V1.5

TBSAB03-DR

24 Bit Differential Analog to SDI-12 Interface

The TBSAB03-DR is a 4 differential channel analog to SDI-12 interface for 24 Bit A/D conversion of sensor signals. A/D conversion and configuration is controlled via SDI-12 commands. The interface is equipped with signal conditioning circuits which can be customized for various input voltage ranges. It offers low current consumption and comes in a Dinrail housing.
Each channel can be independently scaled with a 3rd order polynomial to enable gain and offset calibration of the connected sensors.
The TBSAB03-DR provides digital signals for the power management of the connected sensors. Four on board, SDI-12 controlled high side FET- switches are provided to power on/off connected sensors.

TBSAB03-DR 4 Channel Analog to SDI-12 Interface

Features

- Differential analog to SDI-12 interface
- 4 24 Bit Sigma Delta ADC channels
- 4 analog differential inputs; configurable as 4-20mA current loop or 0-2.5V voltage inputs; other voltage ranges upon order
- Input over-voltage protection
- Configurable 12V warm up and power off time for each channel
- ±0.025%, 2ppm/°C reference voltage
- Chopper stabilized buffer for low offset
- 50Hz & 60Hz line rejection filter
- SDI - 12 standard V1.4
- Plug and play
- 6 - 16V supply voltage
- 80 mm x 120 mm x 57mm
- Dinrail housing
- Operating temperature range: - 40°C … + 85°C

Target Applications

- SDI-12 Sensor Networks

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24 Bit Differential Analog to SDI-12 Interface manual

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1 Introduction

The TBSAB03-DR is a 24 Bit analog to SDI-12 interface to connect sensors with differential voltage or current loop outputs to SDI-12 networks.

1.1 Measurement

The TBSAB03-DR offers 4 differential input channels that are configurable:

Channel 0	differential 0 – 2.5V or 4 – 20mA
Channel 1	differential 0 – 2.5V or 4 – 20mA
Channel 2	differential 0 – 2.5V or 4 – 20mA
Channel 3	differential 0 – 2.5V or 4 – 20mA

Note: above current range is for typical use cases of TBSAB03 targeting 4-20mA sensors. However the full range supported for current input is 0.2-25mA.

Reference voltage:	2.5V, 0.025%, 2ppm/°C
ADC Resolution:	24 Bit, 19 Bit ENOB

1.2 Product Features

- Measurement of input channels with individual M-Commands
- Independent setting of the response time of each channel, configurable with Extended SDI-12 Commands
- Independent sensor power management control outputs for each channel, configurable with Extended SDI-12 Commands
- The measurement result of each channel can be independently scaled with a third order polynomial using Extended SDI-12 Commands
- SDI-12 v1.4 compliant
- Input protection
- 50Hz & 60Hz line rejection filter
- Accuracy:
    - Less than 10µV: not supported
    - Error rate over 10µV - 100µV range: less than 15%
    - Error rate over 100µV – 1mV range: less than 3%
    - Error rate over 1mV – 2.5V range: less than 1%
    - Error rate over 4 - 20mA: less than 1%
- Resolution: 1µV
- Minimum differential voltage: 10µV / Maximum differential voltage: 2.5V
- Dimensions: 80mm x 120mm x 57mm
- Mounted into Dinrail housing

- Operating temperature range: -40 … +85°C
- Idle current: 87µA / Active current: around 12mA

1.3 Calibration

Any offset or gain error of the analog system (sensor + TBSAB03-DR analog frontend) can be compensated using the scaling capability of the TBSAB03-DR.

1.4 Installation

The TBSAB03-DR is compatible with any data logger or remote telemetry unit with SDI-12 interface compliant with SDI-12 v1.3 or v1.4 standard (however the metadata commands are only supported by SDI-12 v1.4 protocol).

Up to 4 analog sensors with differential outputs can be connected to TBSAB03-DR:

From right to left: channel 0, 1 and 2

And

Channel 3

Each sensor must be connected to a specific channel of TBSAB03-DR as following:

ANALOG SENSOR	TBSAB03-DR differential analog port (channel *n*, 0 to 3)
Differential negative output	***n***N (Input) – pin 1

Differential positive output	***n***P (Input) – pin 3
GND (if required)	G (Input) – pin 4
12V power supply (if required)	V (Output) – pin 2

Refer to the data logger or RTU manual and to chapter 2 of this datasheet.

1.5 SDI-12

SDI-12 is a standard for interfacing data recorders with microprocessor-based sensors. SDI-12 stands for serial/digital interface at 1200 baud. It can connect multiple sensors with a single data recorder on one cable. It supports up to 60 meter cable between a sensor and a data logger.

The SDI-12 standard is prepared by

SDI-12 Support Group
(Technical Committee)
165 East 500 South
River Heights, Utah
435-752-4200
435-752-1691 (FAX)
http://www.sdi-12.org

The latest standard is version V1.4 which dates from January 10th, 2019. The standard is available on the website of the SDI-12 Support Group.

2 Application Examples

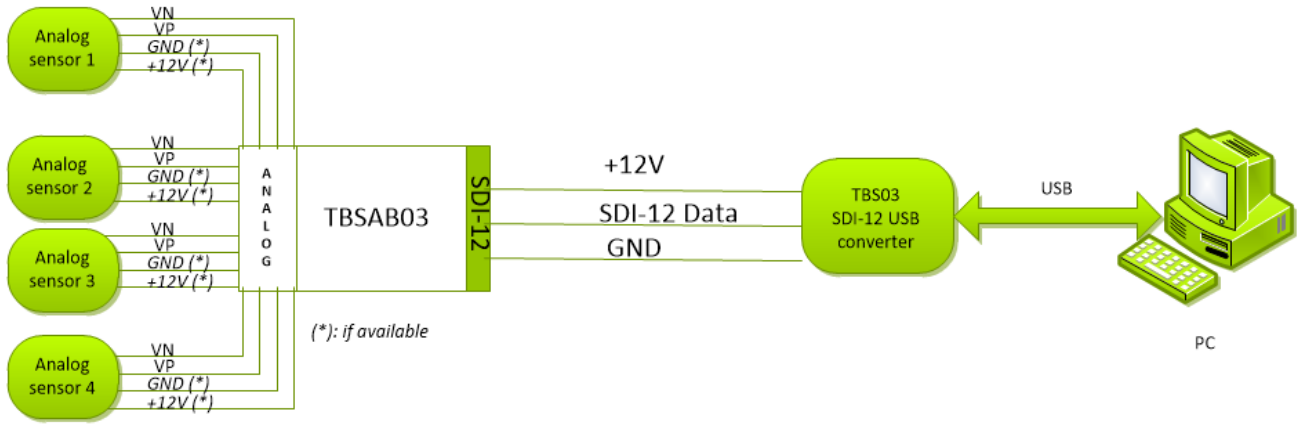


Figure 1 – Analog sensors connected to TBSAB03-DR and to TBS03 SDI-12 to USB converter; setup for controlling / testing sensors and for PC based data recording

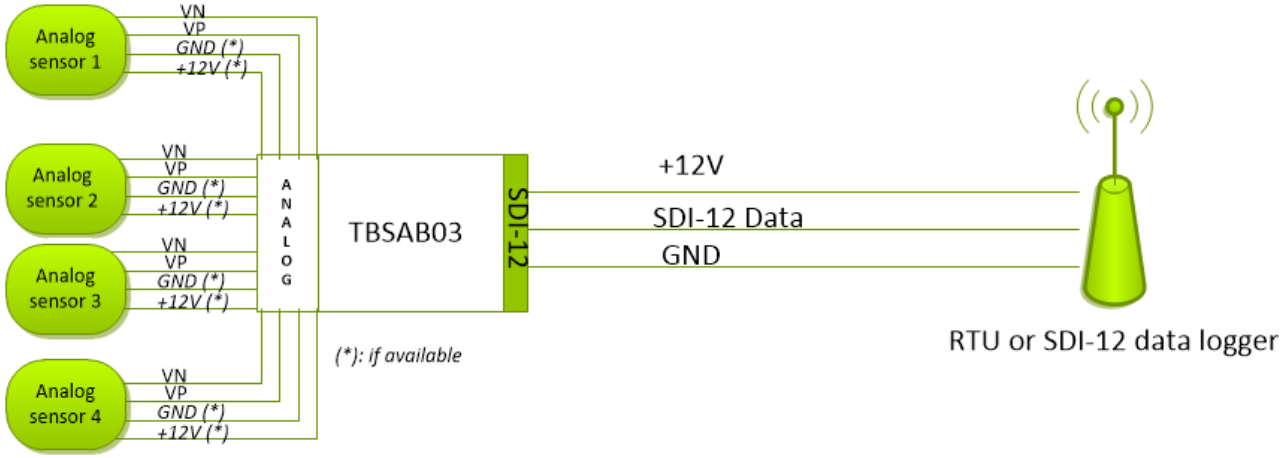


Figure 2 – Analog sensors connected to TBSAB03-DR and to Remote Telemetry Unit or Data Recorder

