

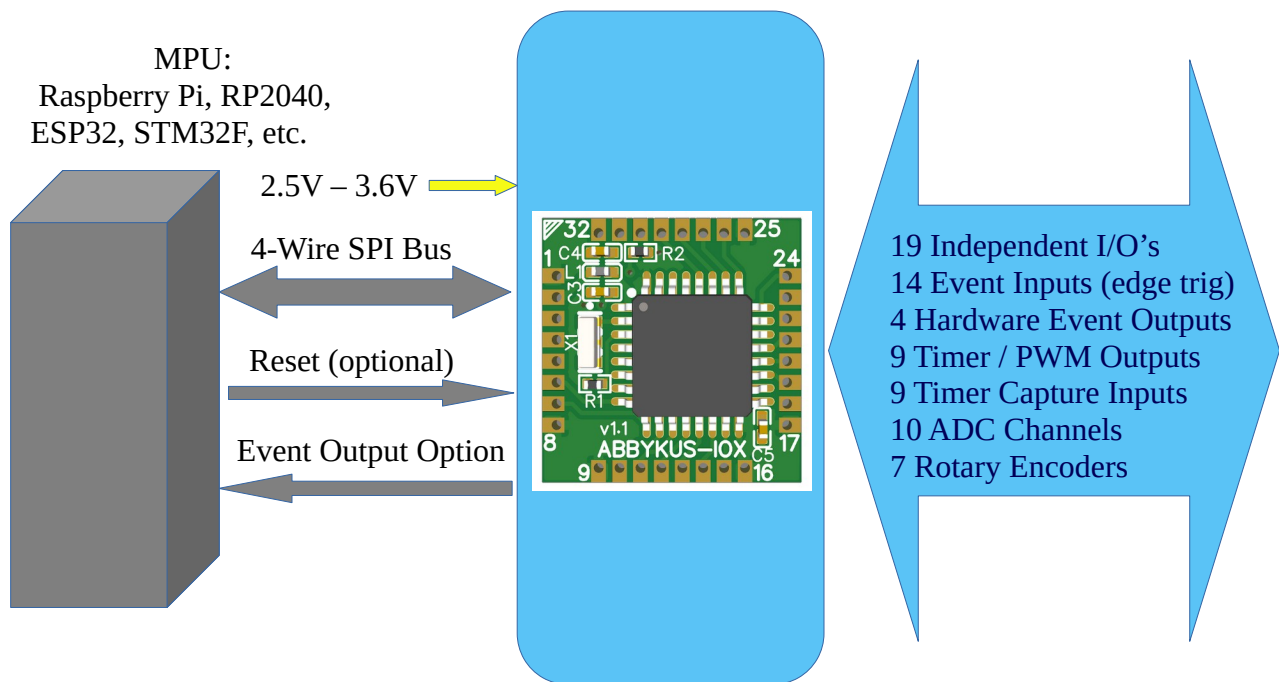
A low cost - high performance I/O co-processor module performs I/O expansion and performance features that can significantly enhance the capabilities of Microprocessor system designs.

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## Features

- High speed serial SPI bus performs serial to parallel I/O expansion with simple integration to MPU's like ESP32, RP2040, Raspberry Pi, STM32Fxxx, etc. *Other serial bus options are available, see below.*
- Up to 19 independent I/O pins, independently configurable as input or output.
- Outputs can be set as push-pull or open drain type with programmable current drive.
- Pull-up and pull-down resistors can be applied to any I/O pin (inputs or outputs).
- Up to 15 inputs can be configured to generate events on rising, falling, or both edges.
- Events can trigger a programmable output pin (hardware notification). Also can be read by software.
- Up to 9 outputs can be configured for PWM output.
- Up to 9 inputs can be used as digital capture windows (frequency and pulse width measurements). Capture event can trigger a programmable output pin (hardware notification).
- 12 bit Analog To Digital Converter (ADC) with up to 10 multiplexed inputs. Range = 0 - 3.3 VDC typical. Conversions can be started via hardware or software.
- Support for 7 rotary encoders with direction, count, and rotational speed calculated. Encoder motion can trigger an event output.
- SPI bus speed tested to 10 Mbits/sec.
- Digital & I/O supply voltage operation from 2.5V to 3.6V.
- Low power operation with sleep and wake from sleep options.
- Small 1.6cm square module can be mounted via 1.27mm (0.05 inch) header, PCB surface mounted, or DIY wired.
- Module contains STM32F 32-bit MCU with crystal resonator, reset time constant, and power filtering.
- Digital & I/O supply voltage operation from 2.5V to 3.6V.

- IOX-SPI library is included to accelerate project inclusion using Arduino, platformio, or other development environments.
- Optional breakout development board with pogo pin fixture connectivity supports DIY custom programming and debugging using the low cost ST-LINK V2 debugger from STMicro.
- Other serial bus options available: 2 wire UART and 2-wire I2C. See ABBY-IOX-UART and ABBY-IOX-I2C versions.



**Figure 1. Basic Block Diagram**

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## INTRODUCTION

In many electronic project designs, even with MPU's and MCU's that feature a large number of general purpose I/O's and bus controllers, it often happens that more resources are needed.

The ABBY-IOX I/O Co-Processor offers a low cost and flexible way to add the needed functionality without additional development time and expense.

The ABBY-IOX-SPI greatly expands I/O capability through a generic serial SPI bus into 19 independent Input / Output pins. Each pin can be programmed to be a digital input, output, analog input for the embedded Analog to Digital converter, or special purpose timer functions.

Additionally, inputs can be configured as event triggers with hardware and software event notification. Inputs can also provide waveform capture functions useful for operating rotary encoders.

Outputs have various timer functions such as PWM with variable frequency & duty cycle, input capture frequency and pulse width measurements, etc.

