Cyclops Smart**load** loadcell amplifier

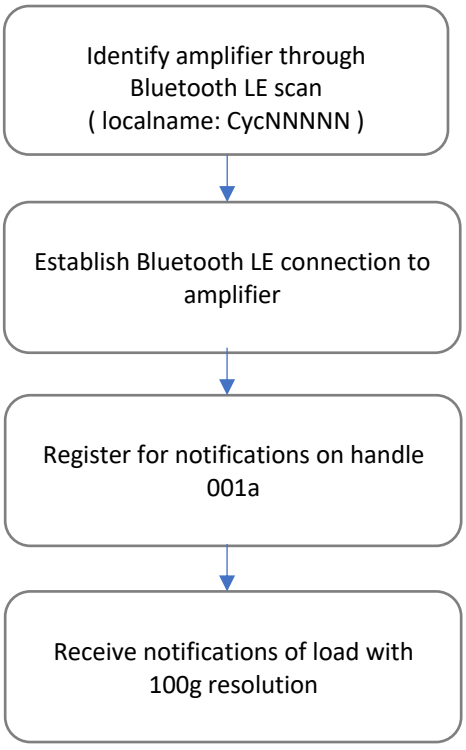
Description

The Smartload load cell amplifier is a low power, dual channel digital load cell amplifier which reports measurements using Bluetooth. The amplifier drives and measures strain gauge bridge load cells.

Measurements are transmitted as manufacturer specific data within a BluetoothLE advertising message. This allows listening devices to collect data without establishing a connection to the amplifier. Measurements may also be received by establishing a Bluetooth connection with the amplifier and either polling for measurements or registering for sensor measurement push notifications. Both modes of operation can be used simultaneously.

Power management allows the amplifier to measure continuously for up to 5000 hours from a CR2032 Lithium coincell battery[1]. The amplifier offers options to trade update rate and measurement noise to match the application.

The amplifier includes a charge manager for a lithium-ion battery.



[1] BluetoothLE advertising mode, single channel measurements at 2s interval without over-sampling