3 Hardware Description

3.1 Board overview

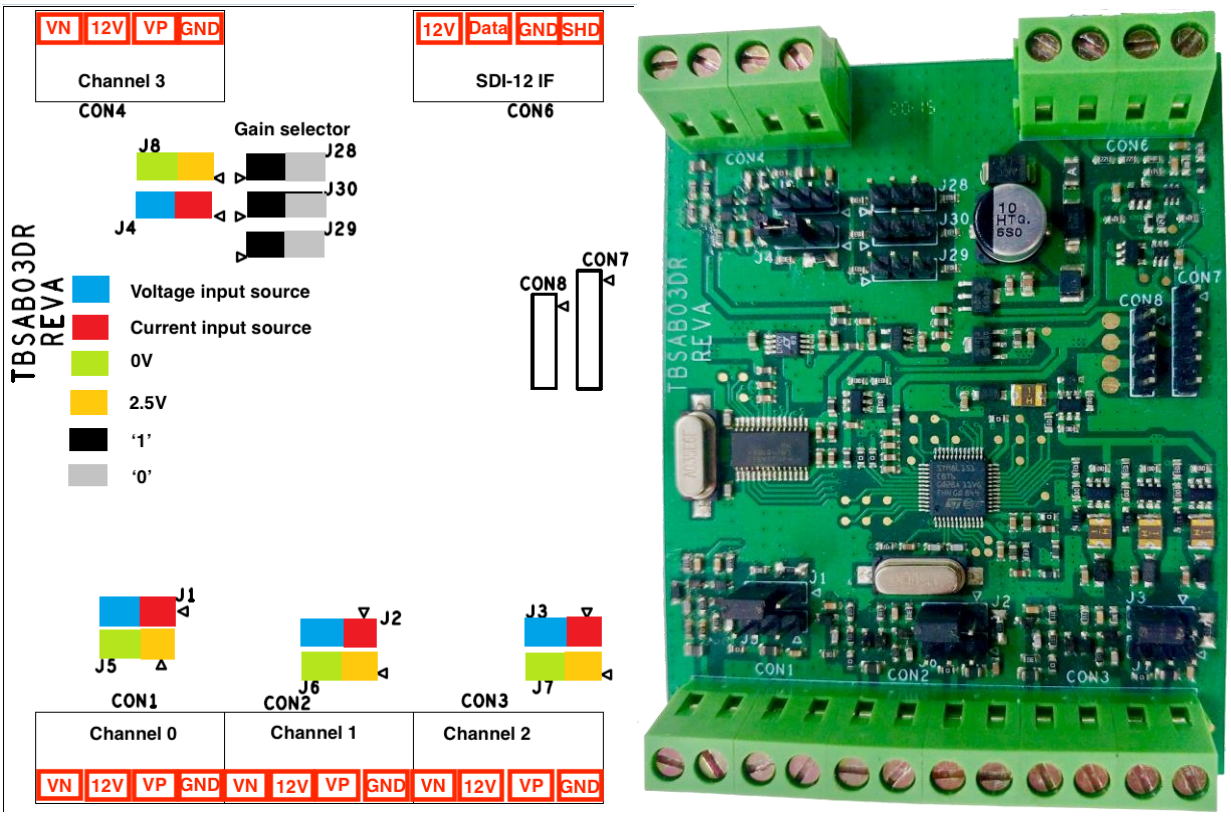


Figure 3 – Board Connections, Jumper Settings

The TBSAB03-DR is based on a sensor front end with a 24 Bit ADC, low noise programmable gain amplifier and a precision voltage reference. A true continuous background calibration feature minimizes gain and offset errors across time and temperature. A microcontroller controls the analog section, power management and the SDI-12 communication.

3.2 Connections

Internal connectors:

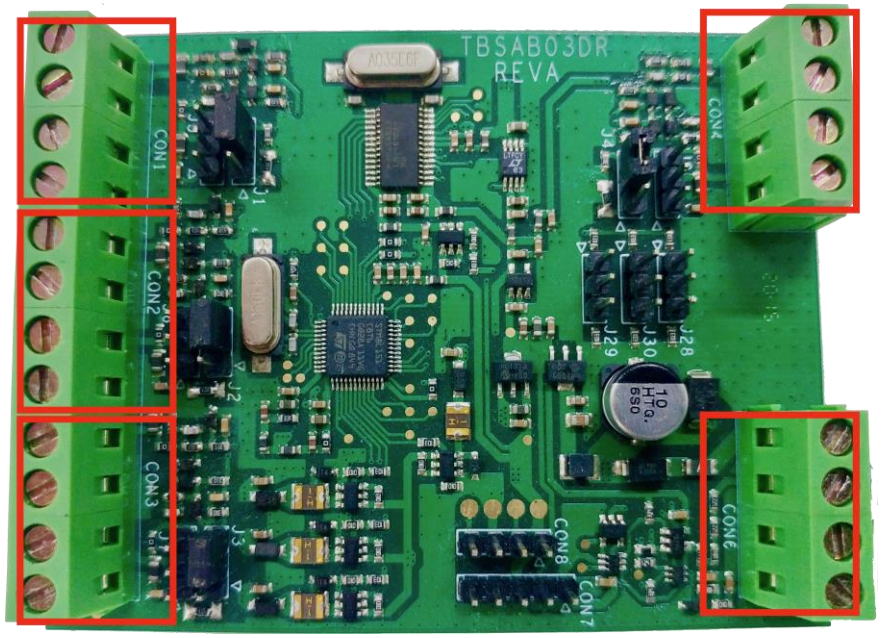
FW programming connector – CON8

Pin number	Description
1	3.3 V
2	SWIM
3	GND
4	/RESET

Internal Power supply sources (output) – CON7

Pin number	Description
1	GND
2	5 V
3	3.3 V
4	3.3 V (Analog)
5	2.5 V (VREF)

External terminal blocks:



There are 5 4-pins terminal blocks:

- 4 differential channels inputs: CON1 / CON2 / CON3 / CON4
- 1 SDI-12 interface connector: CON6

Differential analog input connector

Pin number	Description	Comment
1	Analog differential negative input VN	Connect to sensor's V- differential output
2	+12V sensor power supply	To be used for sensors requiring external power supply..
3	Analog differential positive input VP	Connect to sensor's V+ differential output.
4	GND	Connect to the sensor's ground if available, otherwise leave it unconnected.

SDI-12 terminal block

Pin number	Description	Comment
1	SDI-12 Power (12V)	Connect to the positive supply voltage wire of the SDI-12 cable
2	SDI-12 Data	Connect to the data wire of the SDI-12 cable
3	GND	Connect to the GND wire of the SDI-12 cable
4	Shield	Connect to the shield of the SDI-12 cable or leave it unconnected

3.3 Configuration jumpers

TBSAB03-DR provides 3 categories of configuration jumpers:

- Gain selection: J28/J29/J30
- Analog input type selection (current or voltage source): J1/J2/J3/J4
- Calibration: J5/J6/J7/J8

The jumpers configuration is described in the Board overview and below is the detailed description.

Gain selection jumpers:

3 jumpers are used to apply a common gain to all analog channels.

This can be overridden by using extended SDI-12 commands aXSGCS and configuring the desired gain for each channel with aXSBGC.

Each jumper port has a ‘0’ or ‘1’ state:

Jumper position	State
1 – 2	1
2 - 3	0

J30	J29	J28	Gain
0	0	0	1
0	0	1	2
0	1	0	4
0	1	1	8
1	0	0	16
1	0	1	32
1	1	0	64
1	1	1	128

Default configuration:
Gain=1 (J28/J29/J30 in 2-3 position)

Note:

- Gain=1 is the optimum setting to ensure 1mV accuracy over 1mV – 2.5V range.
- Gains x16 to x128 are reserved for future use.

Analog input type selection

Connector number and configuration jumper	Configuration	Analog input type
CON1 – J1	1 – 2	Current input source
CON1 – J1	2 – 3	Voltage input source
CON2 – J2	1 – 2	Current input source
CON2 – J2	2 – 3	Voltage input source
CON3 – J3	1 – 2	Current input source
CON3 – J3	2 – 3	Voltage input source
CON4 – J4	1 – 2	Current input source
CON4 – J4	2 – 3	Voltage input source

Default configuration
All channels configured as voltage input source (J1/J2/J3/J4 in position 2-3).

