X2-Series Standard Electrical and Mechanical Specifications

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Introduction

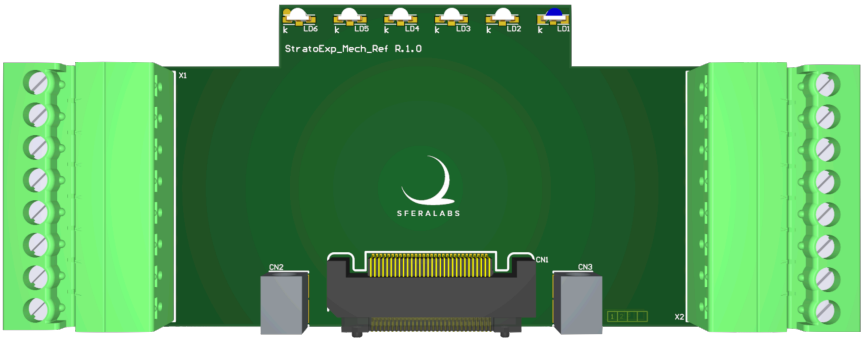
X2 is an electrical and mechanical standard developed by Sfera Labs for the design of expansion boards for the Strato Pi Max family of edge servers, as well as for future products.

The goal of the X2 standard is to define a compact mechanical format for expansion boards that fit into a standard size DIN-rail enclosure, allowing a significant number of lines on pluggable terminal blocks.

The electrical and functional specifications of the X2 standard also aims at making the hardware and software design relatively simple and very flexible.

The connection lines and standard buses implemented in the X2 backplane connector are simple to implement and are arranged to integrate well into host systems with a hybrid CPU/MCU architecture, like the Strato Pi Max family.

The Strato Pi Max also serves as a reference hardware and software implementation of a host system with full support of the X2 expansion boards.



THE X2 EXPANSION BOARD MECHANICAL FORMAT

X2 Electrical and Functional Standard

Power Supply and Power-Up Sequence

The X2 boards main supply is a +5V rail available at multiple pins of the board-to-board connector. All 5V pins should be wired together on the X2 expansion board.

All ground pins should also be connected together.

The X2 board standard includes an identity EEPROM which works when the expansion slot 5V supply is turned off too. The host system can probe the boards before turning on the expansion slots, eventually keeping the slot off in case of compatibility conflicts, like a UPS board being installed in slots other than slot #1.

X2 compatible host systems should not automatically turn on the 5V rail of an expansion slot if a board is not detected or not identified on that slot, is installed in the wrong slot, or is incompatible with other installed boards.

The host may remove the 5V voltage to an X2 slot to save power when a board is not needed or for any other functional reason. While the 5V is not available to an expansion board, the other data lines may still be powered and working. This is particularly true for the shared buses, like I2C and SPI.

The X2 boards must be designed to enter a safe state when 5V is not present, accepting voltage on all other data lines and ensuring that all data lines are not prevented from working normally.

The maximum amount of current that an X2 board can draw from the 5V rail should not exceed 3A, but the host is not required to be able to deliver this amount of current to each board, as all boards share a common 5V regulator. The power budget is application dependant and should be negotiated between the expansion boards and the host.

The X2 boards also receive the host's power supply input voltage (Vin), after protection circuits. This is not switched, and is always present as long as the host is receiving power from its main supply input, or from another X2 UPS board.

Only X2 UPS expansion boards[1], fitted in slot #1, may supply voltage through the Vin pins. All other X2 boards should use Vin only to monitor the Vin voltage, or to receive power from the host at Vin level.

Reverse voltage protection is provided by the host, while X2 boards using the Vin line must implement their own overvoltage protection and current limiting circuitry.

Board Identity EEPROM

Each X2 board is equipped with a 1-Wire identity EEPROM, used by the host system to detect the presence and read the type and serial number of the boards installed in each expansion slot.

The EEPROM IC is an Analog Devices / Maxim Integrated DS28E05, a 112-byte user-programmable EEPROM organized as 7 pages of 16 bytes each. Memory pages can be individually set to write protected or EPROM emulation mode through protection byte

[1] The X2 standard that covers UPS expansion board functionality is not part of this document.

settings. Each part has its own guaranteed unique 64-bit ROM identification number (ROM ID) that is factory programmed into the chip.

