switch
Common wire	GND	B5	A5	GND	Common wire
Channel 2 power switch	PCH2	B6	A6	PCH2	Channel 2 power switch
Common wire	GND	B7	A7	GND	Common wire
Channel 3 power switch	PCH3	B8	A8	PCH3	Channel 3 power switch
Channel 4 power switch	PCH4	B9	A9	PCH4	Channel 4 power switch
Common wire	GND	B10	A10	GND	Common wire
External power to charge the battery	VCHG	B11	A11	PEN2	External control output 2 power switches
External control output 3 power switches	PEN3	B12	A12	PEN1	External control output 1 power switches
Onboard network CAN1 – true signal	CAN1-H	B13	A13	CAN1-L	Onboard network CAN1 –inverse signal
Minus e/c X axis	COIL_X-	B14	A14	COIL_X+	Plus e/c X axis
Minus e/c Y axis	COIL_Y-	B15	A15	COIL_Y+	Plus e/c X axis
Minus e/c Z axis	COIL_Z-	B16	A16	COIL_Z+	Plus e/c X axis
Heater power battery	VHEATER	B17	A17	(NC)	Reserve, do not connect
batter module interface	PWR-TX	B18	A18	PWR-RX	AKB module interface
Dedicated power to the digital part of the battery module	3V3_SENS	B19	A19	3V3_GND	Dedicated power to the digital part of the battery module
The data signal of the debug interface module power supply system	SWDIO-PWR	B20	A20	SWDCK-PWR	The clock signal of the debug interface module power supply system
The data signal of the debug interface module	SWDIO-UHF	B21	A21	SWDCK-UHF	The clock signal of the debug interface module USR

Description	Signal	Contact		Signal	Description
The data signal of the debug interface payload module	SWDIO-PL	B22	A22	SWDCK-PL	The clock signal of the debug interface payload module
The data signal of the debug interface reaction wheel module	SWDIO-WH	B23	A23	SWDCK-WH	The clock signal of the debug interface reaction wheel module
Duplicate network CAN2+	CAN2-H	B24	A24	CAN2-L	Duplicate network CAN2-
Reserved, do not connect	(NC)	B25	A25	(NC)	Reserved, do not connect
Onboard computing unit with payload interface – UART0	CPU-TX0	B26	A26	CPU-RX0	Onboard computing unit with payload interface – UART0
Onboard computing unit with payload interface – UART1	CPU-TX1	B27	A27	CPU-RX1	Onboard computing unit with payload interface – UART1
Reserved, do not connect	Reserved	B28	A28	Reserved	Reserved, do not connect
Onboard computing unit with payload interface – USB (power supply 5V)	CPU-MOSI	B29	A29	Reserved	Reserved, do not connect
Onboard computing unit with payload interface – SPI	CPU-MISO	B30	A30	CPU-SCLK	Onboard computing unit with payload interface – SPI
Onboard computing unit with payload interface – SPI	CPU-NSS1	B31	A31	CPU-NSS0	Onboard computing unit with payload interface – SPI
Onboard computing unit with payload interface – I2C	CPU-SDA	B32	A32	CPU-SCK	Onboard computing unit with payload interface – I2C

The red signals highlighted in the table are the signals required for connection in the payload, in particular:

– PCH4 – the power channel dedicated to the payloads is controlled by the PSS by turning on, the voltage of the positive terminal of the battery is applied;

– GND – common wire;

– CAN1-H, CAN1-L – connecting the device to a common onboard bus.

In blue, the table lists the signals available for working with the payload, if necessary:

– SWDIO-PL, SWDIO-CLK – connecting a two-wire interface for debugging and programming output to the service connector of the assembled SC (by default, SWD, but any 3.3V interface is available);

– CAN2-H, CAN2-L – connecting the device to a redundant common onboard bus (not used).

– CPU-xxx – signals from the Raspberry CM3 slot located on the SXC-MB-04 board.

The remaining signals are used by the SC service systems and their connection to the payload boards must be agreed with the manufacturer.