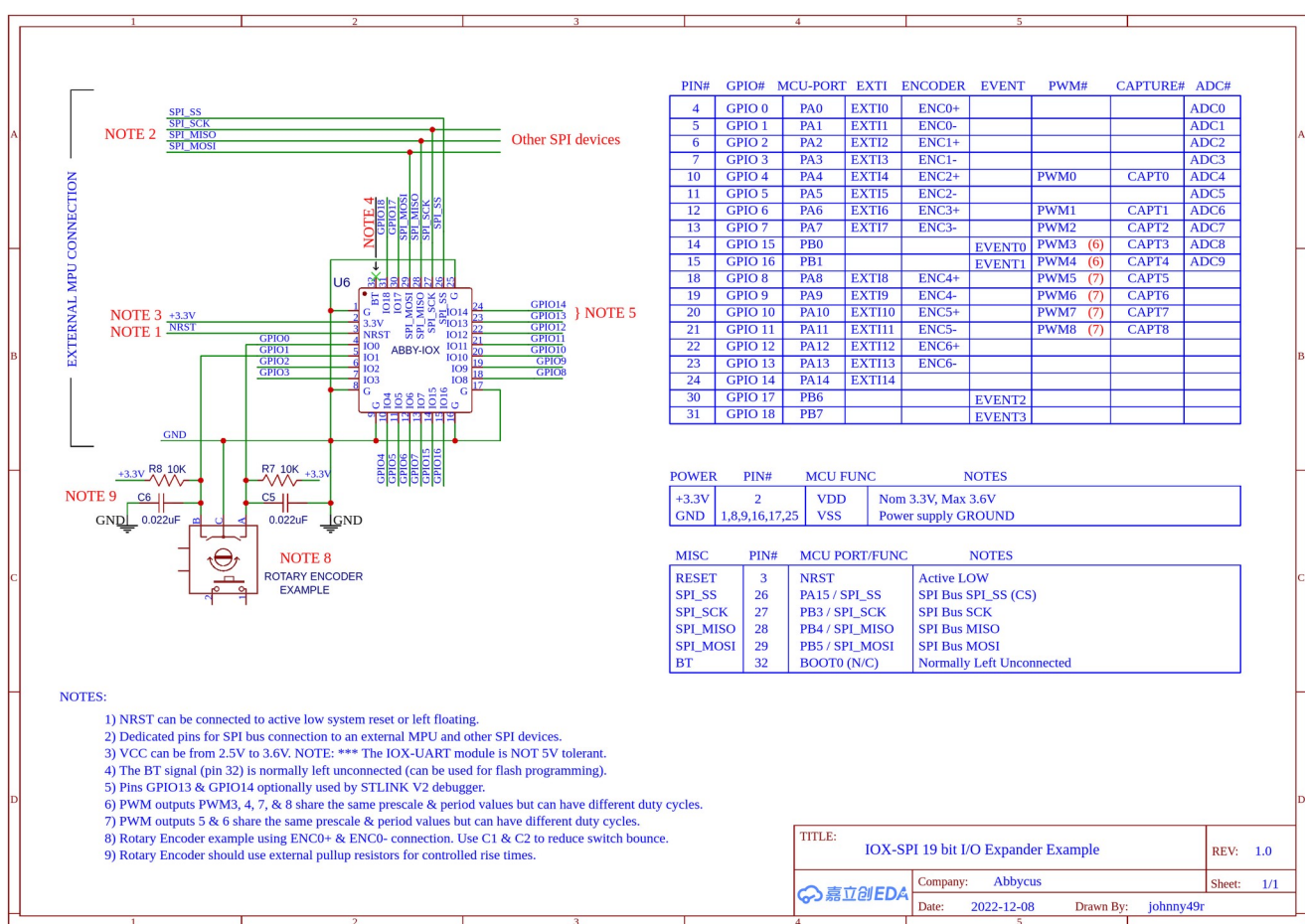
# SPI Bus Basics

The ABBY-IOX-SPI module version employs the popular Serial Peripheral Interface (SPI) 4-wire serial bus used to connect to a system processor. Virtually all MPU's and MCU's support the SPI bus protocol. The IOX-SPI is a synchronous protocol which functions as a slave in full-duplex mode.

The SPI bus consists of 4 wires called SCK (bus clock), MOSI (master out / slave in), MISO (master in / slave out), and SS (chip select). This 4-wire bus can support bit-rate speeds of at least 10 MHz over short distances (20 cm). A more detailed description of the SPI bus can be found [here](#).

The SPI bus can have only one master but can support many slaves. All writes and reads to the IOX device are initiated by the bus master (system MPU / MCU).

Each slave device on the bus responds when its SS (chip select) signal is asserted.



### Figure 2. SPI Example Schematic and Pin Description.

## IOX Package & Pinout

The IOX-SPI package is a 1.6 cm square module with 32 pins numbered counterclockwise. Pin types are as follows:

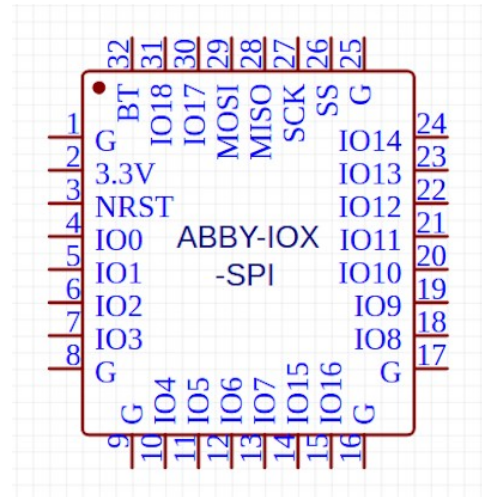
**S** – Supply Pin

**IO** – Programmable Input / Output Pin

**I** – Input only Pin

**O** – Output only pin.

**B** – Dedicated Boot0 Pin



| Pin # | Type | Description  |
|-------|------|--|
| 1     | S    | Ground   |
| 2     | S    | Power supply voltage, 2.5V (minimum) to 3.6V (maximum)           |
| 3     | I    | Reset, active low, 500 ns minimum pulse width. Can be left open. |
| 4     | IO   | GPIO 0 / ETXI0 / ADC0 / ENC0 +                                   |
| 5     | IO   | GPIO1 / EXTI1 / ADC1 / ENC0 -                                    |
| 6     | IO   | GPIO2 / EXTI2 / ADC2 / ENC1 +                                    |
| 7     | IO   | GPIO3 / EXTI3 / ADC3 / ENC1 -                                    |
| 8     | S    | Ground   |
| 9     | S    | Ground   |
| 10    | IO   | GPIO4 / EXTI4 / PWM0 / CAPT0 / ADC4 / ENC2 +                     |
| 11    | IO   | GPIO5 / EXTI5 / ADC5 / ENC2 -                                    |
| 12    | IO   | GPIO6 / EXTI6 / PWM1 / CAPT1 / ADC6 / ENC3 +                     |
| 13    | IO   | GPIO7 / EXTI7 / PWM2 / CAPT2 / ADC7 / ENC3 -                     |
| 14    | IO   | GPIO15 / EVENT0 / PWM3 / CAPT3 / ADC8                            |
| 15    | IO   | GPIO16 / EVENT1 / PWM4 / CAPT4 / ADC9                            |
| 16    | S    | Ground   |
| 17    | S    | Ground   |
| 18    | IO   | GPIO8 / EXTI8 / PWM5 / CAPT5 / ENC4 +                            |
| 19    | IO   | GPIO9 / EXTI9 / PWM6 / CAPT6 / ENC4 -                            |
| 20    | IO   | GPIO10 / EXTI10 / PWM7 / CAPT7 / ENC5 +                          |



|    |    |  |
|----|----|--|
| 21 | IO | GPIO11 / EXTI11 / PWM8 / CAPT8 / ENC5 -              |
| 22 | IO | GPIO12 / EXTI12 / ENC6 +                             |
| 23 | IO | GPIO13 / EXTI13 / ENC6 -                             |
| 24 | IO | GPIO14 / EXTI14 / ENC7 +                             |
| 25 | S  | Ground   |
| 26 | IO | SS – Dedicated SPI chip select                       |
| 27 | IO | SCK – Dedicated SPI clock                            |
| 28 | IO | MISO – Dedicated SPI Master In / Slave Out           |
| 29 | I  | MOSI – Dedicated SPI Master Out / Slave In           |
| 30 | IO | GPIO17 / EVENT2                                      |
| 31 | IO | GPIO18 / EVENT3                                      |
| 32 | B  | Boot0 dedicated programming pin. Normally left open. |

## Command Description

The ABBY-IOX-SPI functions as a synchronous SPI full-duplex device where short fixed length packets are exchanged. A command packet consists of 12 bytes in length and is organized as follows:

| Byte # 1     | 2                | 3                  | 4...12             |
|--------------|------------------|--------------------|--------------------|
| Command Byte | # Bytes to write | # Bytes to receive | Additional data... |

An SPI bus transaction consists of 2 phases: Write then read.