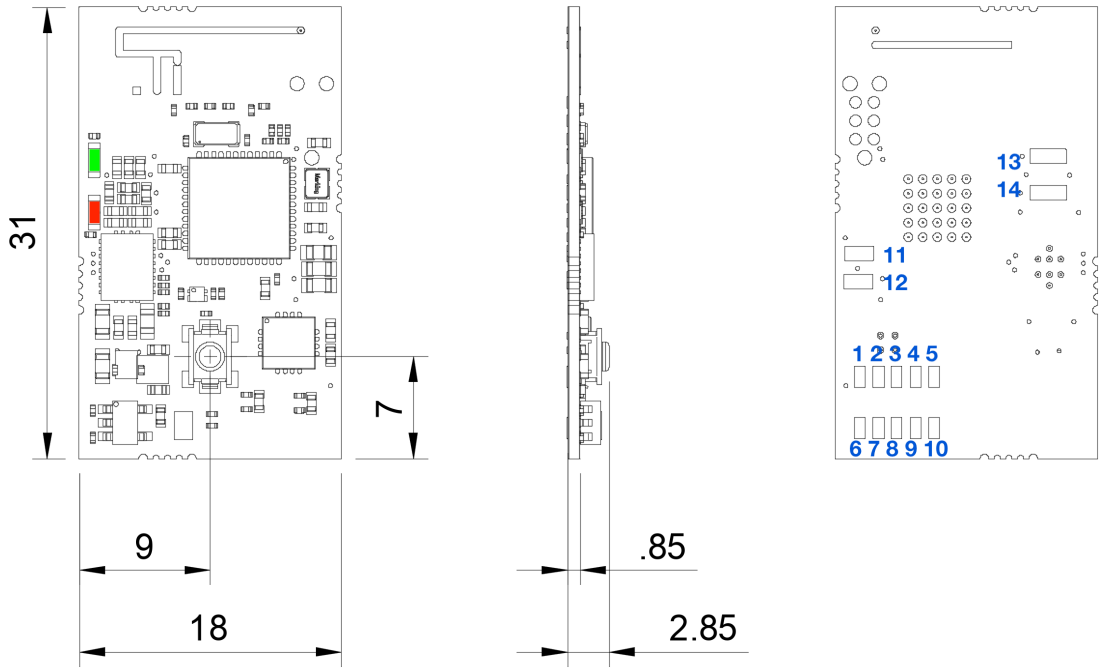


Figure 1 Amplifier dimensions and connections

Pad	Name	Function	Description
1	EX1P	Drive +ve	Strain gauge bridge 1 Wheatstone bridge connections Bridge impedance 350Ω <= Z_b <= 5kΩ
2	S1P	Sense +ve	
3	S1N	Sense -ve	
4	EX1N	Drive -ve	
5	NC1	Spare	Spare pad for bridge connections
6	EX2P	Drive +ve	Strain gauge bridge 2 Wheatstone bridge connections Bridge impedance 350Ω <= Z_b <= 5kΩ
7	S2P	Sense +ve	
8	S2N	Sense -ve	
9	EX2N	Drive -ve	
10	NC2	Spare	Spare pad for bridge connections
11	B-	Battery -ve	LiPo battery connections single cell, nominal 3.6V, 1C, 250mAh
12	B+	Battery +ve	
13	C1	Coil	
14	C2	Coil	

Obtaining measurements

The output of the amplifier can either be read from a BluetoothLE advertisement sent periodically, or from a BluetoothLE GATT characteristic in polling or notify.

Advertisment data

The Channel A value is encoded in the periodic BluetoothLE advertisement from the amplifier. The advertisement rate varies from the measurement update rate as configured, down to a dormant rate of once every 4seconds.

The measurement is delivered in a manufacturer specific data field in the advertisement. This field consists of a manufacturer ID, a protocol identifier, a datatag identifier, status, units and value and a duplicate datatag identifier. The status, units, value and duplicate datatag are obfuscated by XORing their bytes with a obfuscation key. Simply XORing these bytes in a received message by this key will decode the message and allow the 2 datatags to be compared and the message validated.

The value field is presented as a 32bit floating point number scaled in tonnes (1000 kgf).

Field	MFGID		Proto	DataTag		Status	Units	Value				DataTag	
Type	UINT16			UINT16		UINT8	UINT8	IEEE754 FLOAT32				UINT16	
Example	0xc304		0x01	0xa16d		0x00	0x01	-0.00239193				0xa16d	
Raw data	0xc3	0x04	0x01	0xa1	0x6d	0x00	0x01	0xbb	0x1c	0xc2	0x00	0xa1	0x6d
XOR													
Key						0x6c	0x5f	0x1f	0x71	0x11	0x4a	0x16	0x75
=													
Transmitte	0xc3	0x04	0x01	0xc1	0xc4	0x6c	0x65	0xa4	0x6d	0xd3	0x4a	0xb7	0x18

GATT characteristic

The Channel A value is reported using the characteristic with UUID: 0000**ffb1**-0000-1000-8000-00805f9b34fb. The measured value is encoded as a signed 32bit integer in little endian byte order. To read the characteristic a connection should first be made to the amplifier. If requested the amplifier will then start to push measurements to the client. Alternatively the client may read the characteristic value or register for notifications to be sent. New data / notifications will be sent at the measurement rate as configured.

The value of the characteristic is the measured load in 100g increments, i.e. the load in tonnes may be calculated by dividing the reported integer by 10,000.

The Channel B measurement can be similarly read with UUID : 0000**ffb2**-0000-1000-8000-00805f9b34fb.