Calibration
These jumpers allow switching the positive differential input (VP) of each channel to either GND or VREF.
They must be left unconnected for normal operations.

Connector number and configuration jumper	Configuration	Differential positive analog input VP set to
CON1 – J5	1 – 2	VREF
CON1 – J5	2 – 3	GND
CON2 – J6	1 – 2	VREF
CON2 – J6	2 – 3	GND
CON3 – J7	1 – 2	VREF
CON3 – J7	2 – 3	GND
CON4 – J8	1 – 2	VREF
CON4 – J8	2 – 3	GND

Default configuration
These jumpers are not populated.

3.4 Calibration

The TBSAB03-DR is factory calibrated with respect to offset errors and gain errors of the analog signal chain. The TBSAB03-DR has excellent long term stability with respect to offset and gain errors:

Offset drift over time: 100nV/1000hrs
Gain drift over time: 1.6ppm/100hrs

TBSAB03-DR is ready to be used as is over the whole 0-2.5V range without changing any calibration of gain setting.
Therefore it is strongly recommended to keep TBSAB03-Dr default settings and especially the gain should be kept to 1.

Note:

- Default settings ensure 1mV accuracy over 1mV – 2.5V range. Refer to 1.2 for further details about accuracy.
- Differential input below 10µV is not handled by TBSAB03-DR and will result in random values.

In case that the user wants to calibrate the TBSAB03-DR for some specific purposes, offset and gain calibration can be conducted as follows:

Offset error calibration:

Supply the negative (VN – pin 1) and positive (VP – pin 3) so the differential input (VP-VN)=0V and issue the extended SDI-12 command aXSAOC,c! (where 'c' is the channel number).

Gain error calibration:

Supply the negative (VN – pin 1) and positive (VP – pin 3) so the differential input (VP-VN)=2.5V (full range) and issue the extended SDI-12 command aXSAGC,c! (where 'c' is the channel number).

Polynomial calibration:

Additionally the user can proceed with individual channel calibration using a 3rd order polynomial:

- Disable the factory calibrated polynomial for the selected channel and enable the user polynomial calibration
  - 0XSPCS,0,1! => enable custom polynomial calibration on channel 0; other channels still use factory calibration.
- Configure the polynomials coefficients for the desired channel:
  - 0XSFPC,0,5.2, -3.84,4,7.45! => $5.2*x^3 -3.84*x^2 + 4*x + 7.45$ polynomial for channel 0
  - If no correction needs to be applied, the polynomial coefficients (a,b,c,d) should be set to (0,0,1,0).

Note:

- aXSPCS,n,1! automatically resets the polynomial coefficients to (0,0,1,0). Therefore this command must be executed first before setting the new polynomial coefficients to be applied.

3.5 Warm up and power off time

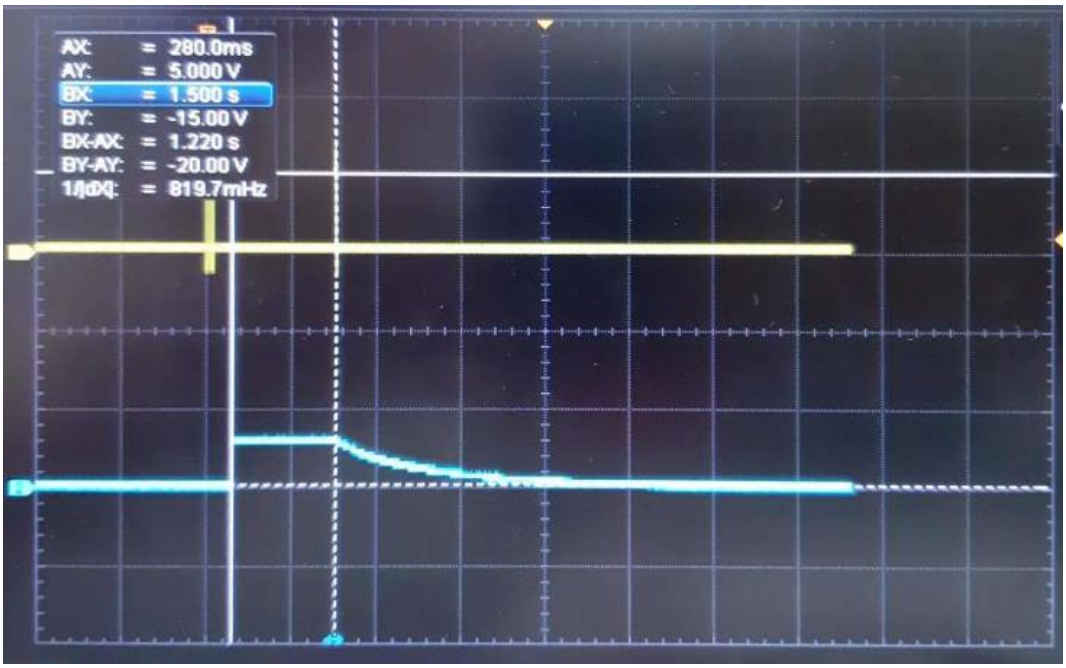
Each channel can be individually configured with a warm up and a power off time.

To configure warm up time of ‘t’ seconds for channel ‘c’: aXSWUT,c,t!
To configure power off time of ‘t’ seconds for channel ‘c’: aXSPOT,c,t!

In the following screenshots, the SDI-12 data line is in yellow and the the power line in blue (pin 2 of the terminal block connector).

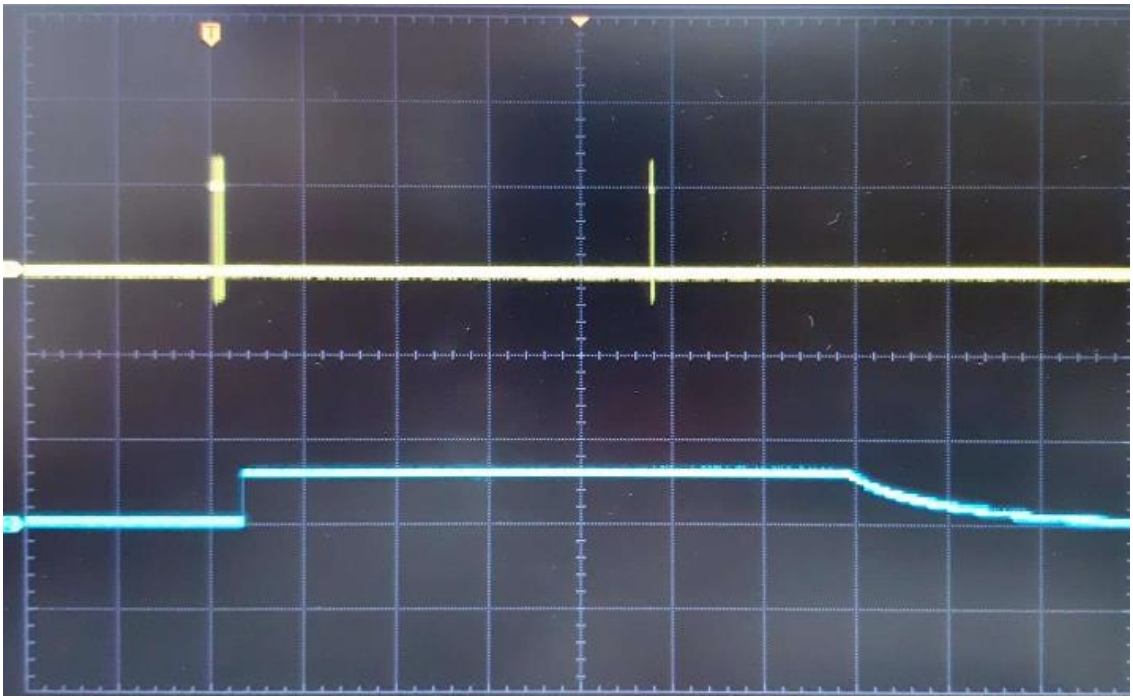
aM! Command is used in this case so the service request can also be observed.

