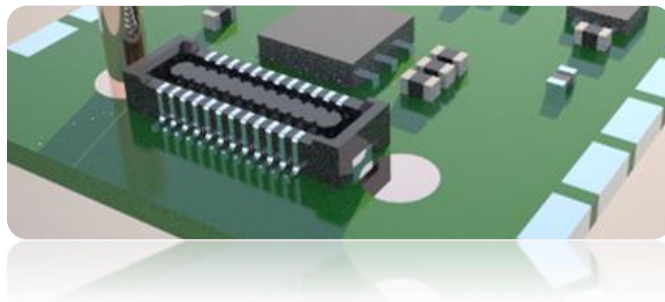




Open Interface Standard for Low Power Internet of Things



Document Version 0.1.4

Version History

| | | |
|------------|-------|--|
| 2015-02-20 | 0.1.4 | Language fixes, better pictures, signal chart added. |
| 2015-02-18 | 0.1.3 | Series resistor of RINT rethought. Interrupts chapter made more accurate. |
| 2015-02-17 | 0.1.2 | First release, document ready to be published. |
| 2015-02-12 | | New pictures, more detailed descriptions. A version to be shared for small audience. |
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| 2015-02-06 | | Document ready for early reviewing, sent for small audience. |
| 2015-02-04 | | First version of this document. Multi-purpose pins defined. |
| 2014 | | Some signal changes, first "aistin bus" |
| 2013 | | First adaptation of the bus by a third party ("Ruuvitracker") |
| 2013 | | Product line utilizing the bus brought to market ("iProtoXi Micro" –family) |
| 2012 | | First version of the bus, a prototype device ("iProtoXi Micro") |

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Introduction

Today's microcontrollers are very flexible devices and there is a wide range of development kits available. While most of them are microcontroller manufacturer specific, there is also a famous independent platform called Arduino. Due to its popularity, also third parties are offering so called *shields* that can be used to add more functionality on top of the actual Arduino processor board (Figure 1). These shields may contain sensors, such as ambient light sensor or air pressure sensor, or they may implement some connectivity function, such as wireless radio interface (e.g. WLAN), or they may have relays for controlling motors, and so on.

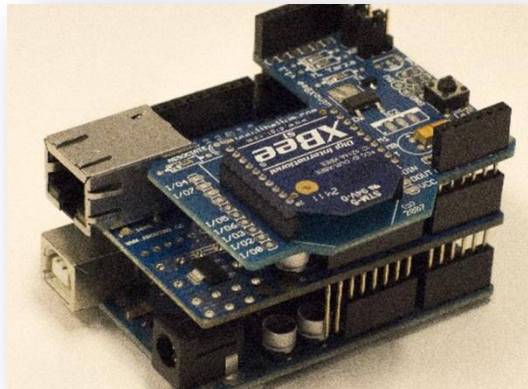


Figure 1. Photo from <http://www.theskyway.net/tag/arduino/>

However, there is two problems with those shields, the first one being incompatibility. Lack of any real standard, or even any winning de-facto solution, has led to very unpractical situation. For example, a shield designed for Arduino “Uno” won’t fit into Arduino “Fio”. The other reason is the big size. Although many shields can be stacked together, the resulting wholeness is soon unusable in many practical cases. It becomes just a desktop prototype.

As a contrast, today's small surface mount components would make possible to build a *wrist prototype*, if there would be a small solution for attaching the building blocks together. This paper presents an open interface designed to make small low power devices modular and easily expandable, yet cost effective (Figure 2). The proposed **AISTIN BUS24**, or shortly **BUS₂₄**, standard includes signal descriptions and connectors as well as recommended module sizes, the smallest being only 12 x 12 mm². In addition to connectors, standard circuit board soldering land-patterns and pads are defined. The solution is not just for prototypes, but fits for end products as well.

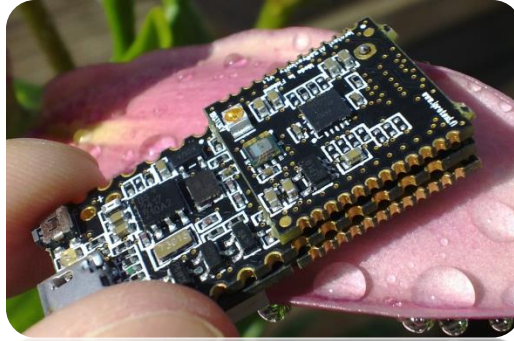
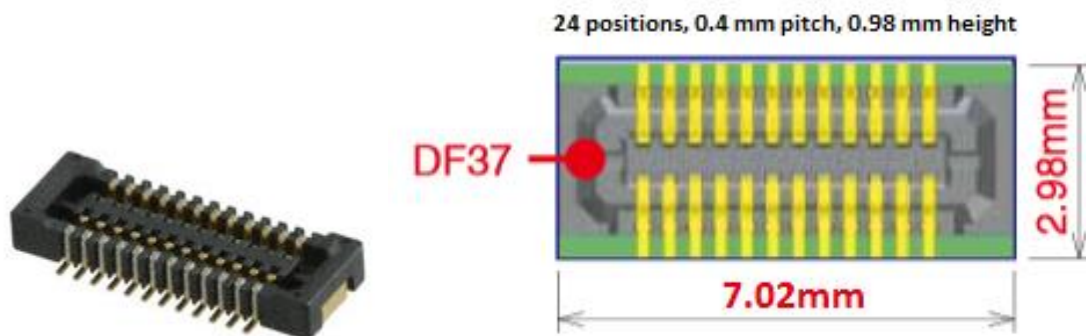


Figure 2. An MCU board with two add-on boards connected together using early version of **BUS₂₄**

Connectors

A very small 24-contact two-row board-to-board connector with 0.4 mm pitch was selected as the basement of the bus. The pin count is a trade-off between connector size and number of available signals. Physical measures are illustrated in the picture below (Hirose DF37NB-24DS-0.4V(51), for details, open the pdf-link). The connector is widely available, reliable, cheap, and provides compact solution to join two small circuit boards together.