Table 4 – X302 «USB» connector pinout

Pin	Signal	Description
1	CM_VBUS	USB power bus (100 mA or less)
2	CM_D_P	Differential data line
3	CM_D_N	Differential data line
4	GND	Comon wire

Table 5 – X6 «CAMERA» connector pinout

Pin	Signal	Description
1	GND	Comon wire
2	CAM1_D0_N	Differential data line 0
3	CAM1_D0_P	Differential data line 0
4	GND	Comon wire
5	CAM1_D1_N	Differential data line 1
6	CAM1_D1_P	Differential data line 1
7	GND	Comon wire
8	CAM1_CK_N	Differential data line CLK
9	CAM1_CK_P	Differential data line CLK
10	GND	Comon wire
11	CAM1_IO0	Camera control signals (1)
12	CAM1_IO1	Camera control signals (2)
13	CV_I2C0_SCL	Camera control interface
14	CV_I2C0_SDA	Camera control interface
15	3V3	Power channel 3V3 RPI



IMPORTANT! The onboard equipment must be galvanically disconnected from the housing with a resistance of at least 1 mOhm.

When developing on-board equipment, it is recommended to use the SXC-DK-02 development kit. Also, to speed up the development, the SXC-MBB-03 base boards can be used, the following materials are available for delivery:

- electrical schematic diagram;
- technical description;
- basic software project with source code and bootloader (optional);
- programmer's guide.

The basic boards of the SXC-MBB-03 are fully mechanically, hardware - and software - compatible with other systems of the Orbicraft-Pro platform and represent an implementation of the rules of good design and programming, provided for modification into final devices. It is also available to conduct training on the integration of devices into the Orbicraft-Pro platform from the manufacturer.

2.4 Information interface

The onboard devices for information exchange uses the CAN-2B interface and the UNICAN protocol.

To develop own software, can be used both own equipment made in accordance with 4.3 and 4.4, and the Raspberry CM3 module installed in the SXC-MB-04 OBCU board.

To control the Orbicraft-Pro platform systems connected to the UNICAN on-board bus, it is recommended to use the Sputnix Houston Control Center software. This software supports work with direct connection to the on-board bus and work via a radio channel as part of the MCC.

To speed up and simplify development, the delivery of the SXC-MBB-03 baseboard includes the source code of an example program for a microcontroller embedded on the board with the unican library, which allows exchange data over this protocol. Also included is a custom protocol description file for Houston Control Center.

2.4.1 Addressing in the Unican protocol

The protocol UniCAN requires assigning individual addresses to each device. Each packet contains the address of the source of the message and the address of the receiver, which are transferred to the identifier field CAN-frame. The placement of addresses in the bits of the standard and extended identifiers is shown in the tables 6 and 7, respectively. Bit «Data» (D.) is set to «1» when transferring data.

Table 6 – The placement of addresses in the standard identifier field of CAN-frame

Identifier field bits										
10	9	8	7	6	5	4	3	2	1	0
Data	Sender's address					Recipient's address				

Table 7 – The placement of addresses in the extended identifier field of CAN-frame

Identifier field bits										
10	9	8	7	6	5	4	3	2	1	0
Data	Sender's address					Recipient's address				

2.4.2 Message ID in the UniCAN protocol

All messages sent in format UniCAN, contain a message id field (MSG_ID), which is not identical to the identifier CAN-frame. Field values MSG_ID determine exactly which data is included in the package, and how this data should be interpreted. Field MSG_ID similar to the destination port number in the protocol TCP. Message ID is 16-bit number in format little-endian. Message IDs in range FF00…FFFF reserved as service data and should not be used to transfer user data.

2.4.3 Format of the message in the UniCAN protocol

The protocol supports the transmission of messages of three formats - short messages, long messages and error messages.

Short messages allow to transfer the data no longer than 6 bytes. They are transmitted by one CAN-frame. The length of the data is determined by the length of the frame carried in the field DLC CAN-frame, minus two bytes to pass the

message id. The field «Data» of short messages is always zero. Control of the correctness of the transfer is provided by the checksum CAN-protocol. The structure of the data field CAN-frame is shown in the table 8.

Table 8 – Data field of CAN-frame when transmitting short UniCAN-message

Data field bytes of CAN-frame							
0	1	2	3	4	5	6	7
MSG_ID		Data 0	Data 1	Data 2	Data 3	Data 4	Data 5

Messages that have a value of zero in the «Data» field and have less than two in the field DLC, are incorrect and should be ignored.

Long messages consist of several CAN-frames. General structure of transmission by example 26-bit message is shown in the table 9. Detailed frame with the command «Start» is shown in the table 10.

