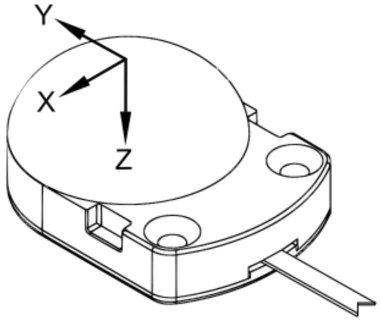
Product Overview

The 3D Force Button Sensor is designed for precise measurement of forces applied to the sensor in three dimensions – X, Y shear, and Z compression (as per the drawing on the right). Constructed with an anodized, machined aluminum housing and a silicone rubber contact surface, this sensor offers accuracy and reliability in diverse force-sensing applications.



The sensor is interfaced via an 8-way, 0.5mm pitch FPC cable, and mechanically mounted with two M1.6 screws.

The 3DFBSxx family contains devices with three different calibrated force ranges and measurement resolutions (N):

Code	X, Y Range (N)	Z Range (N)	Resolution (N)
3DFBS04	±4	0 – 4	±0.005
3DFBS12	±8	0 – 12	±0.010
3DFBS20	±12	0 – 20	±0.010

Other calibrated ranges are available on request.

Applications

- Robotic and prosthetic grippers
- Robotic hands and feet
- Industrial automation
- Gloves for augmented reality
- Rehabilitation tools
- Gaming controllers

Features

- Measure 3D applied forces up to 20 N
- I²C and SPI communication interfaces
- Sample rate up to 1 kHz
- Compact form factor: 14.0 (W) x 19.0 (L) x 8.9 (H) mm

Contents

1 Description

1.1 Overview

The Contactile 3DFBS is a complete 3 axis force measurement system. It uses a silicone pillar paired with an optical sensor and a digital circuit to measure these physical characteristics. Each sensor is pre-calibrated to convert physical movement on the pillar to corresponding force measurements. The sensor communicates with a host system via an I^2C or SPI interface.

1.2 Data Output

The 3DFBS provides the following data:

- Force applied to the sensor the in X, Y, and Z axes in newtons
- On-board temperature in degrees Celsius

1.3 Modes of operation

The sensor can operate in 2 modes, Idle and Active.

1.3.1 Idle Mode

This is the default mode after a sensor reset. All commands are issued in Idle mode. To read data in idle mode, the corresponding command must be issued to the sensor followed by a data phase. Communication in idle mode has an associated overhead.

1.3.2 Active Mode

Active mode minimizes communication overhead and should be used when the host wants to stream data from the sensor. After entering Active mode, the sensor processes force and temperature data at the 'Active Frequency'. The host can simply read the corresponding number of bytes as set by the 'Set Active Data' command. The latest sensor data are sent to the host during a read.

1.3.3 Mode Switching

To enter Active mode, the host issues the 'Enter Active' command. The sensor will automatically exit Active mode and return to Idle mode when any command is issued.