Characteristic 0000**ffb1**-0000-1000-8000-00805f9b34fb Channel A value				
Type	INT32			
Example	0x12	0x13	0xff	0xff
Integer value	0xffff1312			
Raw value	-60654			
Indicated load	-6.0654 tonnes			

System block diagram

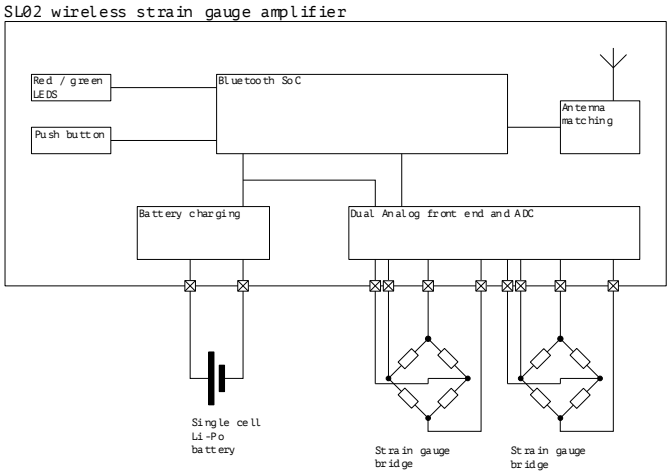


Figure 2 amplifier system block diagram

Measurement function

The amplifier measures signals from resistive strain gauges. It provides differential bridge drive signals and differential inputs. Connections for 2 bridges are provided and the amplifier is able to measure loads from both bridges simultaneously. Bridge drive signals are applied to AD and the differential output taken from C-B of the bridge shown in Figure 3.

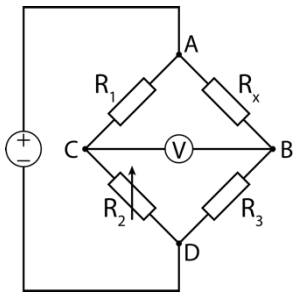


Figure 3 strain gauge bridge

The raw bridge measurement is first compensated for bridge zero offset errors before being scaled into the final reported measurement.

Zero compensation

A strain gauge bridge is intended to indicate zero output for no applied load. However manufacturing errors inevitably lead to some output. This error may be corrected by simply subtracting a fixed offset from the raw measured value. This zero offset correction can be determined during a calibration process. The software correction for zero offset error eliminates the need for precise bridge balancing in manufacture.

The zero offset error is usually influenced by temperature. Hence adjustment should be made for the applied offset as a function of the bridge temperature. The amplifier includes a temperature measurement function and allows the zero offset correction to be linearly adjusted for temperature with a zero offset compensation coefficient. This can be used in place of a zero offset compensation resistor.

Gain

The compensated raw measurement is converted into a reported output value by multiplying by a gain constant. It is normal for strain gauge bridges to require compensation for gain variation with temperature and as with the zero offset compensation a gain temperature compensation coefficient can be programmed to provide first order linear correction for this error.

Linearity

The amplifier includes a correction for first order curvature of the response of a connected load cell to load. This is a multiplicative factor which varies with zero and temperature compensated raw value.

Input range and resolution

The amplifier is configured for a maximum input range of ± 4mV/V and measures with a noise free resolution of 0.24µV/V, 14bits.

The uncalibrated resolution of the amplifier is 0.2384µV/V. Thus if used with a 2 tonne load cell with a nominal gain factor of 2mV/V at 2 tonnes, the system resolution will be 238.4 grammes.

Sampling and measurement rate

The amplifier makes periodic measurements of the loads in the two channels and reports these with low-latency in BluetoothLE messages, either broadcast advertisement or a directed notification. In order to conserve power the measurements are made over a short time window – the amplifier does not provide an average or peak measurement throughout the measurement period, but only over this measurement window. This should born in mind when measuring loads with fast, dynamic variations and peaks.

The measurement period can be chosen between 20ms and 5000ms as required to balance battery lifetime against data.