**Write Phase:** The SPI bus begins communication when the master asserts the SS (chip select) and generates a clock. Data is sent out on the MOSI line and is received by the IOX device. Then the master will de-assert the SS line.

**Read Phase:** If there is any data to be received from the IOX device, SS will be asserted and the master will clock data out on the MISO line. SS is then de-asserted.

If the IOX device was not ready to send data, the first byte of returned data will be '0', otherwise a '1' will indicate valid data. If data was not ready the master can repeat the **Read Phase** until data becomes ready.

Below is a list of command numbers and their meaning.

| CMD # | Command                | Description  |
|-------|------------------------|--|
| 1     | WHO-AM-I               | Validate communications                                    |
| 2     | READ STATUS            | Read IOX status and selected fields                        |
| 3     | CONFIGURE GPIO(s)      | Configure a range of GPIOs with specific attributes        |
| 4     | GET GPIO CONFIGURATION | Return GPIO attributes for a specified pin                 |
| 5     | WRITE GPIO(s)          | Write values to mapped GPIO's                              |
| 6     | TOGGLE GPIO(s)         | Toggle outputs of mapped GPIOs                             |
| 7     | READ GPIO              | Read a single GPIO pin                                     |
| 8     | READ GPIO ALL          | Read all values of mapped GPIOs                            |
| 9     | CONFIGURE EVENT OUTPUT | Configure one of 4 outputs for hardware event notification |
| 10    | START PWM OUTPUT       | Configure & start a PWM waveform on a specified GPIO pin   |
| 11    | UPDATE PWM DUTY CYCLE  | Change the PWM duty cycle of a running output              |
| 12    | CONFIGURE ADC INPUT(s) | Configure a group of GPIO pins to function as              |

|    |                      |   |
|----|----------------------|---|
|    |                      | analog inputs                                 |
| 13 | START ADC CONVERSION | Start ADC conversion on selected pins         |
| 14 | READ ADC CONVERSION  | Read ADC results after conversion             |
| 15 | START CAPTURE        | Start an input capture on a selected GPIO     |
| 16 | READ CAPTURE         | Read results of an input capture measurement  |
| 17 | CONFIGURE ENCODER    | Configure a pair of GPIO's for rotary encoder |
| 18 | READ ENCODER         | Read any detected rotary encoder motion       |
| 19 | SLEEP                | Power reduction mode with specified wakeup    |
| 20 | SET UART BAUDRATE    | Set UART baud rate (UART version only)        |
| 21 | GET VERSION INFO     | Return supported serial bus and FW revision.  |

## IOX-SPI Library Description & Usage

All communication to the IOX-SPI can be made using a supplied library consisting of two C++ files named *iox\_spi.h* and *iox\_spi.cpp*.

Installation is simple – just copy these files in your project source folder and perform the following steps:

1. Include the library into your program with the statement **#include "ioc\_spi.h"**.
2. Create a library object with the following statement: **IOX\_SPI iox\_spi**.
3. Perform a library call to initialize the SPI communication as follows:

```
bool ret = iox_spi.init(uint8_t spi_number, uint8_t pin_sck, uint8_t pin_miso, uint8_t pin_mosi, uint8_t pin_ss0, uint8_t pin_ss1, uint32_t bus_speed)
```

**'spi\_number'** is the number of the SPI controller, usually 0 or 1.

**'pin\_sck'** GPIO pin for SPI clock.

**'pin\_miso'** GPIO pin for SPI MISO signal.

**'pin\_mosi'** GPIO pin for SPI MOSI signal.

**'pin\_ss0'** GPIO pin chip select for the first IOX device.

**'pin\_ss1'** GPIO pin chip select for the second IOX device.

**'bus\_speed'** defines the SPI clock speed, example: 1000000 for 1 Mb/s clock speed.

### Example

```
ret = iox_spi.init(HSPI, 46, 47, 48, 45, 38, 1000000); // init SPI @ 1 Mb/s
```

### Returns

The function should return **'true'** indicating successful initialization. If the result is false, check connections of the pins and try a slower clock speed. Also check that **'HSPI'** is not being used already.

## WHO\_AM\_I

```
bool whoAmI(uint8_t iox_adrs)
```

### Description

The bus master can verify communication at any time using the WHO\_AM\_I function. The master communicates with the IOX-SPI slave device and receives a magic number (0x5D).

The library function simplifies this by returning **true** if communication is successful, or **false** otherwise.

## Parameters

**'iox\_adrs'** is used to select an IOX device in a multi device configuration. Value should be 0 or 1.

## Returns

Returns **true** if communication is successful, or **false** otherwise.

## READ STATUS

`uint8_t read_status(uint8_t iox_adrs, SYS_STATUS * sys_status, uint8_t field_mask)`

## Description

A call to this function writes an 8-bit *STATUS* byte and a 16-bit *FIELD* word into a **SYS\_STATUS** structure.

## Parameters

**'iox\_adrs'** is used to select an IOX device in a multi device configuration. Value should be 0 or 1.

**'sys\_status'** is a pointer to a SYS\_STATUS structure shown as follows:

```
typedef struct {                // SYS_STATUS struct template
    uint8_t status;
    uint16_t field;
} SYS_STATUS;

SYS_STATUS sys_status;        // create a sys_status object
```

**'field\_mask'** is a bit-wise byte that determines the status field returned. See the **FIELD WORD INTERPRETATION** table below for possible values.

## EXAMPLES:

1) **err = read\_status(0, &sys\_status, STATUS\_ERROR)** returns the current status and the ERROR field requested by the field\_mask.

2) **err = read\_status(0, &sys\_status, STATUS\_ENCODER)** returns the current status and any active ENCODERS in the FIELD word.

The function returns an ERROR CODE byte interpreted as follows:

0x00    **ERR\_NONE** – no errors pending.

0x01    **ERR\_PARAM** – parameter out of range occurred during the previous command.

#### FIELD MASK Macro Definitions:

0x01    **FIELD\_ERROR** – returns system error field (0 if no errors).

0x02    **FIELD\_EXTI** – returns a channel map of any externally triggered inputs. This action will clear the channel map and reset the optional hardware event output.

0x08    **FIELD\_ADC\_READY** – returns a channel map of ADC conversions that can be read.

0x10    **FIELD\_CAPTURE** – returns a channel map of input captures that have occurred.

0x20    **FIELD\_ENCODER** – returns a channel map of any encoders triggered by movement.