Table 9 – Long Message Format

Start command			Data 0..7	Data 8..15	Data 16..23	Data 24..26+ CRC
FFFE	MSG_ID	Len				CRC

Table 10 – The format of the command to start a long message

Data field bytes of CAN-frame					
0	1	2	3	4	5
Start ID 0xFFFE		MSG_ID		Length	

All subsequent frames coming from the same device, but with the data bit set to «1», until the number of data bytes equal to the packet length Length (including the checksum, but not including the start command itself), are considered as data of this message. In the last two bytes of a long message, a checksum is written

(CRC16 X-modem). The checksum is calculated for the sending data, not including the transfer start command. All messages marked «Data» that were not preceded by a correct message about the beginning of the transfer are ignored.

2.4.4 Recommended content of the telemetry

It is recommended to divide the payload telemetry into the following types:

– receipts;

– regular;

– extended;

– service.

Receipts are sent in response to the command, if it does not imply the issuance of a response packet. This allows the operator to be sure that the command has passed, because it will always receive some kind of response: the requested data or a receipt. A positive receipt (code messageId = 0x118) is issued if the command is received correctly. Negative (messageId = 0x119) – if the command or its parameters are incorrect. Commands whose messageId code is not processed by the system can be ignored without a receipt.

Regular telemetry has a small size (up to 60 bytes) and can be issued automatically with a specified period or on request. Such telemetry contains the data necessary to assess the overall state of the system – temperature, power parameters, the amount of accumulated data, operating time, etc. The recommended period of such telemetry is 1-2 seconds, by default it is enabled.

Extended telemetry has a larger volume (up to 200-300 bytes) and can also be issued automatically or on request. It contains data necessary for a more detailed analysis of the device status, but which is used less often: data from all sensors, the current configuration, etc. The recommended period of such telemetry is 10-30 seconds, by default it is disabled.

Service telemetry is issued only on request and contains technological data for the developer of the payload.

It is recommended to send a short single packet immediately when switching on with the result of self-diagnosis of the system.

2.4.5 Telemetry address and maximum packet size

In the on-board SXC bus, the sender's address indicates which device on the bus will process the packet, the following cases are possible:

– sending to the address 0x1 – initiates the transmission of this packet to Earth via the UHF channel.

– sending to the address 0x2 – initiates the reception of the packet by the UHF transceivers themselves, this can be used to accumulate data for a radio beacon periodically sent by the UHF transceiver to the radio channel.

– other addresses – processing by the corresponding on-board device.

Maximum packet size to send to Earth via the UHF:

– when using the AX protocol.25 – no more than 204 bytes;

– when using the USP protocol – no more than 184 bytes.

IMPORTANT! Do not allow mass uncontrolled data transfer to the address 0x1. This may lead to the inability to receive commands from the Ground for the entire board.

2.4.6 Using the bootloader

Sputnix provides a CAN bootloader for the microcontroller as part of the SXC-MBB-03 baseboard. It is strongly recommended to use it or develop your own, which allows to flash the device in orbit. This approach saved more than one payload.

2.4.7 Using the telnet terminal and transferring files

The UniCAN protocol and the UHF transceiver ensure the operation of the telnet console and file transfer, if these functions are supported by the payload. For their correct implementation, it is necessary to consult with Sputnix company.

2.5 Electromagnetic compatibility

The payload must not have emitters that create electromagnetic interference with the operation of other systems.

In the case of payload`s emission in the receiving band of the on-board transceiver (400-403 MHz and 430-440 MHz), the power level at the input of the on-board receiver should not exceed 30 dBm.

It is recommended to use SMT electromagnetic filters on the power line for the connectors of external cable connections, as well as on the filters on the input power of the payload connector PC104.

It is recommended to use EMI filters on CAN-DLW21SN921SK2 or an analog.

3. TECHNICAL POSSIBILITY OF THE SXC PLATFORM

3.1 Maximum permissible values

When developing a payload, it is possible to focus on the capabilities of the SXC platform indicated in Table 11. It should be taken into account that this data are a pessimistic forecast, however, more accurate values can be obtained only by knowing the parameters of the target spacecraft.