Oversamping

The amplifier can be configured to oversample the raw load cell output to improve resolution and reduce noise. This can be useful to amplify strain gauge bridges with low output signals. Oversampling makes multiple measurements per reported measurement and averages the multiple measurements before reporting. This comes at the cost of increased power consumption and reduced maximum input range.

Oversampling factor	Input range mV/V	ENOB
x1	± 4	14
x2	± 4	15
x4	± 4	15
x8	± 4	15
x16	± 4	TBC
x32	± 4	TBC
x64	± 4	TBC
x128	± 4	TBC

Faults and errors

The amplifier monitors the load cell and reports errors in the status characteristic and in the advertisement data. In case of error the reported measurement will be 999.9999 tonnes.

Overflow error

The amplifier detects conditions where the load cell output exceeds the input range.

Hardware error

The amplifier detects wiring faults on the load cell and reports these in the status register reported in the advert or readable from the Data Service:

bit7	bit6	bit5	bit4	bit3	bit2	bit1	bit0
Res	Res	CHBHWD	CHAHWD	CHBHWS	CHAHWS	CHBOF	CHAOF

CHAOF Channel A overflow

CHBOF Channel B overflow

CHAHWS Channel A hardware fault on sense inputs

CHBHWS Channel B hardware fault on sense inputs

CHAHWD Channel A hardware fault on bridge drive

CHBHWD Channel B hardware fault on bridge drive

A value of 1 in a bit indicates an error.

Overflow conditions are only detected and reported if the appropriate channel is selected for measurement in the features register and hardware faults only detected if the appropriate channel is configured for hardware test (there is a small increase in power consumption if hardware testing and reporting is selected). Hardware faults may take a number of measurement cycles to be detected and cleared.

Power management

The amplifier actively manages its power consumption to maximise battery lifetime. When not in active use the amplifier enters a semi-dormant 'napping' state, making and reporting measurements once every 4s. The amplifier can be woken from this state by Bluetooth configuration, connection or by a button press.

The amplifier leaves the dormant state whenever a Bluetooth connection is established and maintained.

Whilst connected the amplifier can be commanded to stay fully active for a defined period after the Bluetooth connection is terminated. At the end of this period the amplifier will enter the napping state.

The amplifier can be commanded to enter a hibernation state. In this state the amplifier shuts down the measurement and radio functions and only monitors the power button.

The button allows the amplifier to be woken from either hibernation or the napping state.

	Active				Napping	Hibernating
Runtime / days	10Hz	3Hz	1Hz	1 / 2s	1 / 4s	
2x AAA Alkaline	100	310	710	1000	5.5years	
250mAh LiPo	30	80	180	280	1.5years	
CR2032	20	60	150	220	440	

Button control and LED indication

The power state of the amplifier may be changed by presses of the button. The button may also be used to discover the current power state.

The red and green LEDs respond to the button press and indicate the power state, whether the amplifier is charging a connected battery, the state of the battery, whether a Bluetooth connection is in progress and the measurement function.

Normal operation indication

The LED flashes to indicate measurement interval and awake / napping state.

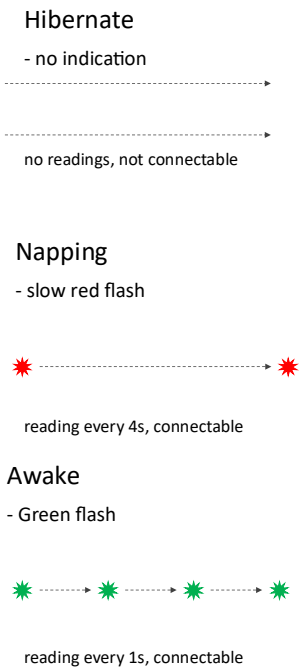


Figure 4 normal power indication

In the awake and napping states the flash period is one 8x the measurement interval – for 1Hz awake measurement the green LED will flash once every 8s, for napping measurement the red LED will flash once every 32s.