Measurement without warm up time and power off time

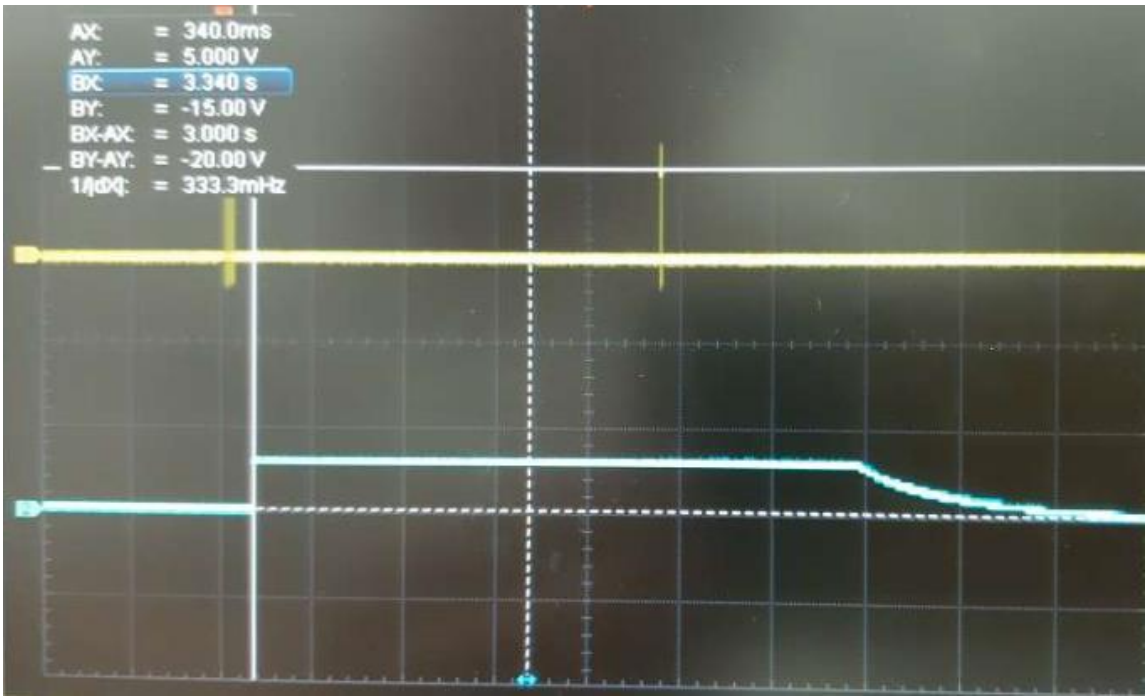


Measurement time: 1.22s

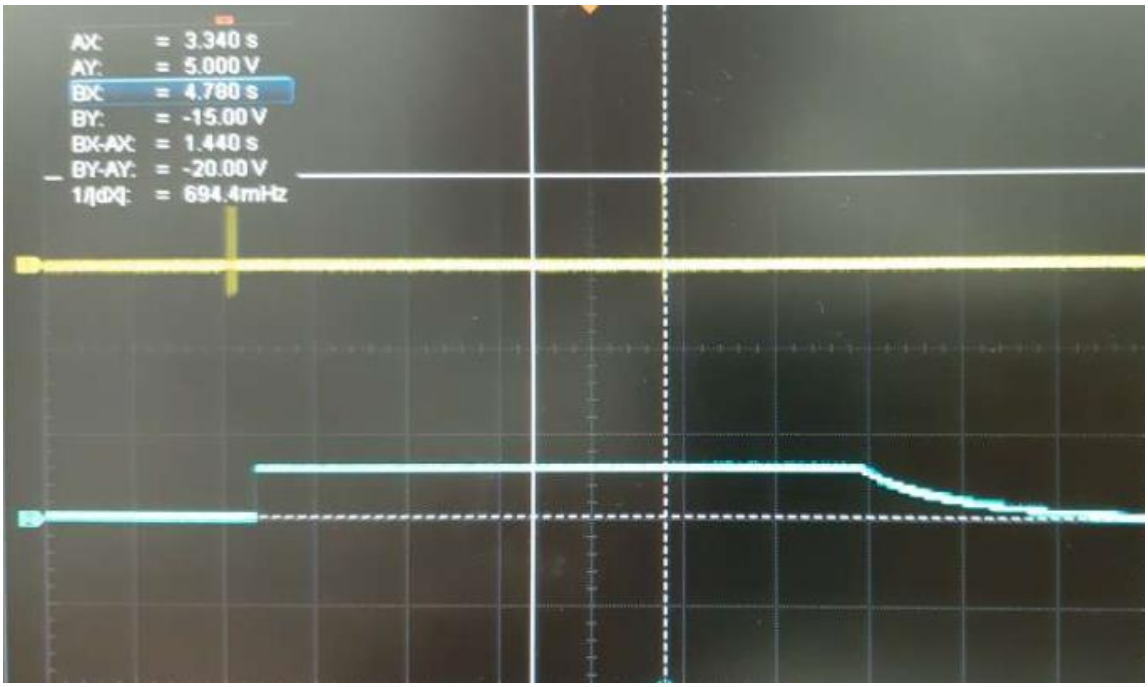
Measurement with warm up and power off time



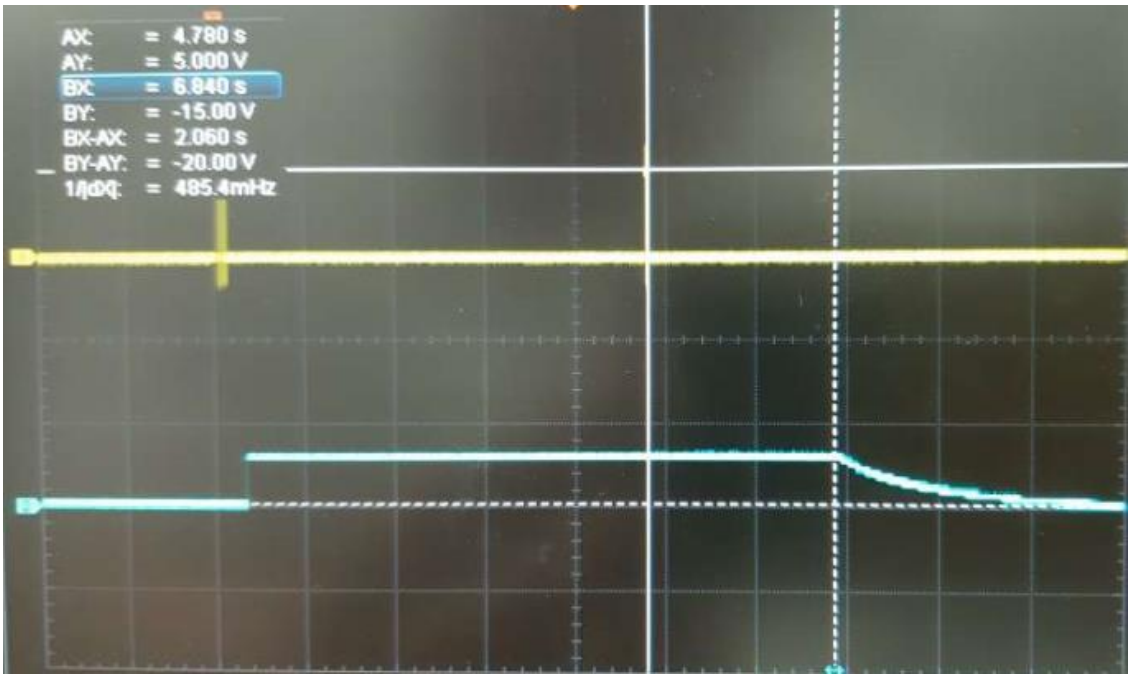
Measurement command and TBSAB03-DR service request



Warm up time: 3.3s



Measurement time: 1.44s



Power off time: 2s

3.6 Measurement Commands overview

SDI-12 Measurement Commands:

aM! aMC! aC! aCC!	**Read voltage or current on channel CH0**
aM1! aMC1! aC1! aCC1!	**Read voltage or current on channel CH1**
aM2! aMC2! aC2! aCC2!	**Read voltage or current on channel CH2**
aM3! aMC3! aC3! aCC3!	**Read voltage or current on channel CH3**
aM4! aMC4! aC4! aCC4!	**Read voltage or current on all configured channels (CH0 to CH3)**

Supported SDI-12 v1.4 Commands

aIM! aIMC! aIC! aICC!	**Identify Measurement Commands**
aIM1! aIMC1! aIC1! aICC1!	**Identify Measurement Commands**
aIM2! aIMC2! aIC2! aICC2!	**Identify Measurement Commands**

aIM3! aIMC3! aIC3! aICC3! **Identify Measurement Commands**

aIM4! aIMC4! aIC4! aICC4! **Identify Measurement Commands**

aIM_001! aIMC_001! aIC_001! aICC_001!	**Identify Measurement Parameter (1rst)**
aIM1_001! aIMC1_001! aIC1_001! aICC1_001!	**Identify Measurement Parameter (1rst)**
aIM2_001! aIMC2_001! aIC2_001! aICC2_001!	**Identify Measurement Parameter (1rst)**
aIM3_001! aIMC3_001! aIC3_001! aICC3_001!	**Identify Measurement Parameter (1rst)**
aIM4_001! aIMC4_001! aIC4_001! aICC4_001!	**Identify Measurement Parameter (1rst)**
aIM4_002! aIMC4_002! aIC4_002! aICC4_002!	**Identify Measurement Parameter (2nd)**
aIM4_003! aIMC4_003! aIC4_003! aICC4_003!	**Identify Measurement Parameter (3rd)**
aIM4_004! aIMC4_004! aIC4_004! aICC4_004!	**Identify Measurement Parameter (4th)**