#### STATUS BYTE

|   |   |
|---|---|
| 7 |   |
| 6 |   |
| 5 | 1 = ENCODER movement detected.  |
| 4 | 1 = INPUT CAPTURE event has been triggered. This bit cleared by calling <i>READ_CAPTURE</i> . |
| 3 | 1 = ADC CONVERSION complete. This bit is cleared after calling <i>READ_ADC</i> .              |
| 2 | 1 = ADC BUSY – Conversion in progress. This bit is automatically set & cleared.               |
| 1 | 1 = EXTI event has been triggered. This bit is cleared after calling <i>READ_EXTI</i> .       |
| 0 | 1 = ERROR - check error codes. This bit & <i>error bits are cleared after READ_STATUS</i> .   |

#### FIELD WORD INTERPRETATION

|     | Mask=0x01 | Mask=0x02 | Mask=0x08 | Mask=0x10  | Mask=0x20 |
|-----|-----------|-----------|-----------|------------|-----------|
| BIT | ERROR     | EXTI      | ADC CONV  | INPUT CAPT | ENCODER   |
| 15  |           | EXTI15    |           |            |           |
| 14  |           | EXTI14    |           |            |           |
| 13  |           | EXTI13    |           |            |           |
| 12  |           | EXTI12    |           |            |           |
| 11  |           | EXTI11    |           |            |           |
| 10  |           | EXTI10    |           |            |           |
| 9   |           | EXTI9     | ADC9      | INCAP9     |           |

|   |  |       |      |        |      |
|---|--|-------|------|--------|------|
| 8 |  | EXTI8 | ADC8 | INCAP8 |      |
| 7 |  | EXTI7 | ADC7 | INCAP7 | ENC7 |
| 6 |  | EXTI6 | ADC6 | INCAP6 | ENC6 |
| 5 |  | EXTI5 | ADC5 | INCAP5 | ENC5 |
| 4 |  | EXTI4 | ADC4 | INCAP4 | ENC4 |
| 3 | 1 = Command Timeout                                  | EXTI3 | ADC3 | INCAP3 | ENC3 |
| 2 | 1 = Serial Mode Failure                              | EXTI2 | ADC2 | INCAP2 | ENC2 |
| 1 | 1 = GP Failure                                       | EXTI1 | ADC1 | INCAP1 | ENC1 |
| 0 | 1 = Parameter error – out of range or invalid value. | EXTI0 | ADC0 | INCAP0 | ENC0 |

## CONFIGURE GPIO(s)

void **config\_gpios**(uint8\_t **iox\_adrs**, uint32\_t **gpio\_map**, uint8\_t **gpio\_config**)

### Description

Configure one or more GPIO's with the same attributes. Up to 19 GPIO's can be set as inputs or outputs using this single command.

On power up or after a reset, all GPIO's will default to analog input mode to minimize power consumption.

### Parameters

'**iox\_adrs**' is used to select an IOX device in a multi device configuration. Value should be 0 or 1.

'**gpio\_map**' is a bit-wise map of all 19 GPIO's to configure as follows:

|         |             |
|---------|-------------|
| 31 : 19 | 18 : 0      |
| Unused  | GPIO 18 : 0 |

Each bit, if set to 1, will configure the associated GPIO with the **gpio\_config** value.

'**gpio\_config**' is an encoded 6 bit value describing the type of I/O configuration requested.

The library header file contains macro constants which can be Ored together to create various configuration choices.

Weak pull-up and pull-down resistors (approx 40K ohms) can be added to either input or output configurations. Note that It's not possible to set both pull-up and pull-down resistors together.

#### **BASIC INPUT / OUTPUT Macro Definitions**

**IO\_OUTPUT\_PP** – I/O is set as a push-pull output type.

**IO\_OUTPUT\_OD** – I/O set as an open-drain output type.

**IO\_INPUT** – I/O is set as an input.

**IO\_LOW\_POWER** – I/O is set as an analog input type (low power or ADC input).

#### **OUTPUT ATTRIBUTE Macro Definitions**

**IO\_SPEED\_LOW** – Lowest current drive output up to 2MHz.

**IO\_SPEED\_MED** – Medium speed drive output up to 10MHz.

**IO\_SPEED\_HIGH** – High speed drive output up to 50MHz.

#### **INPUT ATTRIBUTE Macro Definitions**

**IO\_EXTI\_DISABLE** – Input events disabled.

**IO\_EXTI\_RISING** – Event on input rising edge.

**IO\_EXTI\_FALLING** – Event on input falling edge.

**IO\_EXTI\_BOTH** – Event on either edge.

#### **INPUT & OUTPUT ATTRIBUTE Macro Definitions**

**IO\_NO\_PUPD** – No pull-up or pull-down resistors used.

**IO\_PULLUP** – Weak pull-up resistor to VCC (approx 40K ohms).

**IO\_PULLDOWN** – Weak pull-down resistor to ground (approx 40K ohms).

**NOTE:** Weak pull-up and pull-down resistors (approx 40K ohms) can be added to either input or output configurations. Note that It's not possible to set both pull-up and pull-down resistors together.



## Examples

1. ***config\_gpios(0, 0xFF, IO\_OUTPUT\_OD | IO\_PULLUP)*** creates an open drain output with a weak pull-up resistor on GPIO's 0-7.
2. ***config\_gpios(0, 0xFFFF8, IO\_INPUT | IO\_PULLUP | IO\_EXTI\_RISING)*** creates an input with a weak pull-up resistor and a rising edge event trigger for the GPIO range of 3 – 19.
3. ***config\_gpios(0, GPIO1\_b | GPIO4\_b, IO\_LOW\_POWER)*** creates a low power (analog input) for GPIO1 and GPIO4.

## Returns

The function will return a `ERR_NONE` (0x0) on successful completion or an error code (see **ERROR HANDLING**).

## GET GPIO CONFIGURATION

`uint8_t get_gpio_config(uint8_t iox_adrs, uint8_t gpio_num)`

## Description

Returns the current configuration of the specified GPIO number. The configuration is encoded into a 6 bit value which is a mirror of the I/O configuration value sent by the `CONFIGURE GPIO(s)` command (see above).

| 7 : 6 | 5    | 4 : 0        |
|-------|------|--------------|
| n/a   | Mode | Attribute(s) |

## Parameters

'**iox\_adrs**' is used to select an IOX device in a multi device configuration. Value should be 0 or 1.

'**gpio\_num**' is the logical GPIO number with a value of 0 – 19.

## Returns

The returned configuration is encoded into a 6 bit value which is a mirror of the I/O configuration value sent by the **CONFIGURE GPIOS** command (see above).

**NOTE:** If an error occurs the function will return a value of 0xFF (255 decimal).

## WRITE GPIOS

uint8\_t **write\_gpios**(uint8\_t **iox\_adrs**, uint32\_t **gpio\_map**, uint32\_t **state\_map**)

### Description

This command writes one or more GPIO's with the same '0' or '1' value.

### Parameters

'**iox\_adrs**' is used to select an IOX device in a multi device configuration. Value should be 0 or 1.

'**gpio\_map**' is a bit-wise map of all GPIO's to select for writing. A '1' bit associated with the logical GPIO will select that GPIO for writing (lower 19 bits).

'**state\_map**' is a bit-wise map of the state to write for each GPIO position (lower 19 bits).