The 1-Wire data line is connected to pin EEID_M of the board-to-board connector. These pins are all connected together and routed to a GPIO line of the host system.

The ground pin goes to EXPn_EEID_EN_M(N) of the board-to-board connector. In order to identify which board is connected to each expansion slot, the host system grounds this line on one slot at a time, then handshakes on the 1-Wire data line to read (or write) the EEPROM.

There are no other connections needed, so this EEPROM also works when the expansion slot 5V supply is turned off.

The first two pages, page 0 and page 1, are reserved for factory-configured data, including the board type id. Applications should only set data in these pages during initial factory provisioning. Pages 2 to 6 are available for customers applications.

Unique board type ids are issued exclusively by Sfera Labs on request.

Board Identity EEPROM Data Format

Board type id format scheme 1 uses the first four bytes of page 0:

Addr	Value
00h	A7h
01h	type
02h	type
03h	type 1-complement

Board I2C I/O Expander and Slot Addresses

Two pins on the X2 connector, I2C_ADDR_BIT_0 and I2C_ADDR_BIT_1, are required to be either wired to ground or left floating based on the slot number on the host system.

Slot #	I2C_ADDR_BIT_0	I2C_ADDR_BIT_1
1	GND	GND
2	Float	GND
3	GND	Float
4	Float	Float

Another pin on the X2 connector is reserved to be used to expand physical slot addressing in future versions.

If the X2 board needs to know its slot position, it should pull-up these lines to either 5V or 3.3V.

The X2 standard reserves four I2C addresses on both the MCU and CPU I2C buses so that a board connected to one of the four slots is guaranteed to have a dedicated I2C address.

Slot #	I2C Reserved Address
1	24h
2	25h
3	26h
4	27h

This comes particularly handy when using an I2C I/O expander that needs to have a unique address based on the slot position.

These reserved addresses are compatible with the Microchip MCP23008 and MCP23017 8 and 16 bit I/O expanders.

Connecting the I2C_ADDR_BIT_0 and I2C_ADDR_BIT_1 with pull-ups to the A0 and A1 address lines of these expanders configures them use the I2C addresses according to the X2 dedicated addresses per slot.

Expansion Boards Interconnection

Several lines of the X2 connector are reserved for the interconnection of multiple expansion boards connected to a host. Note that the host CPU/MCU are not required to be connected or drive these lines, the host board only provides passive interconnections between the X2 slots.

All these lines are required to be safe with 3.3V logic. No other requirements are set by the X2 standard.

Four lines, EXP_BUS_1 to EXP_BUS_4 are a parallel bus connecting the corresponding pins of all slots.

Four other lines, EXPn_FW_LNK_1, EXPn_FW_LNK_2, EXPn_BK_LNK_1 and EXPn_BK_LNK_2 are used to create a two-lines round-robin link between the slots.

I2C, SPI and USB Buses

I2C

The X2 connector carries two distinct I2C buses, one connected to the host's CPU (the Raspberry Pi Compute Module in Strato Pi Max) and one to the host's MCU (the Raspberry Pi RP2040 microcontroller in Strato Pi Max).

The host system is required to have 3.3V pull-up resistors on these lines, and X2 expansion boards should not have internal pull-ups.

The X2 standard assumes that X2 expansions boards use the I2C buses as slaves, with the host CPU and MCU being masters.

X2 boards must be able to avoid conflicts with any other I2C devices connected to the same bus, to support speeds that are compatible with all other devices and ensure they never lock the bus or prevent other devices from working properly.

The X2 boards may use the I2C buses differently, e.g. as master, but only if the different behaviour is negotiated and supported by the host's application logic.

The X2 standard doesn't set any specific requirement on which function needs to be implemented on one bus or the other, if any. It all depends on the host's firmware and application support for the specific expansion board.

SPI

The X2 connector carries two distinct SPI buses, one connected to the host's CPU (the Raspberry Pi Compute Module in Strato Pi Max) and one to the host's MCU (the Raspberry Pi RP2040 microcontroller in Strato Pi Max).