Female side of the connector

Circuit board area needed for the connector

Figure 3. The selected connector.

http://www.hirose.co.jp/cataloge_hp/ed_DF37_20140305.pdf

There are different male and female halves. To further ease the plugging of connector halves together and to guide user for correct positioning, a small optional pin of diameter 0.3 mm was added to the other end of the female connector. The pin length is 1.88 mm so as to reach the corresponding hole at male side, when using 0.5 or 0.6 mm boards. For other board types the pin length must be adjusted accordingly. This pin also makes possible to solder circuit boards together in case a robust connection is needed. Female connector was selected to become the *host* connector, whereas male side was defined to be *add-on board* connector. The signal pins are numbered as shown in the pictures below.

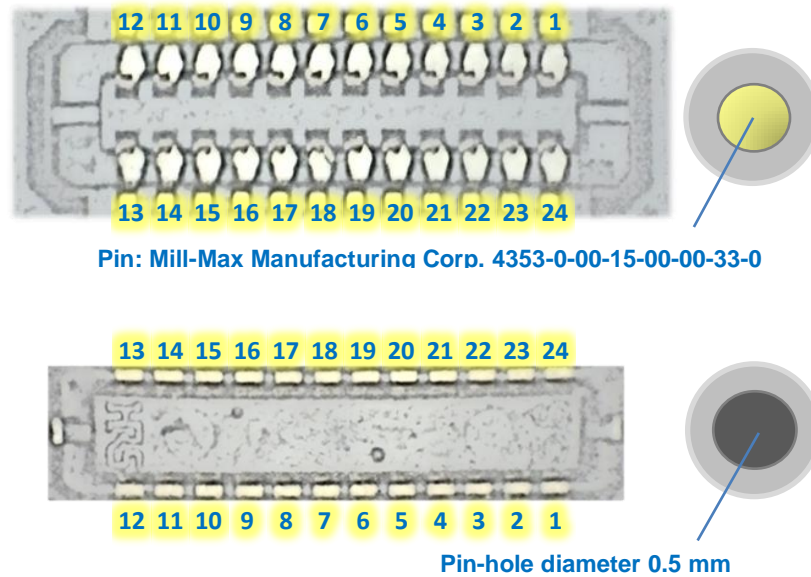


Figure 4. Connector pin numbering.
Top: female connector with the guiding pin, used on the host board.
Bottom: male connector with the guiding hole, used on the add-on board.

The profile design measures in millimeters are shown in Figure 5. The mentioned pin is meant to be used with board thickness of 0.6 mm. If the pin is not used, there should be a possibility to fix boards together with a suitable sticker. When connectors are plugged together, the height left between the boards is 0.98 mm. This also sets maximum height of other components that can be installed on the area that is covered by an add-on board. Although the space in-between the boards seems small, most of the today's low-profile components will still fit there.

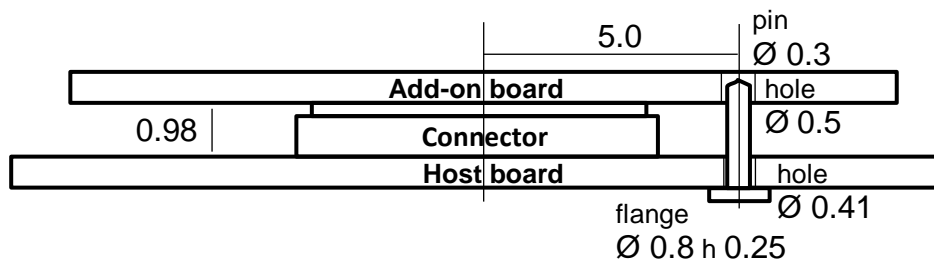


Figure 5. Connector and pin measures in millimeters.
Add-on board plugged onto the host board, side view.

Standard Board Dimensions

There are no limitations or recommendations for the host board physical dimensions. Also, the thickness of the host board is free, but the guiding pin length must be adjusted accordingly so that its top measures 1.3 to 1.5 mm from the board surface. Add-on board thickness should always be from 0.5 mm to 0.7 mm in order to deal correctly with the pin and possible standard mechanics (such as device covers). The bigger standard add-on board measures 16 mm by 17.5 mm (max), producing 280 mm²

(BUS₂₄-16). The smaller one is 12 mm by 12 mm, giving 144 mm² board area (BUS₂₄-12). There are some additional requirements for the boards' shapes and connector placement as illustrated in the Figure 6 below. The height of the add-on board's components is not limited, but it is up to the host housing designer if the height for add-on boards is limited or not. The host circuit board must take care of BUS₂₄ slots as shown in Figure 7.

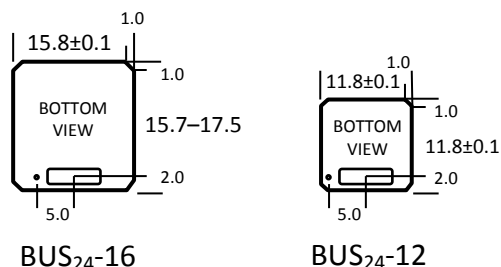


Figure 6. Add-on board dimensions in millimeters, two alternatives supported.