Table 11 – Technical possibility of the SXC platform

Parametres	**Min**	**Typical**	**Max**	**Note**
Supply voltage PCH3, PCH4, V	5,5		8,5	
Peak current consumption per channel, A			1,5	
Power consumption for payload*, mW for a 90-minute turn with a 45-minute illuminated part, with GaAs solar panels, solar orientation				
SXC1			700	
SXC3			4000	
SXC3-ADC			2500	
SXC3-ADC-X			2000	
The volume of daily data on the UHF channel for payload*, Mb				
The ISS orbit, for one ground station with a total communication duration of 6 min AX. 25 at a speed of 4800		1		
The ISS orbit, for one ground station with a total communication duration of 8 minutes USP at a speed of 9600		4		
Digital interfaces	CAN2B/UART/SPI (2xCS)/I2C/USB 2.0			USB 2.0 with a special cable

* - the data is for reference and requires clarification for a specific spacecraft

When developing specific devices based on the platform, the values from the table can be adjusted up.

APPENDIX A. Modes of mechanical testing of the payload

The flight axis of the SC is determined by the installation of the launch container in the upper stage, and therefore, in 100% of cases, it is not possible to determine its direction in advance. Taking this into account, it is necessary to conduct mechanical tests on all axes as for the worst case (i.e., choose the most stringent test mode for each of the axes).

The values of operational loads are defined as the values of qualifying loads divided by the safety factor corresponding to a specific loading case (Table A4).

1. Modal tests

Modal tests should be carried out in the frequency range from 4 to 2000 Hz with an amplitude of 0.2 g. The frequency change rate is not more than 1 oct / min.

2. Quasistatic accelerations

Below are the preliminary (conservative) levels of qualification quasistatic loads that must be taken into account when analyzing the strength and qualification of the payload.

The qualification values of linear quasistatic accelerations should be taken equal to 10g in the direction of the flight axis and equal to 5-9g in each of the transverse directions with an exposure time of 10 minutes along each of the axes.

Note: It is allowed to conduct quasistatic tests with harmonic vibration at a frequency equal to 0.25-0.3 * F1, where F1 is the first natural frequency.

Loading on the vibration stand can be carried out either by an ordinary sine with a constant amplitude at a frequency selected from the specified range, or by a set of «Sine Burst». At the same time, it is necessary to first conduct tests on each of the axes at operational levels with times:

– 180 s on the flight axis;

– 30 s on each of the side axes.

To demonstrate the reserve durability, it is necessary to conduct a test at the qualification loading levels for 2-3 seconds on each of the axes.

3. Vibration effects

The qualification modes in each of the 3 mutually perpendicular directions at the mounting points of the payload are given:

– for harmonic vibration in the frequency range up to 20 Hz in Table A1 (the change in the amplitudes of vibration accelerations within each frequency subband is linear);

– for random vibration in the frequency range from 20 to 2000 Hz in Table A2 (the change in the spectral density values from the frequency within each frequency subband is linear at the logarithmic scale of the frequency and spectral density).

Table A1 – Qualification levels of sinusoidal vibration

Flight events (operational stage)	Period, s	Frequency range, Hz		
		2 – 5	5 - 10	10 - 20
		Vibration acceleration amplitude, g (g = 9,81 m/s^2)		
operation of the launch vehicle stages	600	0,5	0,5-1,0	1,0

Note: If, according to the results of model tests, the natural frequencies of the payload are higher than 40 Hz and qualification for quasistatic loads is carried out, then harmonic vibration tests in the frequency range up to 20 Hz are not allowed to be carried out.

Table A2 – Qualification levels of random vibration

Operation stage	Mode duration, s	Frequency subbands, Hz						rms acceleration
		20-50	50-100	100-200	200-500	500-1000	1000-2000	
		Spectral density of vibration acceleration, g^2/Hz						
Operation of the	120	0.02	0.02	0.02-0.05	0.05	0.05-0.025	0.025-0.013	7.42

launch vehicle stages	480	0,02	0,02	0,02	0,02-0,008	0,008-0,004	0,004-0,002	3.58

4. Impact effects

The qualification levels of the shock spectrum for all axes are shown in the Table A3.

The shock spectrum corresponds to the Q-factor Q = 10. The number of impacts is 5.

Table A3 – Qualification levels of the shock spectrum when the launch vehicle separation systems are triggered

Frequency, Hz	100-200	200-500	500-1000	1000-2000
Acceleration of the shock spectrum A_s, g	30-60	60-255	255-750	750

Note

Table A4 – Safety coefficient

Type of loading	Coefficient
Quasistatic accelerations	1,3
The amplitude of vibration accelerations	1,5
Spectral density of vibration accelerations	2,0
Load duration, s	2,0
Shock spectrum from separation systems	1,5