The host system is required to have 3.3V pull-up resistors on these lines, and X2 expansion boards should not have internal pull-ups.

The X2 standard assumes that X2 expansions boards use the SPI buses as slaves, with the host CPU and MCU being masters.

X2 boards must be able to avoid conflicts with any other SPI devices connected to the same bus, to support speeds that are compatible with all other devices and ensure they never lock the bus or prevent other devices from working properly.

The X2 standard doesn't define a specific SPI chip select mechanism. The expansion board can be designed using the appropriate solution, and implementing it in the host system's software. Each X2 connector has two lines driven by the host CPU and two by the MCU, which could be conveniently used as chip select lines.

The X2 boards may use the SPI buses differently, e.g. as master, but only if the different behaviour is negotiated and supported by the host's application logic.

The X2 standard doesn't set any specific requirement on which function needs to be implemented on one bus or the other, if any. It all depends on the host's firmware and application support for the specific expansion board.

GPIO

The X2 connector offers a total of four 3.3V GPIO lines. Two of these lines are connected to GPIO pins of the CPU on the host system, and two to its MCU.

The X2 standard defines these lines as general purpose digital I/O on the host system. There are no required pull-up or pull-down lines and no required protection circuits. The only assumption is that these lines are dedicated to each X2 slot on the host system.

The X2 boards must be designed so that these lines are compatible with the X2 host system, both electrically and functionally.

USB

The X2 connector has one USB 2.0 High Speed (480Mbps) and Full Speed (12Mbps) compatible interface, to connect a USB slave interface on the X2 board.

The differential pair should be routed as a 90Ω differential pair. The length of the P/N signals should ideally be matched to better than 1.0mm.

Board to Board Connector Pinout

Pin	Signal	I/O	Description
1	Reserved		UPS lines on slot #1; not connected on slots #2, #3, #4
2	Reserved		UPS lines on slot #1; not connected on slots #2, #3, #4
3	Reserved		UPS lines on slot #1; not connected on slots #2, #3, #4
4	Reserved		UPS lines on slot #1; not connected on slots #2, #3, #4
5	Reserved		UPS lines on slot #1; not connected on slots #2, #3, #4
6	Reserved		UPS lines on slot #1; not connected on slots #2, #3, #4
7	Not Connected		Leave not connected
8	Not Connected		Leave not connected
9	GND		Ground (0V)
10	GND		Ground (0V)
11	Vin (Input)		Power supply input voltage, after protection circuits
12	Vin (Input)		Power supply input voltage, after protection circuits
13	Vin (Input)		Power supply input voltage, after protection circuits
14	Vin (Input)		Power supply input voltage, after protection circuits
15	GND		Ground (0V)
16	GND		Ground (0V)
17	5V (Input)		Main 5V power input, after expansion slot power switch
18	5V (Input)		Main 5V power input, after expansion slot power switch
19	GND		Ground (0V)
20	GND		Ground (0V)
21	EEID_M	I/O	Identity EEPROM 1-Wire I/O data line (3.3V)
22	SPI_CLK_C	I	SPI clock from CPU (3.3V pull-up)
23	EXPn_EEID_EN_M(N)		Identity EEPROM ground
24	SPI_MOSI_C	I	SPI MOSI from CPU (3.3V pull-up)
25	GND		Ground (0V)
26	SPI_MISO_C	O	SPI MISO to CPU (3.3V pull-up)
27	EXPn_INT_M(N)	O	Expansion slot interrupt line to MCU I/O (3.3V pull-up)
28	EXPn_GPIOx_C	I/O	GPIO to CPU (3.3V)
29	EXPn_FW_LNK_1	I/O	Connects to line EXPn_BK_LNK_1 of next expansion slot
30	EXPn_GPIOx_C	I/O	GPIO to CPU (3.3V)