Power state indication with button

A brief press of the button will indicate whether the amplifier is awake. A green response indicates awake, red indicates napping or hibernation, and no response indicates that the battery is empty

Charging indication

If the amplifier is charging a battery the LEDs will indicate this by lighting continuously with brief off periods. Red indicates that the battery charge state is less than and green more than 90%.

Battery state indication

In normal operation the LEDs make single flashes. If the battery state is less than 20% the LEDs make double flashes.

Bluetooth activity

If there is an active Bluetooth connection in progress the LEDs will flash, both red and green together at the interval of the normal operation indication.

Changing state with the button

The power state of the amplifier may be changed by making long presses of the button, holding the button down until the amplifier indicates that a state change has occurred. From the awake state the amplifier may be switched to napping or hibernate. From either hibernate or napping the amplifier can only be switched to awake. An extended press in awake mode allows a full software reset of the amplifier.

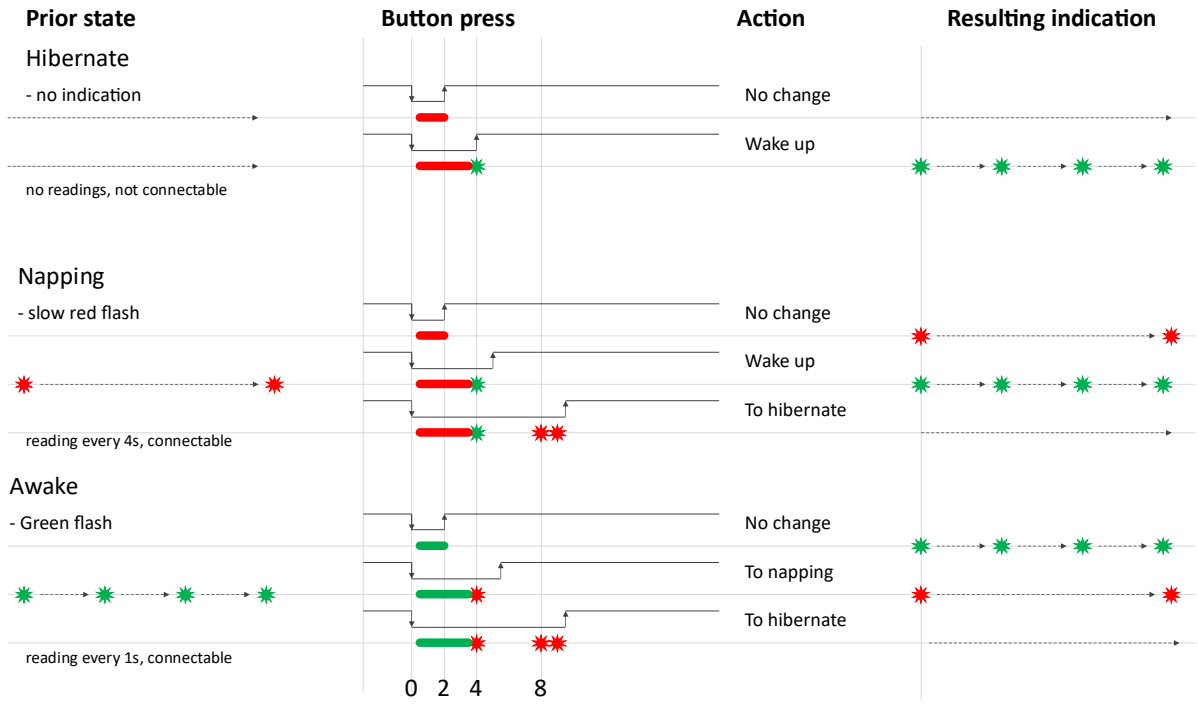


Figure 5 changing state with button presses

Amplifier setup and calibration

The amplifier is configured by writing a number of Bluetooth characteristics within the Setup service. All multibyte parameters must be sent in little-endian format, i.e. [LSB,…,…,MSB], strings in their normal byte order. Aside from writing calibration and temperature compensation values, the following attributes may be configured:

- The Bluetooth local name as will appear in Advertisements
- The measurement rate used while the amplifier is in active measurement mode
- The datatag identity included measurements broadcast through advertising
- The amplifier feature set

The feature set is a collection of settings which includes the oversampling factor, whether the amplifier makes measurements on channel B, whether the amplifier makes temperature measurements, whether continuity tests are performed on the strain gauge bridge and whether the amplifier will automatically try to save power. The default value should be suitable for most applications, and includes aa features required for accurate measurement on channel A with fault detection. Details are available on request.

Bluetooth interface

BluetoothLE services

The amplifier provides information and control through a number of BluetoothLE services.

In summary these are:

Device information service 180a

Characteristic name	handle	UUID
System ID	000b	0000**2a23**-0000-1000-8000-00805f9b34fb
Model number	000d	0000**2a24**-0000-1000-8000-00805f9b34fb
Serial number	000f	0000**2a25**-0000-1000-8000-00805f9b34fb
Firmware revision	0011	0000**2a26**-0000-1000-8000-00805f9b34fb
Hardware revision	0013	0000**2a27**-0000-1000-8000-00805f9b34fb
Software revision	0015	0000**2a28**-0000-1000-8000-00805f9b34fb
Manufacturer name	0017	0000**2a29**-0000-1000-8000-00805f9b34fb

Data service ffb0

Channel A reading	001a	0000**ffb1**-0000-1000-8000-00805f9b34fb
Channel B reading	001e	0000**ffb2**-0000-1000-8000-00805f9b34fb
Temperature	0022	0000**ffb3**-0000-1000-8000-00805f9b34fb
Battery level	0025	0000**ffb4**-0000-1000-8000-00805f9b34fb
Status	0028	0000**ffb5**-0000-1000-8000-00805f9b34fb

Control service ffd0

Runtime	002c	0000**ffd1**-0000-1000-8000-00805f9b34fb
Command	002f	0000**ffd2**-0000-1000-8000-00805f9b34fb

Setup service ffc0

LocalName	0033	0000**ffc1**-0000-1000-8000-00805f9b34fb
DataTag	0036	0000**ffc2**-0000-1000-8000-00805f9b34fb
Measurement period	0039	0000**ffc3**-0000-1000-8000-00805f9b34fb
Measurement features	003c	0000**ffc4**-0000-1000-8000-00805f9b34fb
Channel A calibration	003f	0000**ffc5**-0000-1000-8000-00805f9b34fb
Channel B calibration	0042	0000**ffc6**-0000-1000-8000-00805f9b34fb

Detailed service characteristic descriptions

Each characteristic of the services are detailed below. Characteristics may allow reading, writing and may provide BluetoothLE notifications.

Device information

Service	Device information service 180a	
Characteristic	0000**2a23**-0000-1000-8000-00805f9b34fb	
Name	System ID	
Modes	Read	
Representation	U8[8]	

Service	Device information service 180a	
Characteristic	0000**2a24**-0000-1000-8000-00805f9b34fb	
Name	Model number	
Modes	Read	
Representation	U8[20]	
Typical value	"SmartLoads1"	

Service	Device information service 180a	
Characteristic	0000**2a25**-0000-1000-8000-00805f9b34fb	
Name	Serial number	
Modes	Read	
Representation	U8[20]	
Typical value	"00000001"	

Service	Device information service 180a	
Characteristic	0000**2a26**-0000-1000-8000-00805f9b34fb	
Name	Firmware revision	
Modes	Read	
Representation	U8[20]	
Typical value	"0.0.1"	

Service	Device information service 180a	
Characteristic	0000**2a27**-0000-1000-8000-00805f9b34fb	
Name	Hardware revision	
Modes	Read	
Representation	U8[20]	
Typical value	"0.0.1"	