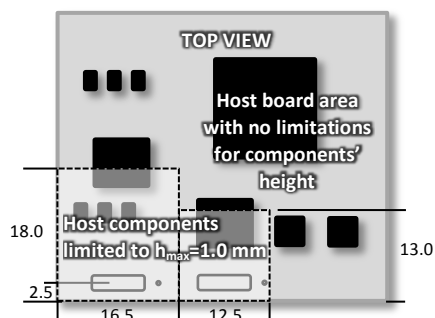


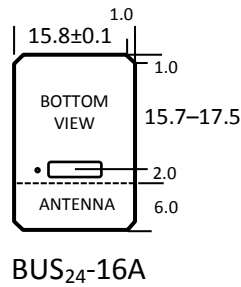
Figure 7. An example of a host board with slots for BUS₂₄-16 and BUS₂₄-12.

Extended Add-On Board

For bigger add-on boards, such as displays, an extended BUS₂₄-16 –based add-on board is defined. Board should be extended only by stretching its length, while the width should be kept fixed at 15.8 mm. Recommended maximum length is 30 mm to provide some hint for host board designers. The length of an extended add-on board can be identified by using a marking like BUS₂₄-16x30.

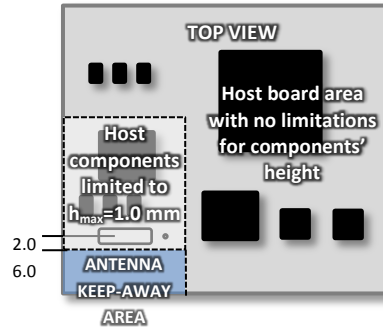
Antenna Considerations

There are special positioning and size considerations for radio boards having board antenna, or crystal antenna, in order to position the antenna optimally. First, the host must offer the connector in such a place that there is extra 16 mm by 6 mm free area for antenna. That area must not be on top of any components, copper layer or any other metal disturbing radio signals. The measures for radio add-on board with antenna are shown in Figure 8, with related reservations for the host board. However, the antenna keep-away area is not needed if the connector is placed as shown in Figure 7. In that case, the antenna will extend out of the board borders having considerations for housing.



BUS₂₄-16A

a) Radio board



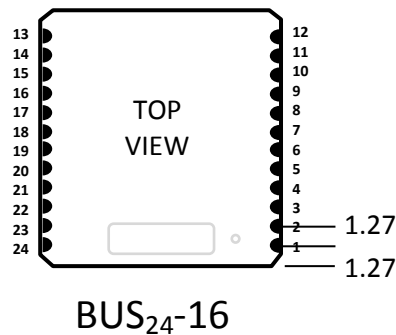
b) Host reservations for radio board

Figure 8. Radio add-on board dimensions with integrated antenna.

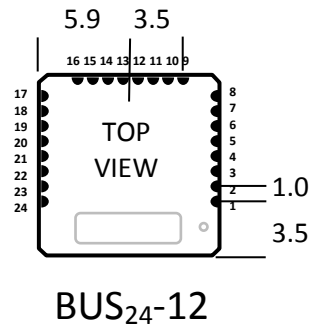
There's no need to take antenna extension into consideration, if no add-on radio will be needed, or if radio boards to be used do not have integrated antenna. The alternative is to have antenna coaxial connector on the add-on board, thus the actual external antenna can be installed away from the board and no keep-away areas will be needed.

Add-on Board Soldering Pads

Add-on boards can have optional soldering pads at the sides of the board to make fixed mounting (soldering) possible on the host board. In that case, connector must be left away and the host must not have components over the add-on board slot. All the BUS₂₄ signal pads are not necessary, but unused pads may be left off. Figure 9 shows positioning of the pads (in mm) and the corresponding BUS₂₄ signal numbering.



BUS₂₄-16



BUS₂₄-12

Figure 9. Add-on board soldering pads with signal numbering.

Stacking Boards

Add-on boards can be stacked on top of each other, if a host side connector (female) is wired from the bottom connector onto the top side. However, many sensors need to have free room on top, so that option is often not feasible. Also, the guiding pin cannot be used in stacked case.

Optional Host Signal Pins

If a host is having signal pins e.g. for debugging BUS₂₄ signals, the pins must be set up as shown in the Figure 10 (0.64 mm pins). That makes possible to make bigger compatible “shields” (BUS₂₄-18) in addition to the small add-on boards. BUS₂₄-16 and/or BUS₂₄-12 slots may be provided in-between the pins. As well, host components may be placed there.

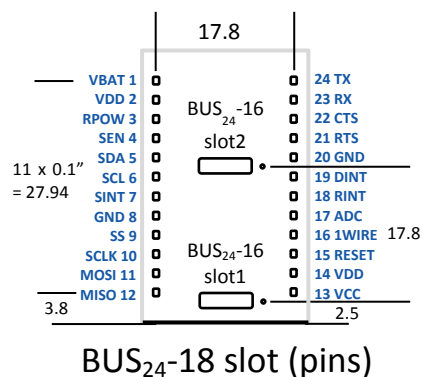


Figure 10. Placement and signal order of optional host signal pins (0.1" spacing).
Two BUS₂₄-16 add-on boards fit in between the pins, example connector positions shown.
Note that host components may be placed also to the slot areas, as long as they are lower than 1 mm.

Signals

The most common related industrial standards are supported: Two-wire (I²C), RS232 serial interface (UART), serial peripheral interface (SPI) and one-wire. In addition, there are several other signaling pins, most important being dedicated interrupt lines and power control to enable power-saving features. The *primary* pin allocations with signal acronyms are shown in Figure 11.