Pin	Signal	I/O	Description
31	EXPn_BK_LNK_1	I/O	Connects to line EXPn_FW_LNK_1 of previous expansion slot
32	GND		Ground (0V)
33	GND		Ground (0V)
34	SPI_CLK_M	I	SPI clock from MCU (3.3V pull-up)
35	EXPn_FW_LNK_2	I/O	Connects to line EXPn_BK_LNK_2 of next expansion slot
36	SPI_MOSI_M	I	SPI MOSI from MCU (3.3V pull-up)
37	EXPn_BK_LNK_2	I/O	Connects to line EXPn_FW_LNK_2 of previous expansion slot
38	SPI_MISO_M	O	SPI MISO to MCU (3.3V pull-up)
39	GND		Ground (0V)
40	EXPn_GPIOx_M	I/O	GPIO to MCU (3.3V)
41	EXP_BUS_1	I/O	Expansion slot bus, line 1 (3.3V)
42	EXPn_GPIOy_M	I/O	GPIO to MCU (3.3V)
43	EXP_BUS_2	I/O	Expansion slot bus, line 2 (3.3V)
44	GND		Ground (0V)
45	EXP_BUS_3	I/O	Expansion slot bus, line 3 (3.3V)
46	I2C_SDA_M	I/O	I2C SDA I/O line to MCU (3.3V pull-up)
47	EXP_BUS_4	I/O	Expansion slot bus, line 4 (3.3V)
48	I2C_CLK_M	I	I2C clock from MCU (3.3V pull-up)
49	5V (Input)		Main 5V power input, after expansion slot power switch
50	GND		Ground (0V)
51	5V (Input)		Main 5V power input, after expansion slot power switch
52	I2C_SDA_C	I/O	I2C SDA I/O line to CPU (3.3V pull-up)
53	Reserved		Leave not connected
54	I2C_CLK_C	I	I2C clock from CPU (3.3V pull-up)
55	Reserved		Leave not connected
56	GND		Ground (0V)
57	I2C_ADDR_BIT_1	I	Grounded on slots #1, #2, not connected on slots #3, #4
58	EXPn_USB_P	I/O	USB 2.0 P line to CPU
59	I2C_ADDR_BIT_0	I	Grounded on slots #1, #3, not connected on slots #2, #4
60	EXPn_USB_N	I/O	USB 2.0 N line to CPU

X2 Mechanical Standard

The X2 mechanical standard defines the PCB dimensions and components placement constraints on the X2 expansion boards. X2 host systems must also consider these constraints to ensure mechanical compatibility.

The standard prescribes the use of a few specific components, or fully equivalent alternatives, like the board-to-board connector, and also recommends the use of specific terminal blocks and front-panel LEDs.

The Dimensions section below shows all mechanical constraints and components positions on the circuit board.

LEDs

The X2 expansion boards may have up to 6 front-panel LEDs. The model and position of these LEDs is defined in order to match the standard Strato Pi Max front panel cutouts and marks.

The standard doesn't define a specific use for these LEDs, that are optional, or color, but offers a few guidelines for consistency across different boards:

- LD1 is a blue LED indicating that the expansion board is turned on
- Preferred LEDs are:
  - Würth Elektronik WL-SMSW series mono-color
  - Würth Elektronik WL-SBSW series bi-color
  - Würth Elektronik WL-SFSW series tri-color
- The LEDs drive current should be set to achieve a similar perceived light intensity for all LEDs. For reference, the blue power LED is driven from 5V and a 4.7 kOhm resistor.

Terminal Blocks

An X2 expansion board may have pluggable terminal blocks or other connectors on both sides of the board.

The X2 compatible host systems are required to have enclosure cutouts that are compatible with the Würth Elektronik WR-TBL Series 322 - 3.81 mm Horizontal PCB Header and matching WR-TBL Series 361 - 3.81 mm Vertical Plug.