Service	Device information service 180a	
Characteristic	0000**2a28**-0000-1000-8000-00805f9b34fb	
Name	Software revision	
Modes	Read	
Representation	U8[20]	
Typical value	"0.0.1"	

Service	Device information service 180a	
Characteristic	0000**2a29**-0000-1000-8000-00805f9b34fb	
Name	Manufacturer name	
Modes	Read	
Representation	U8[20]	
Typical value	"Cyclops Marine"	

Data

Service	Data service ffb0	
Characteristic	0000ffb1-0000-1000-8000-00805f9b34fb	
Name	Channel A value	
Modes	Read / Notify	
Representation	I32 little endian integer	
Resolution	100 grammes	
Example	0xbc4d0000	0x00004dbc == 1990kg

Service	Data service ffb0	
Characteristic	0000ffb2-0000-1000-8000-00805f9b34fb	
Name	Channel B value	
Modes	Read / Notify	
Representation	I32 little endian integer	
Resolution	100 grammes	
Example	0xbc4d0000	

Service	Data service ffb0	
Characteristic	0000ffb3-0000-1000-8000-00805f9b34fb	
Name	Temperature	
Modes	Read / Notify	
Representation	I16 little endian integer	
Resolution	1/32 °C	
Example	0x6602	614 * 1/32 - 19.21°C

Service	Data service ffb0	
Characteristic	0000ffb4-0000-1000-8000-00805f9b34fb	
Name	Battery	
Modes	Read	
Representation	U8 little endian integer	
Resolution	1%	
Example	0x32	50%

Service	Data service ffb0	
Characteristic	0000ffb5-0000-1000-8000-00805f9b34fb	
Name	Status	
Modes	Read	
Representation	U16 little endian integer	
Example	0x0000	No errors

Setup

Service	Setup service ffc0	
Characteristic	0000ffc1-0000-1000-8000-00805f9b34fb	
Name	LocalName	
Modes	Read / Write	
Representation	UTF-8[10] string	
Example	CYCxxxxx	

Service	Setup service ffc0	
Characteristic	0000ffc3-0000-1000-8000-00805f9b34fb	
Name	Measurement period	
Modes	Read / Write	
Representation	U16 little endian integer	
Resolution	1ms	
Range	100 – 2000	
Example	0x4d01 == 333ms	

Service	Setup service ffc0	
Characteristic	0000ffc5-0000-1000-8000-00805f9b34fb	
Name	Channel A calibration	
Modes	Read / Write	
Representation	I32[4] little endian	
Detail	Word0: Offset Word1: Gain	Offset in raw measurement units 0.2384µV/V / bit Gain as 16.16 fixed point binary integer

	Word2: TCO Word3: TCG	Temperature coefficient of offset Temperature coefficient of gain

Service	Setup service ffc0	
Characteristic	0000ffc6-0000-1000-8000-00805f9b34fb	
Name	Channel B calibration	
Modes	Read / Write	
Representation	I32[4] little endian	
Detail	Word0: Offset Word1: Gain Word2: TCO Word3: TCG	Offset in raw measurement units 0.2384µV/V / bit Gain as 16.16 fixed point binary integer Temperature coefficient of offset Temperature coefficient of gain

Bluetooth Certification

The amplifier uses a pre-certified Bluetooth module as detailed

Regulatory body.	Specification	ID (if applicable)
FCC (USA)	Part 15C:2015 + MPE FCC 1.1307 RF Exposure (Bluetooth)	FCC ID: 2A9FYSL02
IC (Canada)	RSS-102 (MPE) and RSS-247 (Bluetooth)	TBC
ETSI/CE (Europe)	EN 300 328 V2.1.1 (Bluetooth)	
	EN 62479:2010 (MPE)	
	Draft EN 301 489-1 V2.2.0 (2017-03)	
	Draft EN 301 489-1 V3.2.0 (2017-03)	
	EN 55024:2010 + A1:2015	
	EN 55032:2015 + AC:2016-07	
	EN 60950-1:2006/A11:2009/A1:2010/A12:2011/A2:2013	
Japan MIC	ARIB STD-T66	TBC
	JATE	TBC

Regulatory Information Europe

Hereby, Cyclops Marine. declares that the radio equipment type SL002 is in compliance with Directive 2014/53/EU.