2 Getting Started

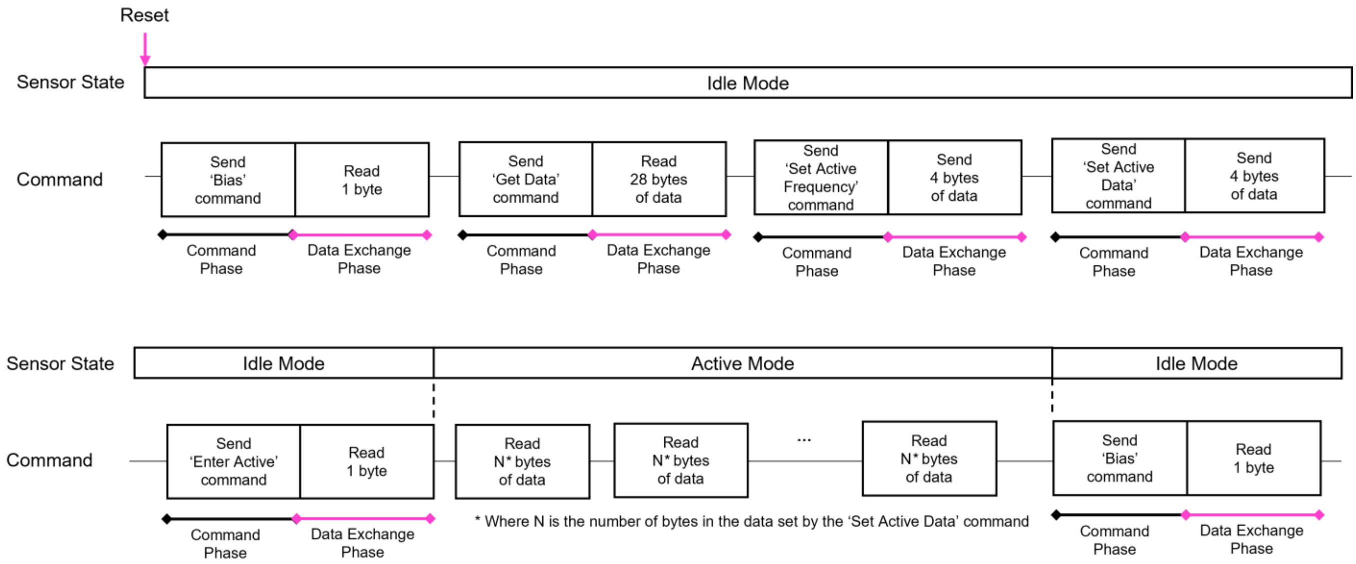
After a reset, the sensor starts in Idle mode. All communication with the sensor should be performed using the communication interface (I^2C/SPI) assigned with Interface Bootstrapping, or the ‘Set Comms Mode’ command. The factory default communication interface is SPI.

Before the sensor can be used for any accurate readings, the ‘Bias Sensor’ command must be issued. This command should be called when no forces are being applied to the sensor, and has the effect of setting all force values to zero – similar to how a weighing scale is tared.

After biasing, the ‘Get Data’ command can be called to retrieve sensor data. Note that without biasing, this command may return NaN values or other incorrect data.

Before entering Active mode, the host should configure which data are to be read during every transaction, by issuing the ‘Set Active Data’ command. For example, sending ‘0x0000 0E00’ will configure the sensor to return processed force data for all 3 axes. Consequently, in Active mode, each read transaction should consist of 12 bytes.

The sensor automatically exits Active mode and returns to Idle mode when any command is issued.



See section 9 Command Descriptions for more details on sending these commands.

3 Absolute Maximum Ratings

Property	Absolute Maximum Ratings	Units
V_{CC}	-0.3 to +3.63	V
RST, INT	-0.3 to V_{CC} + 0.3	V
Output Current (sink) by RST, INT pins	25	mA
GND	100	mA
Operating Temperature	-40 to +105	°C
Compressive Force (Z)	100	N
Shear Force (X,Y)	50	N