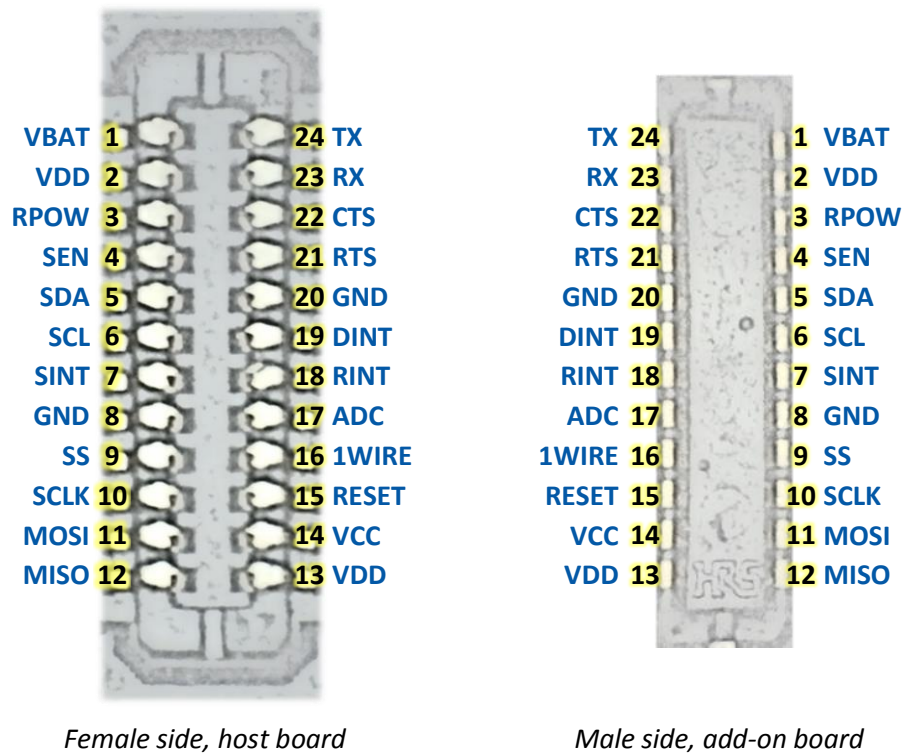


Figure 11. Connector pin allocations for bus signals (pin and hole at top, not shown).

The bus supports three-volt devices with range 2.8 – 3.4 V. Primary signal functions ¹ are listed in table below. Since modern microcontrollers have possibility to configure the same pin for different purposes, the bus also defines several alternative functions for most of the pins. These are marked with numbers ^{2...5} to distinguish from primary functions. However, all of the functions do not need to be implemented. There are alternative signal sets discussed in the next chapter.

| Pin | Name | Function(s) |
|-----|------|--|
| 1 | VBAT | Battery output. In a typical host configuration, this pin is directly wired into the supply battery. The voltage value depends on the used battery, but it must be no more than 4.5 volts. If the system has no battery, the pin must be wired into VDD. |
| 2 | VDD | Regulated power supply. The voltage depends on host implementation, but must be within range 2.8 – 3.4 V. The pin must be able to source minimum of 50 mA. |

| Pin | Name | Function(s) |
|-----|------|--|
| 3 | RPOW | ¹ Output, active high: radio power enable. This pin is used to turn ON any radio (rf transmitter) connected using add-on board. Pin must be able to source at least 5 mA. If a radio board needs more, the pin must be used as an on/off-switch only (using e.g. a FET), and the power must be sourced from power pins (VBAT, VDD or VCC). ² GPIO3 General purpose input/output |
| 4 | SEN | ¹ Output, active high: sensor/add-on board enable. The signal is used to power-up components on add-on boards, other than radio boards. Pin must be able to source at least 5 mA. If this is not enough for an add-on board, the pin must be used as an on/off-switch only, and the power must be sourced from power pins (VBAT, VDD or VCC). ² GPIO4 General purpose input/output |
| 5 | SDA | ¹ Two-wire interface, data. At least 400 kHz mode must be supported in master and slave modes. ² GPIO5 General purpose input/output ³ RXB Secondary serial interface data receive |
| 6 | SCL | ¹ Two-wire interface, clock. At least 400 kHz mode must be supported in master and slave modes. ² GPIO6 General purpose input/output ³ TXB Secondary serial interface data transmit |
| 7 | SINT | ¹ Sensor interrupt, input: active low. The pin must be pulled up by the host (min. 10 kΩ) and several sensors and add-on boards may share the same pin. Typically, this pin is used to signal host that a sensor needs to be read. In case of a interrupt-on-threshold -capable sensor, energy can be saved compared to polling sensor in a loop. ² GPIO7 General purpose input/output |
| 8 | GND | System and signal ground. |
| 9 | SS | ¹ SPI-master mode: slave select, output, active low. Slave mode: slave select, input, active low. ² GPIO9 General purpose input/output ³ ADC9 Analog input ⁴ PRGA/TMS In-system programming A / JTAG Test Mode Select |
| 10 | SCLK | ¹ SPI-clock output (master) or input (slave). At least 125 kb/s must be supported. ² GPIO10 General purpose input/output ³ ADC10 Analog input ⁴ PRGB/TCK In-system programming B / JTAG Test Clock |
| 11 | MOSI | ¹ SPI data, master out, slave in. ² GPIO11 General purpose input/output ³ ADC11 Analog input |