The compliance has been verified in the operating frequency band of 2400 MHz to 2483.5 MHz.

The SL002 has been tested in the 2400-GHz to 2483.5-GHz ISM frequency band at 3.3 V with a maximum peak power of 5.056-dBm EIRP across the temperature range –40°C to +85°C and tolerance.

Federal Communications Commission Statement

You are cautioned that changes or modifications not expressly approved by the part responsible for compliance could void the user's authority to operate the equipment.

This device complies with part 15 of the FCC Rules. Operation is subject to the following two conditions:
(1) This device may not cause harmful interference, and
(2) This device must accept any interference received, including interference that may cause undesired operation.
Any Changes or modifications not expressly approved by the party responsible for compliance could void the user's authority to operate the equipment.

RF warning:
This equipment complies with FCC radiation exposure limits set forth for an uncontrolled environment. This equipment should be installed and operated with minimum distance 20cm between the radiator & your body.

Transmitter Module Approval Conditions

■ Antennas must be installed to provide 20 cm separation distance from the transmitting antenna to the body of the user during normal operating condition. This device must not be co-located or operating in conjunction with any other antenna or transmitter.

■ Only those antennas filed under FCC ID: 2A9FYSL02 can be used with this device.

■ When the module is installed in the final system where the antenna location is less than 20 cm separation distance to the body of user, additional equipment authorization must be applied.

■ FCC ID label on the final system must be labeled with "Contains FCC ID: 2A9FYSL02" or "Contains transmitter module FCC ID: 2A9FYSL02".

■ In the user guide, final system integrator must be ensure that there is no instruction provided in the user guide to install or remove the transmitter module.

■ The transmitter module must be installed and used in strict accordance with the manufacturer's instructions as described in the user documentation that comes with the product. This device complies with the following radio frequency and safety standards.

The host product manufacturer is responsible for compliance to any other FCC rules that apply to the host not covered by the modular transmitter grant of certification. The final host product still requires Part 15 Subpart B compliance testing with the modular transmitter installed.

The end user manual shall include all required regulatory information/warning as shown in this manual, include:

This product must be installed and operated with a minimum distance of 20 cm between the radiator and user body

Limited Module Usage

The SL002 module, FCC ID:2A9FYSL02 is for use limited to being that of a strain gauge amplifier component fitted within the body of a load sensing fitting.

Technical specification

Specification		Min	Typ	Max	Unit
General					
Supply voltage	V_{CC}	2.9	3.6	4.2	V
Supply current	I_{CC}	0.002	0.06	10	mA
Battery charge current	I_{CHG}		240		mA
Operating temperature	T	-20	20	85	°C
Measurement					
Bridge drive signal	V_D		3.3		V
Strain gauge bridge impedance	Z_b	350	1000	5000	Ω
Bridge output	V_S	-	-	4	mV/V
Bluetooth					
Output power				+5	dBm
Version	BTLE Vn5.1				
Profile support	GAP / GATT / Device Info / Notified characteristics				
Supported simultaneous connections		-	-	4	

Glossary

ENOB	Effective number of bits of noise free resolution
Handle	A shorthand identifier used in place of a full UUID
GATT	The Bluetooth Generic Attribute Profile, a set of protocols for data exchange
UUID	Unique identifier numbers for each of the services and characteristics

Document history

Rev.	Date	Author	Notes
A	20/8/2021	EGC	First draft
A.1	25/8/2021	EGC	Four presses runtime changed
B	19/1/2022	EGC	Including new button and LED UI
C	14/3/2023	EGC	Smartload2 features first draft