Extended SDI-12 Commands:

aXSSNnnnnnn! **Set serial number**
nnnnnn: 6 digits serial number

aXSDCF! **Set default configuration**

aXSCHN,n! **Set the number of active analog channels**
n: number of active channels (0-4)

aXGCHN! **Get the number of active analog channels**

aXSAOC,c! **Performs automatic offset calibation**
c: channel number (0-3)

aXSAGC,c! **Performs automatic gain calibration**
c: channel number (0-3)

aXSVCI,c,i! **Configure channels as voltage or current input**
c: channel number (0-3)

i: voltage (0) or current (1)

aXGVCI,c! — **Get channel input configuration (voltage/current)**
c: channel number (0-3)

aXSVCU,c,u! — **Set channel engineering unit range**
c: channel (0-3)
u: A/V (0), mA/mV (1), µA/µV (2)

aXGVCU,c! — **Get channel engineering unit range**

aXSWUT,c,t! — **Set channel warm up time**
c: channel number (0-3)
t: warm up time (s)

aXGWUT,c! — **Get channel warm up time**
c: channel number (0-3)

aXSPOT,c,t! — **Set channel power off time**
c: channel number (0-3)
t: power off time (s)

aXGPOT,c! — **Get channel power off time**
c: channel number

aXSFPC,n,a,b,c,d! — **Set channel FW polynomial calibration coefficients**
n: channel number (0-3)
a,b,c,d: polynomial coefficients (aX^3+bX^2+cX+d)

aXGFPC,c! — **Get channel FW polynomial calibration coefficients**
c: channel number (0-3)

aXSPCS,c,s! — **Set FW polynomial calibration state**
c: channel number (0-3)
s: (0=disabled, 1=enabled)

aXGPCS,c! — **Get FW polynomial calibration state of a channel**
c: channel number (0-3)

aXSFOC,c,o! — **Set channel offset calibration**
c: channel number (0-3)
o: offset

aXGFOC,c! — **Get channel offset calibration**
c: channel number (0-3)

aXSFSC,c,s! — **Set channel scaling calibration**
c: channel number (0-3)
s: scaling value

aXGFSC,c! — **Get channel scaling calibration**
c: channel number (0-3)

aXSGCS,c! — **Select gain calibration mode: HW (jumpers) or FW calibration**
c: (0=HW calibration) / (1=FW calibration)

aXGGCS! — **Get gain calibration mode**

HW specific extended SDI-12 commands:

aXSPNC,i,p,n! — **Set channel's inputs polarity**
i: channel number (0-3)
p: ADC index positive input
n: ADC index negative input

aXGPNC,i! — **Get channel positive and negative voltages**
i: channel number (0-3)

aXSBCM,m! — **Set background calibration mode**
m: (0=disabled), 1, 2, 3

aXGBCM! — **Get background calibration mode**

aXSSCM,m! — **Set system calibration mode**
m: (0=normal), (1=offset), (2=gain)

aXGSCM! — **Get system calibration mode**

aXSBGC,c,n! — **Set channel background gain calibration**
c: channel number (0-3)
n: calibration gain (0:x1, 1:x2. 2:x4. 3:x8, 4:x16, 5:x32, 6:x64, 7:x128)

aXGBGC,c! — **Get channel background gain calibration**

aXSSGC,c,n! **c: channel number (0-3)** **n: system gain calibration value**	**Set channel system gain calibration**
aXGSGC,c!	**Get channel system gain calibration**
aXSSOC,c,f! **c: channel number (0-3)** **f: system offset calibration value**	**Set channel system offset calibration**
aXGSOC,c!	**Get channel system offset calibration**
aXSSSC,c,f! **c: channel number (0-3)** **f: system scaling calibration value**	**Set channel system scaling calibration value**
aXGSSC,c! **c: channel number (0-3)**	**Get channel system scaling calibration value**

4 Functional Description

4.1 Overview

TBSAB03-DR can be controlled over SDI-12 interface by any device supporting at least SDI-12 v1.3 protocol.

For SDI-12 v1.4 compliant RTU/data logger, TBSAB03-DR also supports some specific SDI-12 v1.4 commands:

- Identity Measurement Commands
- Identity Measurement Parameters Commands

A set of extended SDI-12 commands is also provided for configuration and calibration purposes.

4.2 Sensor Identification

The TBSAB03-DR will respond with following string upon sending the *"Send Identification"* command **aI!**:

TEKBOXVNTBSAB3vvvffffffffnnnnnn<CR><LF>

Example: 014TEKBOXVNTBSAB3rvAC000100000005<CR><LF>

Where:	0	SDI-12 Sensor address
	14	SDI-12 version number, version 1.4

TEKBOXVN	Company name
TBSAB3	Model Name
rvA	HW revision A (vvv)
C000100	FW version (fffffff)
000005	Serial number of the device (nnnnnn)

4.3 Sensor Address – default configuration

Each TBSAB03-DR is delivered with default address “0”.

Other default parameters are listed below and can be restored with extended SDI-12 command XSDCF!

Parameter	Default value
System	
SDI-12 address	0
Warm up time	0s (all channels)
Power off time	0s (all channels)
Number of channels	4
Analog input type	Voltage source (all channels)
Custom 3rd order polynomial calibration	Disabled (all channels) Coefficients set to (a=0,b=0,c=0,d=0) Factory calibration enabled
Gain	Applied to all channels – Factory calibration Differential input: 10µV-20mV, Gain=8 Differential input: 20mV – 2.5V, Gain=1
Engineering unit range	V (voltage source) / A (current source)
HW	
AFE clock source	External
System calibration scaling factor	1 (all channels)
AFE background calibration	Disabled
AFE buffer	Disabled
ODR	13.42 SPS 50Hz/60Hz digital filter enabled
Differential positive input	Pin 3 (all channels)
Differential negative input	Pin 1 (all channels)

4.4 Supported SDI-12 v1.3 Commands

In subsequent SDI-12 v1.3 commands list, <a> refers to the sensor SDI-12 address and preceeds all commands and responses.

Following commands are supported by the TBSAB03-DR:

Command	Description	Response
a!	Acknowledge Active	a<CR><LF>
aI!	Send Identification	014TEKBOXVNTBSAB3vvvffffffnnnnnn<CR><LF> With: vvv: HW revision fffffff: FW version nnnnnn: serial number
aAb!	Change Address Change sensor's SDI-12 address	b<CR><LF> Sensor's SDI-12 address has been changed to (b)
?!	Address Query	a<CR><LF>
aM!	Additional Measurement Measures analog input channel 0	a0021<CR><LF> Delay (2) seconds, number of values (1)
aM1!	Additional Measurement Measures analog input channel 1	a0021<CR><LF> Delay (2) seconds, number of values (1)
aM2!	Additional Measurement Measures analog input channel 2	a0021<CR><LF> Delay (2) seconds, number of values (1)
aM3!	Additional Measurement Measures analog input channel 3	a0021<CR><LF> Delay (2) seconds, number of values (1)
aM4!	Start Measurement Measures on all channels	a0064<CR><LF> Delay (6) seconds, number of values (4)
aMC!	Additional Measurement and request CRC Measures analog input channel 0 and calculates CRC	a0021<CR><LF> Delay (2) seconds, number of values (1)
aMC1!	Additional Measurement and request CRC Measures analog input channel 1 and calculates CRC	a0021<CR><LF> Delay (2) seconds, number of values (1)
aMC2!	Additional Measurement and request CRC Measures analog input channel 2 and calculates CRC	a0021<CR><LF> Delay (2) seconds, number of values (1)
aMC3!	Additional Measurement and request CRC Measures analog input channel 3 and calculates CRC	a0021<CR><LF> Delay (2) seconds, number of values (1)
aMC4!	Start Measurement and request CRC Measures all analog input channels and calculates CRC	a0064<CR><LF> Delay (6) seconds, number of values (4)
aC!	Start Concurrent Measurement Measures analog input channel 0	a00201<CR><LF> Delay (2) seconds, number of values (1)
aC1!	Start Concurrent Measurement Measures analog input channel 1	a00201<CR><LF> Delay (2) seconds, number of values (1)