| Pin | Name | Function(s) |
|-----|--------------|---|
| | | ⁴ PRGC/TDO In-system programming C / JTAG Test Data Out |
| 12 | MISO | ¹ SPI data, master in, slave out. ² GPIO General purpose input/output ³ ADC12 Analog input ⁴ PRGD/TDI In-system programming D / JTAG Test Data In |
| 13 | VDD | Duplicate for pin 2, VDD. |
| 14 | VCC | Regulated power supply, same as VDD. However, host may switch off power from this pin so as to save energy consumed by add-on boards. If that kind of control is not used, the pin must be wired to VDD. Any add-on board that must be constantly powered should use VDD, instead. |
| 15 | RESET | ¹ System reset line, active low. The signal is pulled up by the host and may be driven low from either side, host or add-on boards. The actual function of the signal is implementation dependent. ² In-system programming initiation. Typically, reset causes the host to enter bootloader to wait re-programming via pins 9...12. The actual implementation is system-dependent. |
| 16 | 1WIRE | ¹ Onewire bus. Software implementation is allowed. ² GPIO16/SSB General purpose input/output. Secondary SPI slave select. ³ ADC16 Analog input ⁴ PWM16 Pulse width modulated output |
| 17 | ADC | ¹ Analog input ² GPIO17/SSC General purpose input/output. Alternative SPI slave-select. ³ ADCMCP Analog comparator input ⁴ PWM17 Pulse width modulated output |
| 18 | RINT | ¹ Radio (rf transmitter) interrupt, input, active low. Typically, this pin is used to signal host that there is data in the radio that should be read out, or a data block has been sent out. The signal may also be used as an output to wake-up radio module. It is recommended to have a 3k series resistor on the add-on board if two-way driving is used, to avoid high current loop in conflict situation. ² GPIO18 General purpose input/output with limitations caused by series resistor |
| 19 | DINT | ¹ Data interrupt, input, active low. General-purpose interrupt line for add-on-boards, can be used for user input buttons, for example. ² GPIO19 General purpose input/output ³ ADC19 Analog input ⁴ PWM19 Pulse width modulated output |
| 20 | GND | System and signal ground |

| Pin | Name | Function(s) |
|-----|------|---|
| 21 | RTS | ¹ Serial interface RTS handshaking signal, output: ready-to-receive. ² GPIO21 General purpose input/output ³ SDAB Secondary two-wire interface, data ⁴ PWM21 Pulse width modulated output |
| 22 | CTS | ¹ Serial interface CTS handshaking signal, input: clear-to-send. ² GPIO22 General purpose input/output ³ SCLB Secondary two-wire interface, clock ⁴ INT22 Interrupt input |
| 23 | RX | ¹ Serial interface data receive. ² GPIO23 General purpose input/output ³ INT23 Interrupt input |
| 24 | TX | ¹ Serial interface data transmit. ² GPIO24 General purpose input/output ³ PWM24 Pulse width modulated output |

Pull-Up and Pull-Down Resistors

To enable flexible configuration and to avoid current leaks, there should be generally no fixed pull-up (or pull-down) resistors in any signal pin. Instead, all needed pull-ups should be implemented by the add-on boards. Some microcontrollers also support pull-ups that can be activated by software, but an add-on board designer should not count on that. However, interrupt lines SINT, RINT and DINT make an exception and pull-ups are either fixed on the host board, or can be activated by the host software (typically, 30–50 kΩ).

Interrupts

All add-on board should implement their interrupts towards host using “active low” behavior. Since several board may share the same lines (SINT, RINT and DINT), the add-on boards must not drive the line high, while there’s no interrupt. Instead, they must keep the interrupt line in high impedance state (open collector), or if that is not possible, a series diode towards the interrupting chip must be included.

Add-on board’s interrupt reaction activated by host may be based on any concept, “active low”, “active high”, “falling edge” or “rising edge”. It is up to the host application programmer to take care of correct handling of the interrupt towards add-on board.

Limited, Complete and Extended Host Implementations

Since there is wide range of different kind of microcontrollers, from the tiniest 8-bit PICs to the 32-bit ARMs with lots of I/O-pins, the BUS₂₄ was designed to stretch into three different categories. The first one supports *at least* one of the data busses, TWI, SPI or UART and the implementation is named as

BUS_{24T}, **BUS_{24S}** or **BUS_{24U}** accordingly (or any combinations of _{TSU}). The second one supports all of those busses and also all other primary signals discussed earlier. This kind of implementation is marked with **BUS₂₄₊**. The last one is the most flexible having all the alternative signals and is called **BUS₂₄₊₊**. However, programming and JTAG signals are always optional. The needed signals for the different configurations are listed in detail in the tables below. Figure 12 shows all available signals collected to a simple chart.

| BUS ₂₄ type | Minimum set of signals supported |
|---------------------------|---|
| BUS_{24T} | SCL + SDA (= TWI), SEN, SINT, two GPIO's and ADC |
| BUS_{24S} | SS + SCLK + MOSI + MISO (=SPI), SEN, SINT, two GPIO's and ADC |
| BUS_{24U} | RX + TX (= UART), SEN, SINT, two GPIO's and ADC |
| BUS₂₄₊ | All the primary signals shared with 14 GPIO's, another ADC and two PWM's |
| BUS₂₄₊₊ | All the primary signals shared with 17 GPIO's, additional five ADC's, five PWM's, two more interrupt lines, ADCMP, another TWI bus and another UART |
| BUS₂₄ | Compatible signals, but none of the above sets are completely included |