### Examples

```
uint32_t gpio_map = 0x7FFFF;           // write all GPIO's
uint32_t state_map = 0x55555;           // write even bits with '1', odd bits with '0'
ret = write_gpios(0, gpio_map, gpio_map); // write gpio's

-----

uint32_t gpio_map = 0b100010000000000100001; // select GPIO's 0, 5, 15, & 19
uint32_t state_map = 0x7FFFF;                 // write selected GPIO's with a '1'
ret = write_gpios(0, gpio_map, gpio_map);      // write gpio's
```

### Returns

The function will return a ERR\_NONE (0x0) on successful completion or an error code (see [ERROR HANDLING](#)).

## TOGGLE GPIO(s)

uint8\_t **toggle\_gpios**(uint8\_t **iox\_adrs**, uint32 **gpio\_map**)

### Description

One or more I/O outputs can be toggled (inverted) using this single command.

## Parameters

**‘iox\_adrs’** is used to select an IOX device in a multi device configuration. Value should be 0 or 1.

**‘gpio\_map’** is a bit-wise map of all GPIO’s (lower 19 bits). A ‘1’ in the associated GPIO position will cause the associated logical output to be toggled.

| 31 : 19 | 18 : 0        |
|---------|---------------|
| Unused  | GPIO’s 18 : 0 |

## Examples

```
uint32_t toggle_map = 0x00105;
```

```
ret = toggle_gpios(0, toggle_map)    // invert gpio outputs 0, 2, and 8
```

## Returns

The function will return a ERR\_NONE (0x0) on successful completion or an error code (see **ERROR HANDLING**).

## READ GPIO

```
uint8_t read_gpio(uint8_t iox_adrs, uint8_t gpio_num, uint8_t * gpio_value)
```

## Description

Any GPIO pin can be read using this command. The function will return the current value of the specified pin (pin can be either input or output).

## Parameters

**‘iox\_adrs’** is used to select an IOX device in a multi device configuration. Value should be 0 or 1.

**‘gpio\_num’** is the logical GPIO number and must be in the range of 0 – 18, otherwise the function will set the ERROR bit in the STATUS register and a ERR\_PARAM bit in the ERROR REGISTER (see **READ STATUS** and **ERROR HANDLING**).

**‘gpio\_value’** is a pointer to an 8 bit memory location where the state of the GPIO pin will be written.

## Examples

```
uint8_t gpio_val;  
ret = read_gpio(0, 13, (uint8_t *) &gpio_val); // gpio_val will have the state of GPIO 13
```

## Returns

The function will return a `ERR_NONE` (0x0) on successful completion or an error code (see **ERROR HANDLING**).

## READ GPIO ALL

```
uint8_t read_gpio_all(uint8_t iox_adrs, uint32_t * gpio_map)
```

## Description

All I/O's configured as inputs can be read with this command.

## Parameters

'**iox\_adrs**' is used to select an IOX device in a multi device configuration. Value should be 0 or 1.

'**gpio\_map**' is a pointer to a 32 bit memory location where the 19 bit map will be written.

| 31 : 19 | 18 : 0           |
|---------|------------------|
| Unused  | GPIO 18 : GPIO 0 |

If the any GPIO is configured as an output, the function will return the current value of the output pin.

## Examples

```
uint32_t gpio_map;  
ret = read_gpio_all(0, (uint32_t *) &gpio_map); // map written into gpio_map memory loc
```

## Returns

The function will return a `ERR_NONE` (0x0) on successful completion or an error code (see **ERROR HANDLING**).

## CONFIGURE EVENT OUTPUT

uint8\_t **config\_event\_output**(uint8\_t **iox\_adrs**, uint8\_t **event\_type**, uint8\_t **event\_num**)

### Description

This command configures one of four possible event outputs. When an event occurs the GPIO output will go high and will be cleared to a low state by calling **READ STATUS**.

Logical event output vs physical GPIO:

EVO0 = GPIO15

EVO1 = GPIO16

EVO2 = GPIO17

EVO3 = GPIO18

The default event output is set to IO\_OUTPUT\_PP with medium speed current drive. See **CONFIGURE GPIOS**.

### Parameters

‘**iox\_adrs**’ is used to select an IOX device in a multi device configuration. Value should be 0 or 1.

‘**event\_type**’ parameter is one of the following:

0 - **EVENT\_NONE** clears the specified event output.

1 – **EVENT\_EXTI** sets the event output when a change occurs on one or more GPIO’s configured as inputs triggered by edge changes (see **CONFIGURE GPIOS**).

2 – **EVENT\_ADC** sets the specified event output when an ADC conversion is complete and is ready to be read (see **READ ADC**).

3 – **EVENT\_CAPTURE** sets the specified event output when an INPUT CAPTURE operation is complete and is ready to be read (see **READ CAPTURE**).

4 – **EVENT\_ENCODER** sets the specified event output when a ROTARY ENCODER movement is detected and is ready to be read (see **READ ENCODER**).

When an event occurs, the event output can be cleared by calling **READ STATUS** with the ‘**field\_mask**’ set to the appropriate value.

‘**event\_num**’ is the logical event output pin and should be in the range 0 – 3.

## Example

```
ret = config_event_output(0, EVENT_ADC, EVO0);    // event 0 (GPIO15) output when ADC
conversion is done.
```

## Notes

An event output can be disabled by calling the CONFIGURE EVENT OUTPUT function with the EVENT\_NONE parameter:

```
ret = config_event_output(0, EVENT_NONE, EVO0);
```

A GPIO configured as an event output will be cleared by calling **CONFIGURE GPIOS** with GPIO's 15 – 18. Example:

```
ret = config_event_output(0, EVENT_ENCODER, EVO0);    // enable encoder event
```

```
ret = config_gpios(0, 0x10000, IO_OUTPUT_OD | IO_PULLUP); // clears event 0
```

## Returns

The function will return a ERR\_NONE (0x0) on successful completion or an error code (see **ERROR HANDLING**).

## START PWM OUTPUT

```
uint8_t config_PWM(uint8_t iox_adrs, uint8_t pwm_num, uint16_t clk_div, uint16_t
pwm_freq, uint16_t pwm_duty, bool polarity)
```

## Description

The command configures a GPIO pin to output a desired Pulse Width Modulated (PWM) waveform.

## Parameters

**'iox\_adrs'** is used to select an IOX device in a multi device configuration. Value should be 0 or 1.

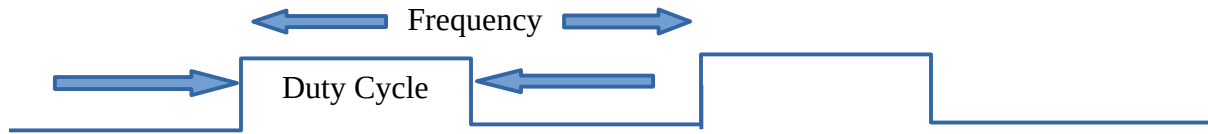
**'pwm\_num'** is the logical PWM pin (0 - 9) to output the desired PWM waveform.

**'clk\_div'** is the PWM timer prescaler value. The timer runs from a base clock of 48 MHz and is first divided by this value. The division factor is 'n+1' so a value of 0 means that the base clock will be divided by 1 so the PWM timer clocks at 48 MHz. A value of 47 means that the base clock will be divided by 48 so the base clock is 1 MHz, etc.