aC2!	Start Concurrent Measurement Measures analog input channel 2	a00201<CR><LF> Delay (2) seconds, number of values (1)
aC3!	Start Concurrent Measurement Measures analog input channel 3	a00201<CR><LF> Delay (2) seconds, number of values (1)
aC4!	Start Concurrent Measurement Measures all analog input channels	a00604<CR><LF> Delay (6) seconds, number of values (4)
aCC!	Start Concurrent Measurement and request CRC Measures analog input channel 0 and calculates CRC	a00201<CR><LF> Delay (2) seconds, number of values (1)
aCC1!	Start Concurrent Measurement and request CRC Measures analog input channel 1 and calculates CRC	a00201<CR><LF> Delay (2) seconds, number of values (1)
aCC2!	Start Concurrent Measurement and request CRC Measures analog input channel 2 and calculates CRC	a00201<CR><LF> Delay (2) seconds, number of values (1)
aCC3!	Start Concurrent Measurement and request CRC Measures analog input channel 3 and calculates CRC	a00201<CR><LF> Delay (2) seconds, number of values (1)
aCC4!	Start Concurrent Measurement and request CRC Measures all analog input channels and calculates CRC	a00604<CR><LF> Delay (6) seconds, number of values (4)
aD0!	Data Command Get Measurement Result(s)	a<values><CR><LF> or a<values><CRC><CR><LF> <values> depends on the executed measurement commands and is formatted as per SDI-12 standard.
aV!	Start Verification	a0000<CR><LF> Not supported
aRn! **aRCn!**	Continuous Measurement Continuous Measurement + CRC	a<CR><LF> Not supported

Table 1 – Standard SDI-12 commands

4.5 Supported SDI-12 v1.4 commands

In subsequent SDI-12 v1.4 commands list, <a> refers to the sensor SDI-12 address and preceeds all commands and responses.

Command	Description	Response
aIM!	aM! Identify Measurement	a0021<CR><LF>

	Returns delay and number of parameters	Delay: (2) seconds and number of values (1)
aIMC!	aMC! Identify Measurement Returns delay and number of parameters	a0021<CR><LF> Delay: (2) seconds, number of values (1)
aIC!	aC! Identify Measurement Returns delay and number of parameters	a00201<CR><LF> Delay: (2) seconds and number of values (01)
aICC!	aCC! Identify Measurement Returns delay and number of parameters	a00201<CR><LF> Delay: (2) seconds, number of values (01)
aIM1!	aM1! Identify Measurement Returns delay and number of parameters	a0021<CR><LF> Delay: (2) seconds and number of values (1)
aIMC1!	aMC1! Identify Measurement Returns delay and number of parameters	a0021<CR><LF> Delay: (2) seconds, number of values (1)
aIC1!	aC1! Identify Measurement Returns delay and number of parameters	a00201<CR><LF> Delay: (2) seconds and number of values (01)
aICC1!	aCC1! Identify Measurement Returns delay and number of parameters	a00201<CR><LF> Delay: (2) seconds and number of values (01)
aIM2!	aM2! Identify Measurement Returns delay and number of parameters	a0021<CR><LF> Delay: (2) seconds and number of values (1)
aIMC2!	aMC2! Identify Measurement Returns delay and number of parameters	a0021<CR><LF> Delay: (2) seconds and number of values (1)
aIC2!	aC2! Identify Measurement Returns delay and number of parameters	a00201<CR><LF> Delay: (2) seconds and number of values (01)
aICC2!	aCC2! Identify Measurement Returns delay and number of parameters	a00201<CR><LF> Delay: (2) seconds and number of values (01)
aIM3!	aM3! Identify Measurement Returns delay and number of parameters	a0021<CR><LF> Delay: (2) seconds and number of values (1)
aIMC3!	aMC3! Identify Measurement Returns delay and number of parameters	a0021<CR><LF> Delay: (2) seconds and number of values (1)
aIC3!	aC3! Identify Measurement Returns delay and number of parameters	a00201<CR><LF> Delay: (2) seconds and number of values (01)
aICC3!	aCC3! Identify Measurement Returns delay and number of parameters	a00201<CR><LF> Delay: (2) seconds and number of values (01)
aIM4!	aM4! Identify Measurement Returns delay and number of parameters	a0064<CR><LF> Delay: (6) seconds and number of values (4)
aIMC4!	aMC4! Identify Measurement Returns delay and number of parameters	a0064<CR><LF> Delay: (6) seconds, number of values (4)
aIC4!	aC4! Identify Measurement Returns delay and number of parameters	a00604<CR><LF> Delay: (6) seconds and number of values (04)
aICC4!	aCC4! Identify Measurement Returns delay and number of parameters	a00604<CR><LF> Delay: (6) seconds, number of values (4)
aIM_001! **aIMC_001!** **aIC_001!** **aICC_001!**	aIM! / aIMC! / aIC! / aICC! Identify Measurement Parameters (1rst) Returns parameter's identification and unit	• Voltage source (aXSVCI=0): ○ a,Voltage,V<CR><LF> (aXSVCU=0) ○ a,Voltage,mV<CR><LF> (aXSVCU=1) ○ a,Voltage,uV<CR><LF> (aXSVCU=2) • Current source (aXSVCI=1): ○ a,Current,A<CR><LF> (aXSVCU=0) ○ a,Current,mA<CR><LF> (aXSVCU=1) ○ a,Current,uA<CR><LF> (aXSVCU=2)

aIM1_001! **aIMC1_001!** **aIC1_001!** **aICC1_001!**	aIM1! / aIMC1! / aIC1! / aICC1! Identify Measurement Parameters (1rst) Returns parameter's identification and unit	• Voltage source (aXSVCI=0): ○ a,Voltage,V<CR><LF> (aXSVCU=0) ○ a,Voltage,mV<CR><LF> (aXSVCU=1) ○ a,Voltage,uV<CR><LF> (aXSVCU=2) • Current source (aXSVCI=1): ○ a,Current,A<CR><LF> (aXSVCU=0) ○ a,Current,mA<CR><LF> (aXSVCU=1) ○ a,Current,uA<CR><LF> (aXSVCU=2)
aIM2_001! **aIMC2_001!** **aIC2_001!** **aICC2_001!**	aIM2! / aIMC2! / aIC2! / aICC2! Identify Measurement Parameters (1rst) Returns parameter's identification and unit	• Voltage source (aXSVCI=0): ○ a,Voltage,V<CR><LF> (aXSVCU=0) ○ a,Voltage,mV<CR><LF> (aXSVCU=1) ○ a,Voltage,uV<CR><LF> (aXSVCU=2) • Current source (aXSVCI=1): ○ a,Current,A<CR><LF> (aXSVCU=0) ○ a,Current,mA<CR><LF> (aXSVCU=1) ○ a,Current,uA<CR><LF> (aXSVCU=2)
aIM3_001! **aIMC3_001!** **aIC3_001!** **aICC3_001!**	aIM3! / aIMC3! / aIC3! / aICC3! Identify Measurement Parameters (1rst) Returns parameter's identification and unit	• Voltage source (aXSVCI=0): ○ a,Voltage,V<CR><LF> (aXSVCU=0) ○ a,Voltage,mV<CR><LF> (aXSVCU=1) ○ a,Voltage,uV<CR><LF> (aXSVCU=2) • Current source (aXSVCI=1): ○ a,Current,A<CR><LF> (aXSVCU=0) ○ a,Current,mA<CR><LF> (aXSVCU=1) ○ a,Current,uA<CR><LF> (aXSVCU=2)
aIM4_001! **aIMC4_001!** **aIC4_001!** **aICC4_001!**	aIM4! / aIMC4! / aIC4! / aICC4! Identify Measurement Parameters (1rst) Returns parameter's identification and unit	• Voltage source (aXSVCI=0): ○ a,Voltage,V<CR><LF> (aXSVCU=0) ○ a,Voltage,mV<CR><LF> (aXSVCU=1) ○ a,Voltage,uV<CR><LF> (aXSVCU=2) • Current source (aXSVCI=1): ○ a,Current,A<CR><LF> (aXSVCU=0) ○ a,Current,mA<CR><LF> (aXSVCU=1) ○ a,Current,uA<CR><LF> (aXSVCU=2)
aIM4_002! **aIMC4_002!** **aIC4_002!** **aICC4_002!**	aIM4! / aIMC4! / aIC4! / aICC4! Identify Measurement Parameters (2nd) Returns parameter's identification and unit	• Voltage source (aXSVCI=0): ○ a,Voltage,V<CR><LF> (aXSVCU=0) ○ a,Voltage,mV<CR><LF> (aXSVCU=1) ○ a,Voltage,uV<CR><LF> (aXSVCU=2) • Current source (aXSVCI=1): ○ a,Current,A<CR><LF> (aXSVCU=0) ○ a,Current,mA<CR><LF> (aXSVCU=1) ○ a,Current,uA<CR><LF> (aXSVCU=2)
aIM4_003! **aIMC4_003!** **aIC4_003!** **aICC4_003!**	aIM4! / aIMC4! / aIC4! / aICC4! Identify Measurement Parameters (3rd) Returns parameter's identification and unit	• Voltage source (aXSVCI=0): ○ a,Voltage,V<CR><LF> (aXSVCU=0) ○ a,Voltage,mV<CR><LF> (aXSVCU=1) ○ a,Voltage,uV<CR><LF> (aXSVCU=2) • Current source (aXSVCI=1): ○ a,Current,A<CR><LF> (aXSVCU=0) ○ a,Current,mA<CR><LF> (aXSVCU=1) ○ a,Current,uA<CR><LF> (aXSVCU=2)
aIM4_004! **aIMC4_004!** **aIC4_004!**	aIM4! / aIMC4! / aIC4! / aICC4! Identify Measurement Parameters (4th) Returns parameter's identification and unit	• Voltage source (aXSVCI=0): ○ a,Voltage,V<CR><LF> (aXSVCU=0) ○ a,Voltage,mV<CR><LF> (aXSVCU=1) ○ a,Voltage,uV<CR><LF> (aXSVCU=2)