| Pin | Signals | BUS _{24TSU} | BUS ₂₄₊ | BUS ₂₄₊₊ |
|-----|---|----------------------|--------------------|---------------------|
| 1 | VBAT | X | X | X |
| 2 | VDD | X | X | X |
| 3 | ¹ RPOW ² GPIO3 | - - | X X | X X |
| 4 | ¹ SEN ² GPIO4 | X - | X X | X X |
| 5 | ¹ SDA ² GPIO5 ³ RXB | T - - | X - - | X X X |
| 6 | ¹ SCL ² GPIO6 ³ TXB | T - - | X - - | X X X |
| 7 | ¹ SINT ² GPIO7 | X - | X - | X X |

| Pin | Signals | BUS _{24TSU} | BUS ₂₄₊ | BUS ₂₄₊₊ |
|-----|---|----------------------|--------------------|---------------------|
| 13 | VDD | X | X | X |
| 14 | VCC | X | X | X |
| 15 | RESET | - | X | X |
| 16 | ¹ 1WIRE ² GPIO16/SSB ³ ADC16 ⁴ PWM16 | - - - - | X X X X | X X X X |
| 17 | ¹ ADC ² GPIO17/SSC ³ ADCMP ⁴ PWM17 | X - - - | X X - X | X X X X |
| 18 | ¹ RINT ² GPIO18 | - - | X X | X X |
| 19 | ¹ DINT ² GPIO19 ³ ADC19 ⁴ PWM19 | - - - - | X X - - | X X X X |

| Pin | Signals | BUS ₂₄ TSU | BUS ₂₄ + | BUS ₂₄ ++ | Pin | Signals | BUS ₂₄ TSU | BUS ₂₄ + | BUS ₂₄ ++ |
|-----|--|-----------------------|---------------------|----------------------|-----|---|-----------------------|---------------------|----------------------|
| 8 | GND | - | X | X | 20 | GND | X | X | X |
| 9 | ¹ SS ² GPIO9 ³ ADC9 ⁴ PRGA/TMS | S - - - | X X - - | X X X (X) | 21 | ¹ RTS ² GPIO21 ³ SDAB ⁴ PWM21 | - X - - | X X - - | X X X X |
| 10 | ¹ SCLK ² GPIO10 ³ ADC10 ⁴ PRGB/TCK | S - - - | X X - - | X X X (X) | 22 | ¹ CTS ² GPIO22 ³ SCLB ⁴ INT22 | - X - - | X X - - | X X X X |
| 11 | ¹ MOSI ² GPIO11 ³ ADC11 ⁴ PRGC/TDO | S - - - | X X - - | X X X (X) | 23 | ¹ RX ² GPIO23 ³ INT23 | U - - | X X - | X X X |
| 12 | ¹ MISO ² GPIO12 ³ ADC12 ⁴ PRGD/TDI | S - - - | X X - - | X X X (X) | 24 | ¹ TX ² GPIO24 ³ PWM24 | U - - | X X - | X X X |

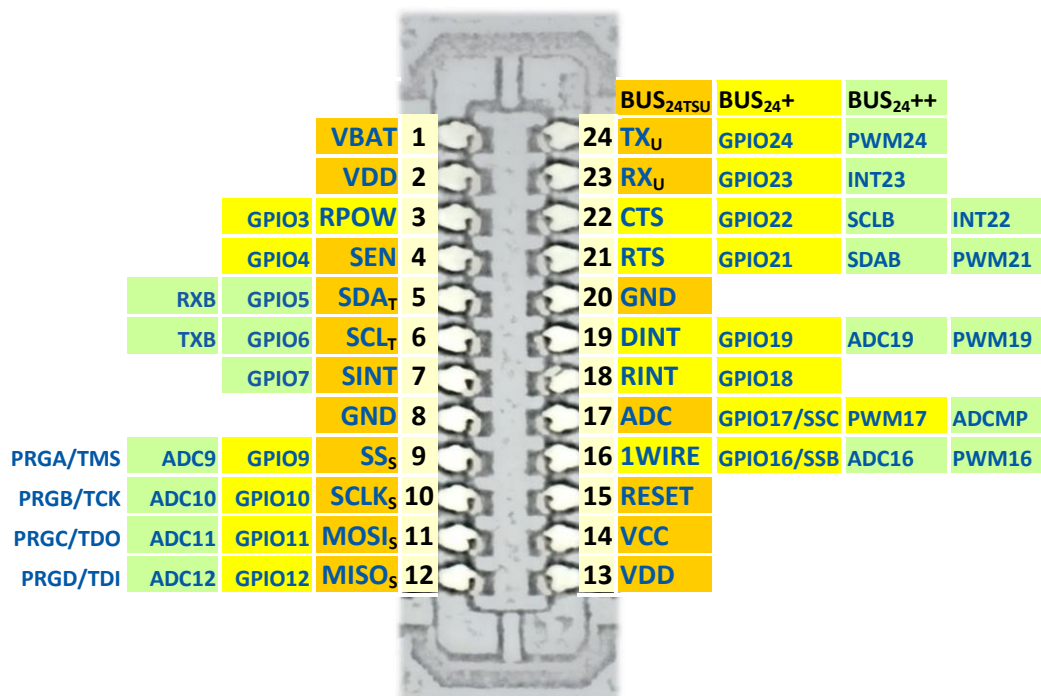


Figure 12. BUS₂₄ complete signal chart shown with host connector.

Several Connectors in a Single Host

There are two basic options to wire two BUS₂₄ connectors for a single host: both connectors may share the same signal lines, or they may be completely separated having their own signals. While the first alternative suits for small controllers having limited number of pins, the latter one is generally better for a microcontroller with enough signal pins.