**'pwm\_freq'** is the frequency (or period) of the PWM waveform in prescaled clock cycles +1. So a value of 999 would yield a period of 1000 clocks.

**'pwm\_duty'** is the number of clock cycles that define the 'on-time' of the PWM waveform.

**'polarity'** inverts the waveform output if true.



## Examples

```
// Start PWM on IOX device 0, PWM2 channel, clk = 1 us, frequency = 2000 clocks,
```

```
// 1000 us duty cycle (50%), non-inverted
```

```
ret = start_PWM(0, 2, 47, 1999, 1000, false);
```

## Returns

The function will return a `ERR_NONE` (0x0) on successful completion or an error code (see **ERROR HANDLING**).

See also **NOTES ON PWM GENERATION**.

## UPDATE PWM

```
uint8_t update_PWM(uint8_t iox_adrs, uint8_t pwm_num, uint16_t pwm_duty)
```

### Description

The duty cycle of a PWM waveform can be updated asynchronously to achieve variable pulse width (servo control). The change to the duty cycle occurs at the beginning of the next PWM period.

Note that the PWM channel should have been initialized by calling `START PWM OUTPUT` function.

### Parameters

**'iox\_adrs'** is used to select an IOX device in a multi device configuration. Value should be 0 or 1.

**'pwm\_num'** is the logical PWM channel and can be in the range of 0 – 9.

**'pwm\_duty'** has a range of 0 – 65535 which determines the on-time during the waveform period.

## Examples

```
ret = update_PWM(0, PWM2, 666); // change duty cycle on PWM2 to 666 usec.
```

## Returns

The function will return a `ERR_NONE` (0x0) on successful completion or an error code (see [ERROR HANDLING](#)).

## CONFIGURE ADC CHANNEL

```
bool config_ADC(uint8_t iox_adrs, uint16_t adc_chnls, uint8_t adc_resol)
```

### Description

The IOX co-processor contains one 12-bit configurable Analog to Digital Converter (ADC) which can convert analog voltages from 0 to 3.3V to a digital value.

The function configures a group of GPIO pins as inputs to the ADC. Up to 10 channels can be multiplexed into the ADC.

### Parameters

‘**iox\_adrs**’ is used to select an IOX device in a multi device configuration. Value should be 0 or 1.

‘**adc\_chnls**’ is a 16 bit map where the low order 10 bits represent all logical ADC channels. A ‘1’ bit will configure the logical ADC channel as a high impedance analog pin. Multiple channels will be converted starting from the lowest channel number up to the highest.

‘**adc\_resol**’ is the converter’s width in bits. Valid values are 6, 8, 10, and 12. Higher values yield finer resolution but have longer conversion times. The ADC is a successive approximation type meaning that the conversion time varies over a span of about 12:1. Therefore the conversion time for a 12 bit width is in the range of 1 microsecond to 12 microseconds.

The reference voltage for all channels is the VCC of the device (typically 3.3V). Accuracy of measurement depends on the accuracy of the external voltage applied to the IOX power input pin 2.

## Examples

```
ret = config_ADC(0, 1, ADC_RESOL_12); // config ADC chnl 1 for 12 bit conversion.
```



## Returns

The function will return a `ERR_NONE` (0x0) on successful completion or an error code (see [\*\*ERROR HANDLING\*\*](#)).

## START ADC CONVERSION

`uint8_t start_ADC(uint8_t iox_adrs, uint16_t adc_chnls, uint16_t num_samples)`

### Description

This function starts an ADC conversion sequence on the designated channels. Configured ADC channels are scanned from the lowest numbered to the highest.

Conversion values for each channel can be averaged over many samples to achieve more accurate and stable results (oversampling).

### Parameters

**'iox\_adrs'** is used to select an IOX device in a multi device configuration. Value should be 0 or 1.

**'adc\_chnls'** is a 16 bit map where the low order 10 bits represent all possible ADC inputs. A '1' bit in the map will start the A/D conversion on the associated logical channel. Each conversion channel should be previously configured by the [\*\*CONFIGURE ADC CHANNEL\*\*](#) function.

**'num\_samples'** is a 16 bit value allowing up to 65535 samples for each channel. The averaged result is obtained using the [\*\*READ ADC\*\*](#) function. The number of samples should be a minimum of 1. A value of 0 will result in an error status with a parameter error code.

A conversion sequence begins by setting `STATUS_ADC_BUSY` in the `STATUS` byte indicating the ADC has been started but conversion is not yet complete.

When all conversions in a sequence have completed, the `STATUS_ADC_BUSY` will be cleared and the `STATUS_ADC_READY` will be set. See [\*\*READ STATUS\*\*](#) command.

### Examples

```
uint16_t adc_map = 0b1000001001; // read channels 0, 3, and 9
ret = start_ADC(0, ADC0, adc_map, 256); // start conversion and average over 256 samples.
```

## Returns

The function will return a `ERR_NONE` (0x0) on successful completion or an error code (see [ERROR HANDLING](#)).

## READ ADC

`uint8_t read_ADC(uint8_t iox_adrs, uint8_t adc_chnl, ADC_CONVERT * adc_conv)`

## Description

Following a START ADC command the ADC will begin reading conversions and averaging samples. When all conversions have been completed the `STATUS_ADC_BUSY` will be cleared and the `STATUS_ADC_READY` will be set.

## Parameters

‘`iox_adrs`’ is used to select an IOX device in a multi device configuration. Value should be 0 or 1.

‘`adc_chnl`’ specifies the logical channel number 0 – 9.

‘`adc_conv`’ is a pointer to an `ADC_CONVERT` structure (included in `iox_spi.h`) as follows:

```
typedef struct {           // ADC_CONVERT struct template  
  
    uint16_t mean;           // mean (averaged) result of the conversion(s)  
  
    uint16_t min;           // minimum value read.  
  
    uint16_t max;           // maximum value read.  
  
    uint16_t samples;       // number of samples converted.  
  
} ADC_CONVERT;  
  
ADC_CONVERT adc_conv;     // create a adc_conv object
```

When all channels involved in the conversion have been read, the `STATUS_ADC_READY` bit in the `STATUS` byte will be cleared and another conversion process can begin.

## Examples

```
ADC_CONVERT adc_conv;  
  
ret = read_ADC(0, ADC9, &adc_conv);    // read results of ADC9 conversions  
  
Serial.printf("ADC9 average= %d\n", adc_conv.mean);
```

## Notes:

Conversion from ADC reading to volts is as follows:

ADC bit resolution:

12 bit:  $2^{12} = 4096$

10 bit:  $2^{10} = 1024$

8 bit:  $2^8 = 256$

6 bit:  $2^6 = 64$

Volts = (VCC (3.3V) / bit resol) \* reading.

**Example:**  $(3.3 / 4096) * 1241 = 0.9998 \text{ V}$

## Returns

The function will return a ERR\_NONE (0x0) on successful completion or an error code (see **ERROR HANDLING**).