aICC4_004!		• Current source (aXSVCI=1): ○ a,Current,A<CR><LF> (aXSVCU=0) ○ a,Current,mA<CR><LF> (aXSVCU=1) ○ a,Current,uA<CR><LF> (aXSVCU=2)

4.6 Supported Extended Commands

In subsequent extended SDI-12 commands list:

- <a> refers to the sensor SDI-12 address and preceeds all commands and responses.
- If the extended SDI-12 command is not successfully executed, aX_FAIL is returned.

Command	Description	Response
aXSSNnnnnnn!	Set serial number <nnnnnn>: 6 digits serial number	a1_003<CR><LF> Execution time: 3s
aXSDCF!	Set default configuration	a1_010<CR><LF> Execution time: 10s
aXSCHN,n!	Set the number of active analog channels <n>: number of active channels (1-4)	a1_003<CR><LF> Execution time: 3s
aXGCHN!	Get the number of active analog channels	an<CR><LF> <n>: number of active channels (1-4)
aXSAOC,c!	Trigger automatic offset calibration of the 24-bit sensor AFE. <c>: channel number (0-3)	a1_003<CR><LF> Execution time: 3s
aXSAGC,c!	Trigger automatic gain calibration of the 24-bit sensor AFE. <c>: channel number (0-3)	a1_003<CR><LF> Execution time: 3s
aXSVCI,c,i!	Configure channels as voltage or current input <c>: channel number (0-3) <i>: voltage (0) or current (1)	a1_003<CR><LF> Execution time: 3s
aXGVCI,c!	Get channel input configuration (voltage/current) <c>: channel number (0-3)	ai<CR><LF> <i>: voltage input (0) or current input (1)
aXSVCU,c,u!	Set channel's engineering unit range <c>: channel (0-3) <u>: A/V (0), mA/mV (1), µA/µV (2)	a1_003<CR><LF> Execution time: 3s
aXGVCU,c!	Get channel's engineering unit range	au<CR><LF> <u>: 0 for A/V 1 for mA/mV 2 for µA/µV
aXSWUT,c,t!	Set channel's warm up time <c>: channel number (0-3) <t>: warm up time in seconds, maximum 255s	a1_003<CR><LF> Execution time: 3s

aXGWUT,c!	Get channel's warm up time <c>: channel number (0-3)	attt<CR><LF> <ttt>: warm up time between 0 and 255s
aXSPOT,c,t!	Set channel power off time <c>: channel number (0-3) <t>: power off time (s), maximum 255s	a1_003<CR><LF> Execution time: 3s
aXGPOT,c!	Get channel power off time <c>: channel number	attt<CR><LF> <ttt>: warm up time between 0 and 255s
aXSFPC,n,a,b,c,d!	Set channel FW polynomial calibration coefficients <n>: channel number (0-3) <a,b,c,d>: polynomial coefficients (aX^3+bX^2+cX+d)	a1_003<CR><LF> Execution time: 3s
aXGFPC,c!	Get channel FW polynomial calibration coefficients <c>: channel number (0-3)	aq,r,s,t<CR><LF> q,r,s,t: the coefficients of the polynomial qX^3+rX^2+sX+t
aXSPCS,c,s!	Set the polynomial calibration state for a channel. <c>: channel number (0-3) <s>: polynomial calibration state 0: disabled 1: enabled (this sets the polynomial coefficients to a,b,d=0 and c=1)	a1_003<CR><LF> Execution time: 3s
aXGPCS,c!	Get the polynomial calibration state for a channel <c>: channel number (0-3)	as<CR><LF> <s>: 0 if disabled, 1 if enabled
aXSFOC,c,o!	Set channel offset calibration <c>: channel number (0-3) <o>: offset	a1_003<CR><LF> Execution time: 3s
aXGFOC,c!	Get channel offset calibration <c>: channel number (0-3)	af<CR><LF> <f>: offset value
aXSFSC,c,s!	Set channel scaling calibration <c>: channel number (0-3) <s>: scaling value	a1_003<CR><LF> Execution time: 3s
aXGFSC,c!	Get channel scaling calibration <c>: channel number (0-3)	af<CR><LF> <f>: scaling value
aXSGCS,c!	Select gain calibration mode: <c>: gain calibration mode 0: HW calibration, gain selected with jumpers J28/J29/J30 is applied to all channels. 1: FW calibration, channels specific gains configured with aXSBGC command are applied.	a1_003<CR><LF> Execution time: 3s
aXGGCS!	Get gain calibration mode	am<CR><LF> <m>: gain calibration

		mode 0: HW 1: FW
HW specific extended SDI-12 commands		
aXSPNC,i,p,n!	Set the differential channel pins polarity <i>: channel number (0-3) <p>: index of the ADC used for the positive input (0-7 – cf HW schematic) <n>: index of the ADC used for the negative input (0-7 – cf HW schematic)	a1_003<CR><LF> Execution time: 3s
aXGPNC,i!	Get the ADC indexes used as positive and negative inputs for the differential analog channel i. <i>: channel number (0-7)	ap,n<CR><LF> <p>: index of ADC used for positive input <n>: index of ADC used for negative input
aXSBCM,m!	Select 24-bit sensor AFE background calibration mode <m>: mode 0: background calibration disabled 1: background calibration mode 1 2: background calibration mode 2 3: background calibration mode 3	a1_003<CR><LF> Execution time: 3s
aXGBCM!	Get 24-bit sensor AFE background calibration mode	am<CR><LF> m: background calibration mode 0 disabled 1 mode 1 2 mode 2 3 mode 3
aXSSCM,m!	Select 24-bit sensor AFE system calibration mode <m>: system calibration mode 0: Normal mode 1: System Calibration Offset Coefficient Determination mode 2: System Calibration Gain Coefficient Determination mode	a1_003<CR><LF> Execution time: 3s
aXGSCM!	Get 24-bit sensor AFE system calibration mode	am<CR><LF> <m>: system calibration mode 0: Normal mode 1: System Calibration Offset Coefficient Determination mode 2: System Calibration Gain Coefficient

		Determination mode
aXSBGC,c,n!	Set 24-bit AFE sensor internal amplifier gain <c>: channel number (0-3) <n>: gain 0: x1 (FGA off) 1: x2 (FGA off) 2: x4 (FGA off) 3: x8 (FGA off) 4: x16 (FGA on) 5: x32 (FGA on) 6: x64 (FGA on) 7: x128 (FGA on)	a1_003<CR><LF> Execution time: 3s
aXGBGC,c!	Get 24-bit sensor AFE internal amplifier gain	an<CR><LF> <n>: gain index 0: x1 (FGA off) 1: x2 (FGA off) 2: x4 (FGA off) 3: x8 (FGA off) 4: x16 (FGA on) 5: x32 (FGA on) 6: x64 (FGA on) 7: x128 (FGA on)
aXSSGC,c,n!	Set 24-bit sensor AFE system gain calibration coefficient <c>: channel number (0-3) <n>: system gain calibration coefficient	a1_003<CR><LF> Execution time: 3s
aXGSGC,c!	Get 24-bit sensor AFE system gain calibration coefficient <c>: channel number (0-3)	af<CR><LF> <f>: AFE system gain calibration coefficient
aXSSOC,c,f!	Set 24-bit sensor AFE system offset calibration coefficient <c>: channel number (0-3) <f>: system offset calibration coefficient	a1_003<CR><LF> Execution time: 3s
aXGSOC,c!	Get 24-bit sensor AFE system offset calibration coefficient <c>: channel number (0-3)	af<CR><LF> <f>: AFE system offset calibration coefficient
aXSSSC,c,f!	Set 24-bit sensor AFE system scaling calibration coefficient <c>: channel number (0-3) <f>: system scaling coefficient	a1_003<CR><LF> Execution time: 3s
aXGSSC,c!	Get 24-bit sensor AFE system scaling calibration coefficient <c>: channel number (0-3)	af<CR><LF> <f>: AFE system scaling calibration coefficient

Table 2 – Extended SDI-12 Commands

5 Configuration Examples

This chapter describes the steps to follow for some typical configurations.