** Exposure to absolute maximum rating conditions for extended periods may affect device reliability.*

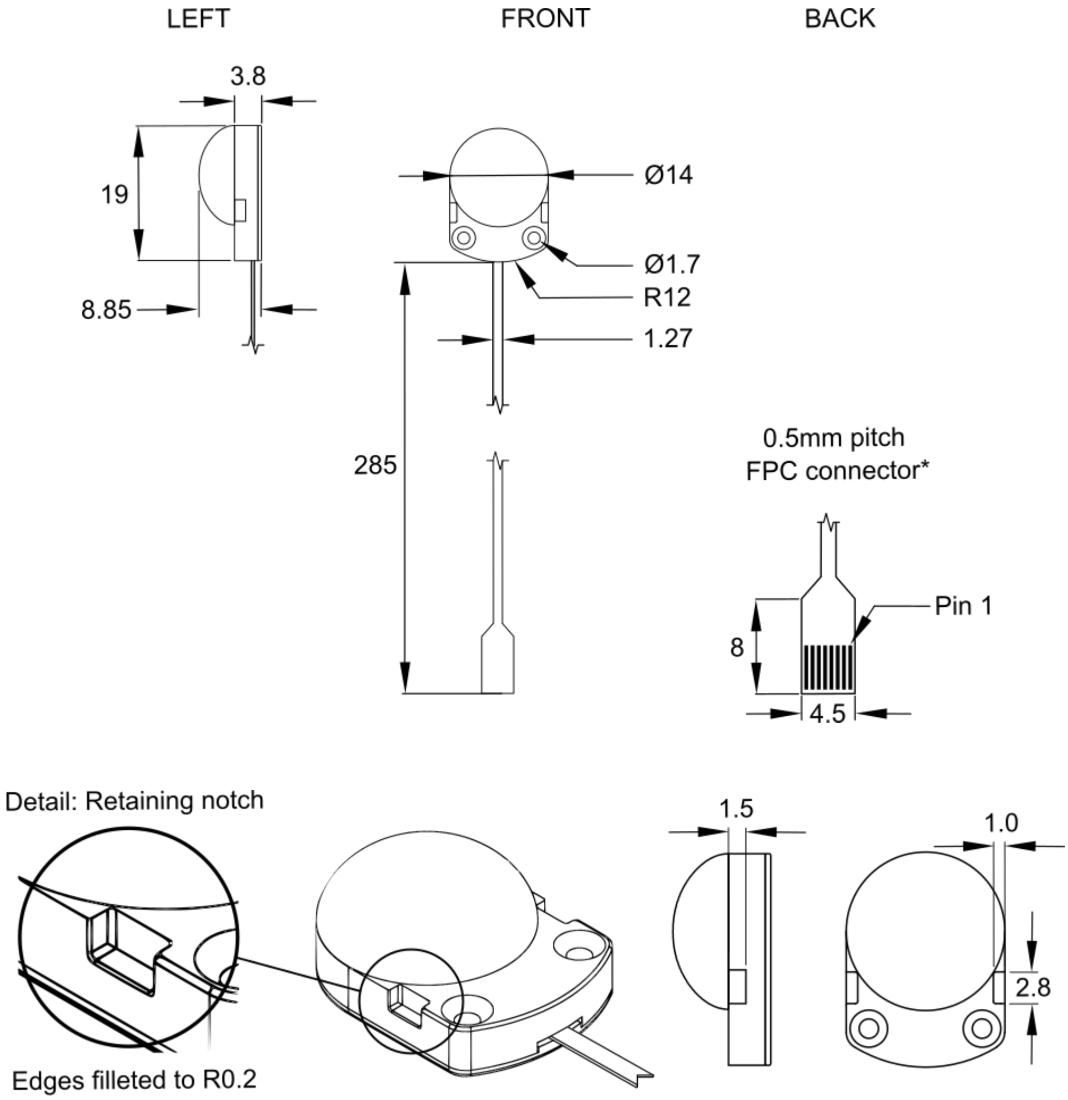
4 Electrical Characteristics

Parameter	Symbol	Min	Typical	Max	Units
Supply Voltage	V_{CC}	2.6	3.3	3.6	V
GPIO Input Low	V_{IL}	-	-	0.3 x V_{CC}	V
GPIO Input High	V_{IH}	0.7 x V_{CC}	-	-	V

5 Pinout

Pin	Name	Description	Direction
1	GND	Connect to system ground.	N/A
2	V_{CC}	Connect to 3V3	N/A
3	$\overline{\text{RESET}}$	Active low reset. The sensor has a 100k pull-up resistor connected to this pin.	Input
4	MOSI	SPI Master Out Slave In	Input
5	MISO	SPI Master In Slave Out	Output
6	SCL / SCK	I^2C Serial Clock / SPI clock	Input
7	SDA / $\overline{\text{CS}}$	I^2C Serial Data / SPI Chip Select	Input/Output
8	INT	Interrupt	Output

6 Mechanical Drawing



All units in millimeters.

** FPC connector conforms to Molex FFC specification PS-15266-001*

7 Communication

7.1 Interface Bootstrapping

The communication interface (I^2C/SPI) may be changed immediately following a device reset.