## START CAPTURE

`uint8_t start_capture(uint8_t iox_adrs, uint8_t capt_chnl, uint8_t trig_edge, uint8_t capt_type)`

## Description

The START CAPTURE command configures the specified channel for Input Capture and arms the capture trigger to begin measuring on the next specified edge. An internal timer measures the time between two consecutive edges (frequency) or between two opposite edges (pulse width).

The resulting measurement is saved as the number of timer clocks between edges. The timer clock is 48 MHz or 20.8333 nanoseconds per tick.

## Parameters

**'iox\_adrs'** is used to select an IOX device in a multi device configuration. Value should be 0 or 1.

**'capt\_chnl'** specifies the channel to be used (0 – 9).

**'trig\_edge'** defines the edge to be used to begin the measurement. The trig\_edge macros are defined in the *iox\_spi.h* file and can be one of the following:

0 – **INPUT\_CAPT\_RISING**: measurement starts at the next rising edge of the signal.



1 – **INPUT\_CAPT\_FALLING**: measurement starts at the next falling edge of the signal.



5 – **INPUT\_CAPT\_BOTH**: measurement starts at the next edge change (rising or falling).



‘**capt\_type**’ determines the measurement type:

0 – **CAPTURE\_TYPE\_PW**: measures time between opposite edges (pulse width):



1 – **CAPTURE\_TYPE\_FREQ**: measures time between same edges (frequency):



## Examples

```
// start a pulse width measurement on CAPT1 starting on the rising edge
```

```
ret = start_capture(0, CAPT1, INPUT_CAPT_RISING, CAPTURE_TYPE_PW);
```

## Returns

The function will return a **ERR\_NONE** (0x0) on successful completion or an error code (see **ERROR HANDLING**).

See also **NOTES ON INPUT CAPTURE MEASUREMENTS**.

## READ CAPTURE

`uint32_t read_capture(uint8_t iox_adrs, uint8_t capt_chnl)`

### Description

This command returns the value of the last START CAPTURE command. The 32 bit value represents the number of clock periods measured during the capture operation.

The capture clock runs at 48 MHz so each clock period is equivalent to 20.8333 nanoseconds.

### Parameters

‘**iox\_adrs**’ is used to select an IOX device in a multi device configuration. Value should be 0 or 1.

‘**capt\_chnl**’ specifies the logical capture channel to read (0 – 9).

### Examples

```
capt = read_capture(0, CAPT1); // read last measurement on CAPT1 channel
```

As an example, if the capt count == 99, the time would be 2.0625 microseconds ( $99 * 0.0208333$ ).

### Returns

The returned value will be 0 if an error occurs.

## CONFIGURE ENCODER

`uint8_t config_encoder(uint8_t iox_adrs, uint8_t enc_chnl)`

### Description

This command configures an adjacent pair of GPIO’s for use as a Rotary Encoder input.

The IOX device can support up to 7 rotary encoders that provide direction, rotational position, and rotational velocity when rotated. Rotary encoders generate 2 signals that are 90 degrees apart (Clk / Data, +/-, A / B, etc.) and require 2 inputs to the IOX device.

Some encoders use optical sensors whereas lower cost encoders may be mechanical switch encoders (KY-040 type for example). See [Figure 2](#) for an example using a mechanical encoder type.

### Parameters

‘**iox\_adrs**’ is used to select an IOX device in a multi device configuration. Value should be 0 or 1.

‘**enc\_chnl**’ defines the GPIO pair that is connected to the encoder’s +/- pair. See **IOX Package & Pinout**. Also see **Figure 2** for an example of encoder connection and note the external pull-up resistors and capacitors used to debounce noisy signals.

Whenever the encoder is rotated the **STATUS\_ENCODER** bit in the **STATUS** byte will indicate encoder motion. The status **FIELD** bits will indicate which encoder channel is active.

A call to READ ENCODER will clear individual encoder FIELD bits and the STATUS\_ENCODER in the STATUS byte will be cleared when all active encoder channels have been read.

Optionally a designated hardware output pin can notify encoder motion (see **CONFIGURE EVENT OUTPUT**).

## Examples

```
ret = config_encoder(0, ENC1);    // attach an encoder to GPIO's 2 & 3.
```

## Returns

The function will return a ERR\_NONE (0x0) on successful completion or an error code (see **ERROR HANDLING**).

## READ ENCODER

```
uint8_t read_encoder(uint8_t iox_adrs, uint8_t enc_chnl, ROT_ENC * rot_enc)
```

## Description

Whenever an encoder is rotated, the **STATUS\_ENCODER** bit in the **STATUS** byte will indicate encoder motion. Optionally a designated hardware output pin can notify encoder motion (see **CONFIGURE EVENT OUTPUT**).

The **READ STATUS** command with the field mask set to STATUS\_ENCODER will return a map of encoder channels indicating which encoders were rotated.

## Parameters

‘**iox\_adrs**’ is used to select an IOX device in a multi device configuration. Value should be 0 or 1.

‘**enc\_chnl**’ is the logical channel to read (0 – 7).

‘**rot\_enc**’ is a pointer to a ROT\_ENC structure (defined in iox\_spi.h) as follows:

```
typedef struct {  
    bool dir;           // true indicates CW rotation
```

```

    int16_t count;          // running count (reset to 0 when encoder is read)

    uint16_t speed;        // approx rotational speed in RPM
} ROT_ENC;

ROT_ENC rot_enc; // create a rot_enc struct object

```

‘**dir**’ value is true if the encoder is rotated clockwise, false otherwise. NOTE: If this is opposite of the desired indication, the encoder signal pair can simply be reversed.

‘**count**’ value will increment or decrement depending on the direction of rotation. This value is reset to 0 after reading the encoder value.

‘**speed**’ value is an approximation of the rotational velocity expressed as RPM. This may not be accurate as encoders may have a different numbers of commutators.

## Examples

```

ROT_ENC rot_enc;

ret = read_encoder(0, ENC1, &rot_enc);    // read last encoder values for ENC1

Serial.printf("count=%d\n", rot_enc.count); // print current count value

```

Whenever the encoder is rotated the **STATUS\_ENCODER** bit in the **STATUS** byte will indicate encoder motion has been detected. The status **FIELD** bits will indicate which encoder channel is active.

A call to READ ENCODER will clear individual encoder status FIELD bits. The STATUS\_ENCODER flag in the STATUS byte will be cleared when all active encoder channels have been read.

## Returns

The function will return a ERR\_NONE (0x0) on successful completion or an error code (see [ERROR HANDLING](#)).

## SLEEP

```

uint8_t sleep(uint8_t iox_adrs, uint8_t wake_gpio)

```

## Description

The IOX module can save power by putting the device into sleep mode. Power consumption will be reduced to approximately 4ma in sleep mode. When the device is put into sleep mode the internal CPU clock will be stopped but I/O's and most peripheral controllers remain active.

## Parameters

**'iox\_adrs'** is used to select an IOX device in a multi device configuration. Value should be 0 or 1.

**'wake\_gpio'** specifies the GPIO that will wake the sleeping device.

Wake up from sleep can happen three different ways:

- 1) If NRST (pin 3) is pulled to ground and released, the device will re-boot and operate normally. This may not be desirable since the device will need to be reconfigured to the state it was in prior to sleep.
- 2) Wake up can be programmed to occur on activity from one of the GPIO pins specified by **'wake\_gpio'**. This means that the device will remain in its current configuration and will not incur boot up time or re-configuration through the serial bus.
- 3) Wake up from SPI bus activity. This functions the same way as option #2 except that the **'wake\_gpio'** should be set to 255 (0xFF). This may not work if there are two devices on the SPI bus since all devices would wake together.