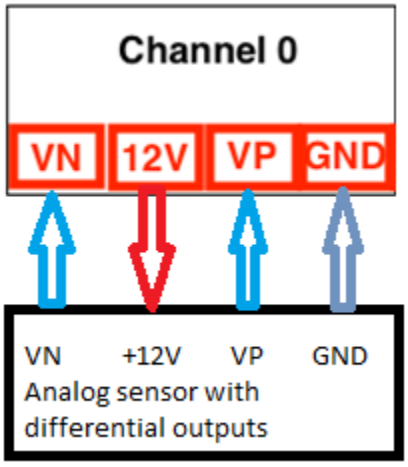
For each configuration, it is assumed the user is using a brand new TBSAB03-DR or has restored the default settings by sending aXSDCF!:

```
0XSDCF!
01_010
```

This commands takes 10s to be fully executed.

Connect the sensors to each port and note carefully which channel is assigned to which sensor

Example for channel 0:



12V: If sensor requires to be supplied
GND: If sensor's GND is available

5.1 4 differential voltage inputs channels

Set all channels as voltage input

All channels are configured as voltage inputs by default.
If required to switch them back to this mode, use aXSVCI to configure each of them:

aXSVCI,0,0! Configure channel 0 as voltage input
aXSVCI,1,0! Configure channel 1 as voltage input
aXSVCI,2,0! Configure channel 2 as voltage input
aXSVCI,3,0! Configure channel 3 as voltage input

Ex:

```
0XSVCI,1,0!
01_003
```

Then sets jumpers J1/J2/J3/J4 in position 2-3 as described in the analog input types selection table.

Set HW gain

By default FW selectable gain per channel is disabled and common HW gain is applied to all channels based on jumpers J28/J29/J30 configuration.

Default HW gain is 1 with J28/J29/J30 in position 2-3 (refer to the gain selection table for further details).

Take measurements

Use aM0! to aM3! to measure on each channels or aM4! to return the measurements of all 4 channels with one single command.

5.2 4 differential current input channels

Channel inputs need then to be configured as current input source.

Set all channels as current input

Use aXSVCI command to switch the channels to current input source mode:

aXSVCI,0,1! Configure channel 0 as current input
aXSVCI,1,1! Configure channel 1 as current input
aXSVCI,2,1! Configure channel 2 as current input
aXSVCI,3,1! Configure channel 3 as current input

Then sets jumpers J1/J2/J3/J4 in position 1-2 as described in the analog input types selection table.

Take measurements

aM0!, aM1!, aM2!, aM3! and aM4! returns the current measurements without any further configuration.

5.3 Mixed voltage and current input channels

For instance it is required to configure channels 0 and 1 as voltage input and channels 2 and 3 as current inputs.

First the channels must be configured accordingly at FW side:

aXSVCI,0,0! Configure channel 0 as voltage input
aXSVCI,1,0! Configure channel 1 as voltage input
aXSVCI,2,1! Configure channel 2 as current input

aXSVCI,3,1! Configure channel 3 as current input

Then the jumpers should be configured accordingly:
J1 – Position 2-3 – Channel 0
J2 – Position 2-3 – Channel 1
J3 – Position 1-2 – Channel 2
J4 – Position 1-2 – Channel 3

5.4 Individual gains

In case individual gains are required for each channel, then the HW gain selection with jumpers J28/J29/J30 must be overridden by extended SDI-12 commands.

Disable HW gain
aXSGCS,0! Enable FW gain (ie HW gain disabled)

Set the gain for each channel
aXSBGC,0,2! Set channel 0 with gain x2
aXSBGC,1,4! Set channel 1 with gain x16
aXSBGC,2,6! Set channel 2 with gain x64
aXSBGC,3,7! Set channel 3 with gain x128

5.5 Mixed polynomial and factory calibrated channels

Each TBSAB03-DR comes factory calibrated and can be used without any further calibration.

However for some specific applications it might be needed to apply a custom polynomial calibration instead.

The custom polynomial calibration can be enabled only for some channels while keeping the factory calibration for others.

Enable custom polynomial calibration for channels 1 and 2 – factory calibration retained for channel 0 and 3
0XSPCS,1,1! Enable custom polynomial calibration for channel 1, coefficients set to (0,0,1,0)
0XSPCS,2,1! Enable custom polynomial calibration for channel 2, coefficients set to (0,0,1,0)

If factory calibration was not already applied to channels 0 and 3:
0XSPCS,0,0! Enable factory calibration for channel 0
0XSPCS,3,0! Enable factory calibration for channel 1

0XGPCS,c! can be used to know if factory or custom polynomial calibration is enabled for a given channel (c).

Set the custom polynomials coefficients

Each channel can be configured with its own calibration polynomial coefficients.

0XSFPC,1,5.8,3.27,0,-3! Channel 1: $5.8x^3 + 3.27x^2 - 3$

0XSFPC,3,7.23,2.82,-9.3,5.25! Channel 3: $7.23x^3 + 2.82x^2 - 9x + 5.25$

6 Technical Specifications

Symbol	Parameter	Conditions	Min	Typ	Max	Unit
Is	Supply current	Active mode (during measurement)		7		mA
Is	Supply current	Sleep mode		95		µA
Vs	Supply voltage		6	12	17	V
tm	Measurement Time	Time in active mode upon receiving a measurement command			1	s
Vr	Voltage measurement range		0		2.5	V
R	Voltage measurement resolution			24		Bit
INL	Integral nonlinearity			±7	±15	ppm of FSR
ENOB	Noise free resolution			19		Bit
N	Noise			8.6		µV RMS
GE	Gain error			7		ppm
GET	Gain error over temperature			0.5		ppm/°C
GED	Gain error over time			1.6		ppm / 1000hrs
OE	Offset error			9.5		µV
OET	Offset drift over temperature			25		nV/°C
OED	Offset drift over time			100		nV / 1000hrs
ATT_50/60	50/60 Hz line rejection			>90		dB
Vref	2.5V reference voltage accuracy				0.025 2	% ppm/°C
TR_int	Internal sensor: Temperature measurement range		-40		+85	°C
TA_int	Internal sensor: Temperature calibration accuracy	@ 25°C		±0.5		°C
TL_int	Internal sensor: Temperature measurement linearity	from -40°C to +85°C		±1	±3	°C
TL_int	Internal sensor: Temperature measurement linearity	from -40°C to +85°C		±1	±3	°C
ZIN_v	Input Impedance	voltage measurement mode		1		MOhm
ZIN_i	Input Impedance	current measurement mode		100		Ohm
OV_V	Input overvoltage protection	voltage measurement mode		±75		V

Table 3 – Technical Specifications

7 Environmental Specifications

Symbol	Parameter	Conditions	Min	Max	Unit
T_A	Operating Ambient Temperature Range		-40	+85	°C
T_{STG}	Storage Temperature Range		-40	+85	°C
	Moisture level	closed housing	-	100	%

Table 4 - Environmental Specifications

8 Ordering Information

Part Number	Description
TBSAB03-DR	TBSAB03 Dinrail, Differential Analog to SDI-12 Interface

Table 5 – Ordering Information

9 History

Version	Date	Author	Changes
V1.0	28th May 2020	Philippe Hervieu	Creation of the document (applies to FW 0C.00.01.00)
V1.1	04th June 2020	Philippe Hervieu	Updates related to polynomial calibration and accuracy (applies from FW 0C.00.01.01)
V1.2	10th June 2020	Philippe Hervieu	Fix typo error on aXSSN command
V1.3	08th January 2021	Philippe Hervieu	Add PCB picture
V1.4	9th May 2022	Philippe Hervieu	Update product reference to Dinrail version.
V1.5	28th March 2023	Philippe Hervieu	Current input range and accuracy

Table 6 – History