For an application point of view it is more flexible to have two separated BUS₂₄₊ connectors than having two BUS₂₄₊₊ connectors with shared signal lines. For example, powering of add-on boards can be made separately as needed. Also, separated connectors make possible to use e.g. two UART add-on boards in a single host, even if they are both wired to the default UART pins. The same applies to other busses, TWI, SPI and One-wire.

Having some signal lines separated and some shared between several connectors is also possible. A good trade-off could be to separate SEN and SINT signals, for example.

Add-on Boards and Host Compatibility

There are few limitations of having alternative signals in the same pins: add-on boards using another signal configuration will not work with a board that is using the same pins differently. As a result, when using several add-on boards in a single host, possible conflicting pin allocations must be checked first. Also, UART is actually point-to-point media and not a real *bus*, thus it is limited to a single add-on board by definition. In any case, the software must be set-up to support the possible target board configurations. The bus itself does not support any auto-configuration or plug'n'play detection of add-on boards.

There's no certification process, and it is up to the manufacturer to ensure compatibility. To make end-user's life easier, it is recommended that the category of the BUS₂₄ that a host is supporting, is clearly marked. Indeed, add-on boards must have same kind of marking, but it should naturally indicate the *minimum* requirement for the needed host bus. The table below lists resulting compatibility between hosts and add-on boards. For example, labels like shown below can be used to indicate compatibility.



| Host type | Add-on board types that can be used with that host |
|---------------------------|---|
| BUS_{24T} | BUS _{24T} |
| BUS_{24S} | BUS _{24S} |
| BUS_{24U} | BUS _{24U} |
| BUS₂₄₊ | BUS _{24T} , BUS _{24S} , BUS _{24U} , BUS ₂₄₊ |
| BUS₂₄₊₊ | BUS _{24T} , BUS _{24S} , BUS _{24U} , BUS ₂₄₊ , BUS ₂₄₊₊ |
| BUS₂₄ | Must be checked case-by-case |

Basic Add-on Board Types

TWI Board (BUS_{24T})

Two-wire interface (I²C) is very suitable for sensor boards, because most sensor chips are directly supporting it as slaves. Because it is a real bus, there can be multiple sensors in a single board and many boards can be connected to the same BUS₂₄ quite freely. The biggest problem is the 7-bit address of I²C: care must be taken to avoid address conflicts between sensors and boards. Thus, it is recommended to have zero-ohm configuration resistors for changing I²C address if the used chip makes that possible.

Each TWI board should have pull-up resistors in the SDA and SCL lines. Most often, 10 kΩ is suitable, but that depends on the add-on board in question. Note that when multiple TWI-boards are connected, the resulting total pull-up resistance will follow the formula of parallel connected resistors (e.g. 2 x 10 kΩ results to 5 kΩ).

In the case of a *master* TWI add-on board, there should be possibility to configure the bus into the secondary TWI signals available in BUS₂₄₊₊ configuration, i.e. to SDAB and SCLB. This can be implemented e.g. by having places for zero-ohm resistors in order to change the connected signal lines.

SPI Board (BUS_{24S})

SPI provides generally better throughput than TWI, but is more limited in the number of devices that can be connected. Each SPI slave device must have an activation line (“slave select”) that the host can use to address that particular device. By default, an SPI add-on board must be configured for activation by the BUS₂₄ SS line. However, there should still be configuration possibility (e.g. by 0Ω resistors) for the alternate lines SSB (shared with 1WIRE pin) and SSC (shared with ADC pin) so as to allow multiple SPI slave boards to be connected to a single host. In case of SPI master add-on board, ¹SS is always used as the slave select. Host software must take care of selecting the SPI mode accordingly.

UART Board (BUS_{24U})

As mentioned, UART is not a real bus but point-to-point connection. Thus, only one add-on board using UART lines (CTS, RTS, RX and TX) can be active at a time. Handshaking lines RTS and CTS are not necessary, but it is up to the add-on board and host configuration whether they are used or not. An UART add-on board may also support secondary RX and TX lines found in BUS₂₄₊₊. That makes possible to use two UART boards in a host supporting those secondary serial lines, RXB and TXB.

Sensor Board

To enable good power saving features, a sensor add-on board should have no power or run with as low power as possible by default. The SEN signal should then be used to power-up sensors. Depending on the maximum current consumption, the signal may directly run the sensors, or it may behave as a gate control for e.g. a FET that drives the power from some of the power lines. Several sensors and boards can share the same SEN signal.

Most sensors have interrupt pin (usually open-collector) that must be connected to the SINT pin by default. Several sensors and boards can share the same interrupt line (active low). When a host gets interrupt from that line, it can then read out all the sensors from the TWI bus (or other bus) to determine which one caused the interrupt. However, in some cases more interrupt lines may be needed. It is recommended that the board has 0Ω resistors that can be used to change interrupt line between SINT, RINT and DINT. It is up to the user to build up an interrupt configuration that fits best to the purpose.

Actuator Board

An actuator add-on board, such as a LED board, can be built like a sensor board. Special care must be taken considering current consumption. It is a host dependent feature how much current it can source from the power-pins. However, the BUS₂₄ connector's safe limit is 300 mA per pin, thus by using both VDD pins 600 mA of continuous current can be sourced, in case the host supports that.

Radio Board

Low-power radio board is one of the main purposes the BUS₂₄ was designed for, in addition to sensors. To enable flexible power control, the dedicated signal RPOW should be used to switch the radio on and off, or from active state to a stand-by state. The RINT line is offered for the radio board to wake-up the host only when needed, so as to save power used by the host. However, RINT line can be used two-way if necessary. In that case, host can wake-up the radio board with RINT.