Prior to issuing the **sleep** command the wake method **'wake\_gpio'** should be configured to generate an interrupt by calling the **CONFIGURE GPIOS** command.

## Examples

```
config_gpios(0, 0x8, IO_INPUT | IO_PULLUP | IO_EXTI_FALLING);    // wake on falling edge
ret = sleep(0, 3); // sleep & wake on falling edge of GPIO3
```

Further power savings can be implemented by setting all unused GPIO pins to IO\_LOW\_POWER (Analog) inputs. See **CONFIGURE GPIOS**.

## Returns

The sleep function does not return any data.

## SET UART BAUDRATE (IOX-UART version only)

```
uint8_t set_uart_baud(uint8_t iox_adrs, uint32_t baudrate)
```



## Description

This function is supported for compatibility, it has no effect if called.

## Parameters

‘**iox\_adrs**’ is used to select an IOX device in a multi device configuration. Value should be 0 or 1.

‘**baudrate**’ is the requested speed in bits/second.

## Examples

```
uint8_t set_uart_baud(0, 250000);    // IOX device 0, set new baudrate = 250000 baud
```

## Returns

The SET UART BAUDRATE command will return a ERR\_NONE (0x0)

## GET VERSION INFO

```
uint8_t get_version(uint8_t iox_adrs, VERSION_INFO * version)
```

## Description

Returns 4 bytes of information used to identify the serial bus type and firmware version number.

## Parameters

‘**iox\_adrs**’ is used to select an IOX device in a multi device configuration. Value should be 0 or 1.

‘**version**’ is a pointer to a VERSION\_INFO structure (defined in iox\_spi.h) as follows:

```
typedef struct {  
    uint8_t reserved;           // for future use...  
    uint8_t bus_version;       // 1 == I2C, 2 == UART, 3 == SPI  
    uint8_t major_rev;         // major part of version number  
    uint8_t minor_rev;         // minor part of version number  
} VERSION_INFO;  
  
VERSION_INFO version; // version object
```

## Examples

```
ret = iox_spi.get_version(0, &version);
```

```
Serial.printf("Bus version=%d, version=%.02d.%.02d\n", version.bus_version, version.major_rev, version.minor_rev);
```

## Returns

The function will return a `ERR_NONE` (0x0) on successful completion or an error code (see **ERROR HANDLING**).

## ERROR HANDLING

Errors can occur as a result of serial bus communication problems or as a result of command execution after the IOX receives a command.

Most functions return an 8-bit error code indicating if communication to the IOX device was successful. The following is a list of possible codes:

| Hex Code | Description                              |
|----------|--|
| 0x00     | ERR_NONE - Function successful           |
| 0x01     | ERR_PARAM - Parameter out of range.      |
| 0x02     | ERR_GP_FAILURE - General Failure         |
| 0x04     | ERR_SERIAL_MODE - Serial bus mode error. |
| 0x08     | ERR_TIMEOUT - Communication timeout.     |
|          |  |

When an error occurs during serial bus communication, the library will return a bus failure error. The error is as follows:

When an error occurs during command execution (after receiving the command correctly) the IOX will assert `STATUS_ERROR` bit in the `STATUS` byte. Details about the error can be discovered by issuing a `READ STATUS` with the 'field\_mask' set to `STATUS_ERROR`. See **READ STATUS**.

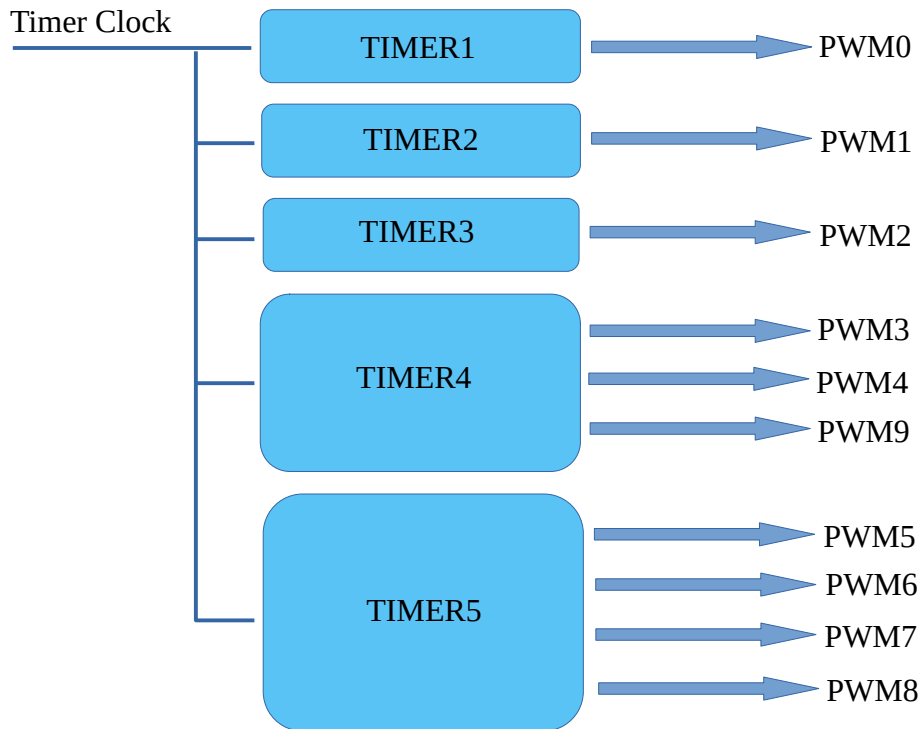
When an error occurs during serial bus communication, the library will return a bus failure error. The error is as follows:

When an error occurs during command execution (after receiving the command correctly) the IOX will assert `STATUS_ERROR` bit in the `STATUS` byte. Details about the error can be discovered by issuing a `READ STATUS` with the 'field\_mask' set to `STATUS_ERROR`. See **READ STATUS**.

## NOTES ON PWM GENERATION

PWM waveforms are created using timers embedded in the IOX MPU. There are a total of five timers that can be used for PWM generation. Three of these timers are independent from the others while the remaining two timers have multiple shared output channels.

Timers that have multiple outputs can have different duty cycle values but share the same prescaler and period frequency values. Common period frequency is probably not an issue for servo control since multiple servos would require the same period frequency.



## NOTES ON INPUT CAPTURE MEASUREMENTS

Input Capture measurements use timers embedded in the IOX MPU. There are a total of five timers that can be used for Input Capture. Three of these timers are independent from the others while the remaining two timers have multiple shared input channels.

Timers used for Input Capture cannot be used simultaneously for PWM generation.

The clock for all timers used for Input Capture is 48 MHz. Capture measurements are reported as the number of clocks between two edge transitions. The measured time reported is an unsigned 32 bit value which limits the measurement interval to 89.48 seconds or 0.011 Hz.