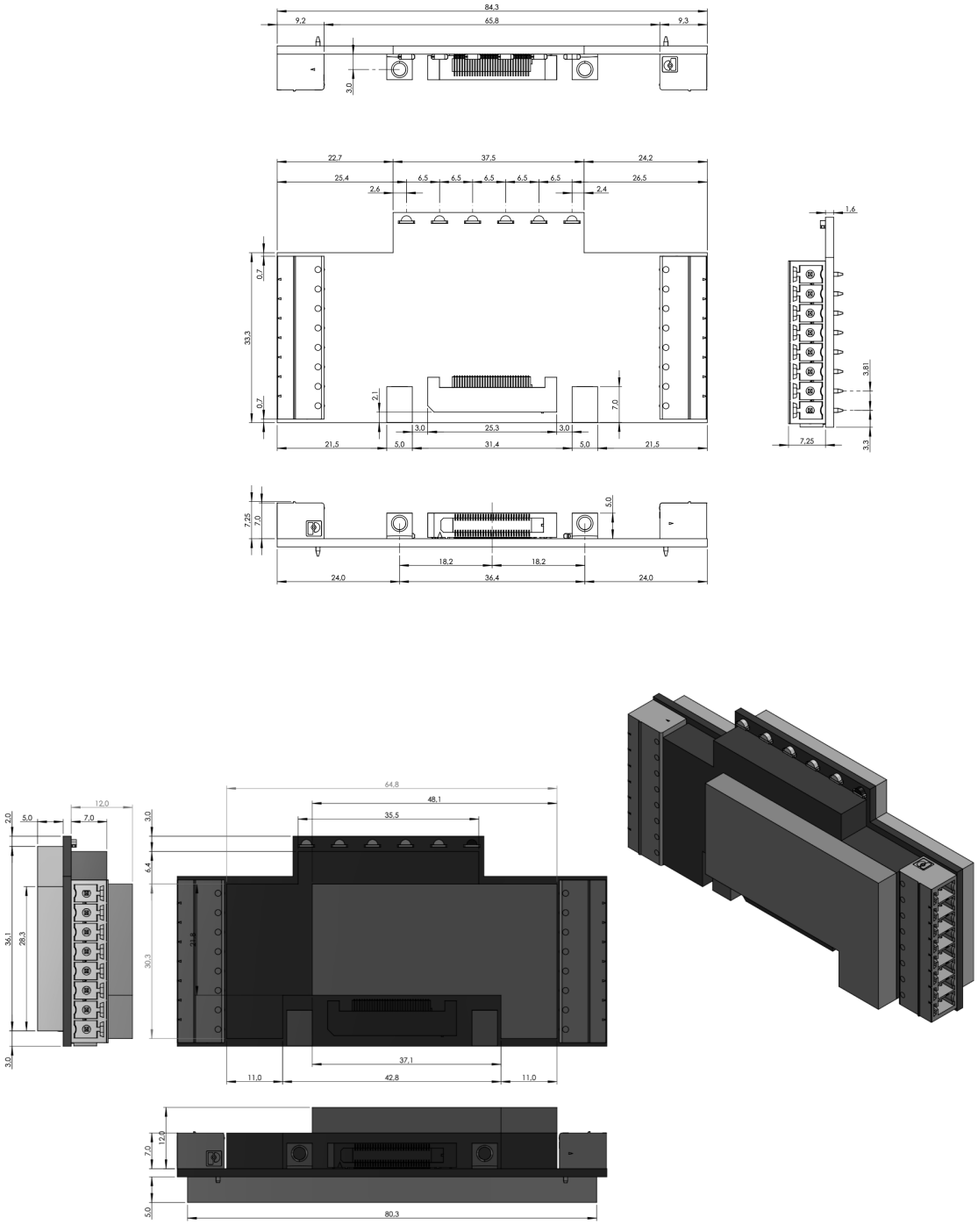
Bill Of Material

The following components are required to meet the X2-Series electrical and mechanical specifications. Fully equivalent components are allowed, but not recommended.

Des.	Manufacturer	P/N	Description
CN1	Samtec	ERF5-030-01-L-D-RA-TR	ERF5-Series high-speed 60 positions board to board connector
CN2	Wurth Elektronik	7466303	WP-SMRA REDCUBE
CN3	Wurth Elektronik	7466303	WP-SMRA REDCUBE
U1	Analog Devices	DS28E05R+T	1-Wire EEPROM

Dimensions

In order to be compliant with the X2-Series specifications, custom boards should respect the circuit board size, components positions and available volume for components placement as shown below. Note that components can be placed on both sides.



X2-SERIES STANDARD DIMENSIONS (mm)