Power-Saving Scenarios

In a typical sensor application, the host stays in sleep state and a connected radio is listening (RPOW is set high). When the radio receives incoming signal, it wakes up the host with RINT (pulled low) and sends the received data via TWI, SPI or UART (depending on the interface) to the host. Based on the received data the host may decide it needs to read sensors from a sensor board. In order to do that, it needs to power-up sensors by rising up SEN signal. A short delay may then be required to wait for sensor value to become available. Then the value can be read out, and SEN may be set low immediately to power-down sensors.

Since many radios are consuming a lot of power, e.g. a WLAN module may drain several milli-amperes even when listening only, the RPOW signal can be used to implement time-based power saving algorithms. For example, a sensor "node" can be set up to listen in some predefined intervals, such as five seconds in each minute (in such a case, time synchronization must be handled). Another possible approach is to make the sensor to autonomously send out its data e.g. once per hour. In between these short periods, the host can pull down RPOW signal thus saving energy that would otherwise be wasted by the radio.

Reference Implementations

As of this writing (2015-02-17), several BUS₂₄ host implementations have been successfully realized, including ones based on Atmel Atmega32u4, Microchip PIC16LF1938 and Nordic nRF51822. Also, existing and upcoming add-on boards include Bluetooth, Bluetooth LE, WLAN, iQRF-868MHz radio transmitter, barometer, ambient light sensor and "9-axis" motion sensor, just to mention some. Figure 13 shows one possibility to wire Atmega32u4 into BUS₂₄ and photos in Figure 14 show working implementations based on two different microcontroller types.

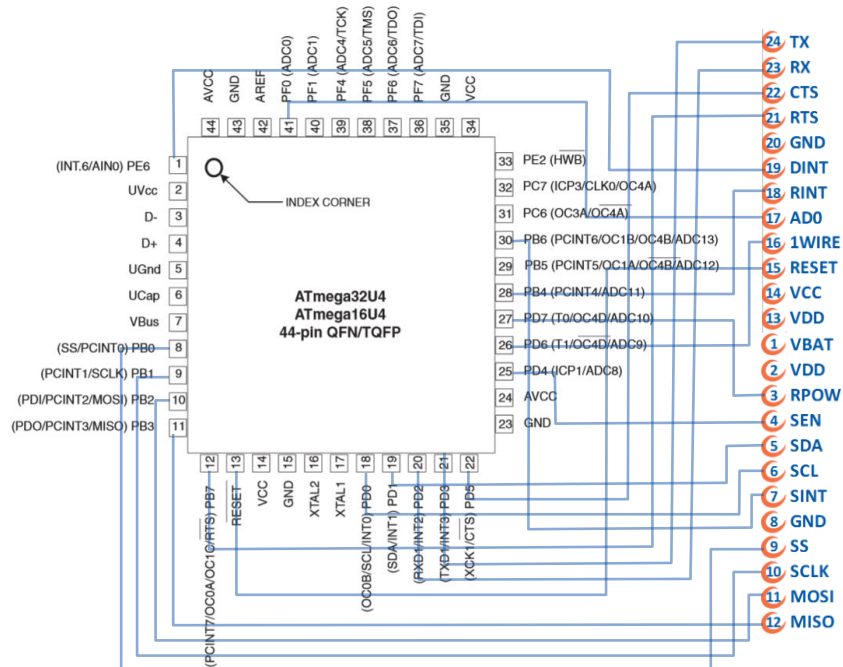
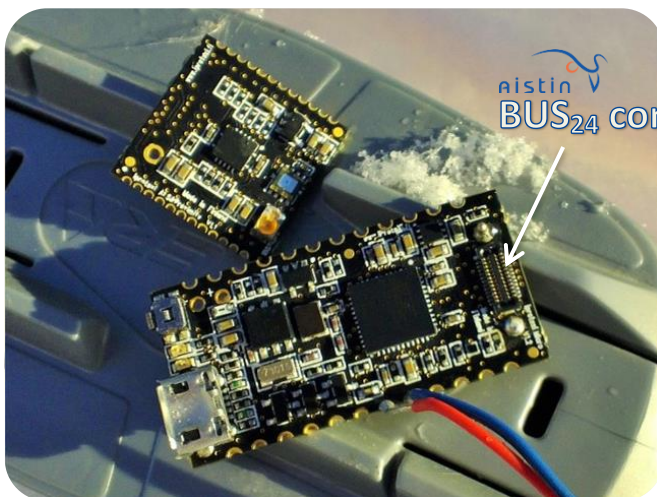
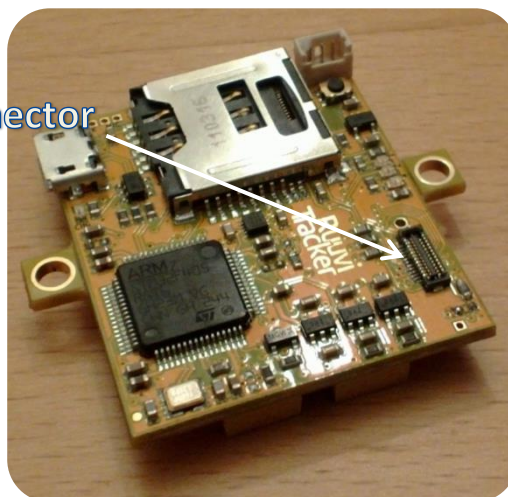


Figure 13. Example schematics of atmega32u4 wired to BUS₂₄.



(a) Atmega-based host



(b) ARM-based host

Figure 14. Examples of two different BUS₂₄ hosts and a light sensor add-on board (early versions).