To change the communication interface, the host must:

- Set the $\overline{\text{RESET}}$ pin LOW for at least 50ms to shutdown the sensor.
- Hold the INT pin LOW.
- Set the $\overline{\text{RESET}}$ pin HIGH to enable the sensor.
- Wait 50ms for the sensor to start-up. With the INT pin held LOW it will enter bootstrapping mode.
- The state of the SDA/$\overline{\text{CS}}$ and SCL/SCK pins are then used to set the desired communication interface according to the logic table below.

INT	SCL/SCK	SDA/$\overline{\text{CS}}$	Communication Interface
HIGH	x	x	Unchanged
LOW	LOW	LOW	I^2C
LOW	LOW	HIGH	SPI
LOW	HIGH	LOW	Unchanged
LOW	HIGH	HIGH	Unchanged

- Set the INT pin HIGH again *within three seconds* to lock-in the desired communication interface.
- Wait at least 30ms to allow the new communication interface to be saved before issuing any commands.
- If the INT pin remains LOW for more than three seconds, the sensor will boot as normal, using the last saved communication interface.
- If the INT pin is HIGH on start-up (default), the sensor will boot immediately without entering bootstrapping mode.

The communication interface is persistent, so this operation does not need to be performed every time the sensor is powered on.

The communication interface may also be changed using the 'Set Comms Mode' command, sent via the currently active communication interface.

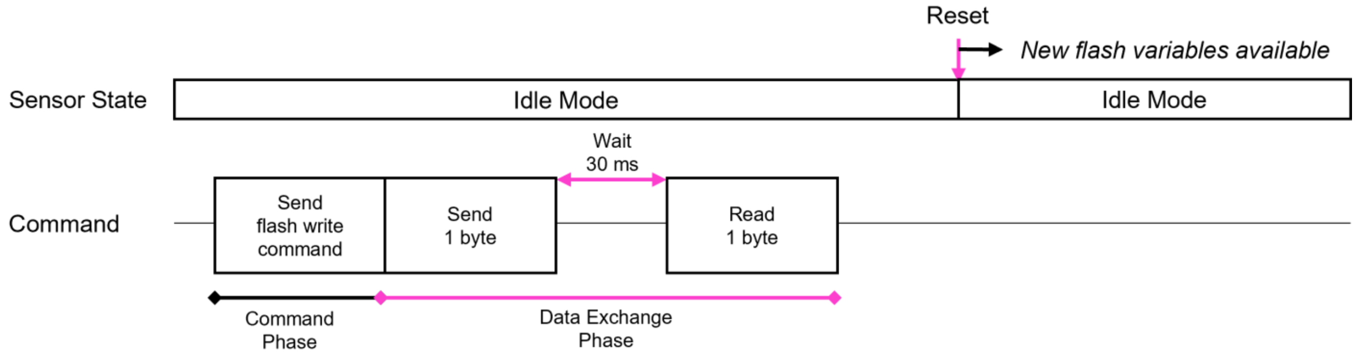
7.2 Protocol

All communication is performed in two phases: a *command phase* whereby a command byte is sent from the host to the sensor, followed by a *data exchange phase* where data are optionally exchanged between host and sensor. See section 8 Command List for a list of possible commands and the corresponding data exchanged.

The byte order of all data exchanged is little-endian.

7.3 Flash Write Commands

When sending a command that modifies flash memory (Set I^{2}C Address, Set Comms Mode), the host needs to wait 30ms between transmitting the new value, and reading the response back from the sensor, to allow time for the sensor to commit the new value to memory. New flash variables only take effect after a device reset.



7.4 Interrupts

The INT pin is used during Active Mode to synchronize data transfer from the sensor to the host. When the sensor has acquired data, the INT pin is asserted to alert the host that new data are available. The process for retrieving data is different depending on the communication protocol. See section 7 Communication for more details.

Interrupt line functionality will be expanded in future revisions.

7.5 I^{2}C Interface

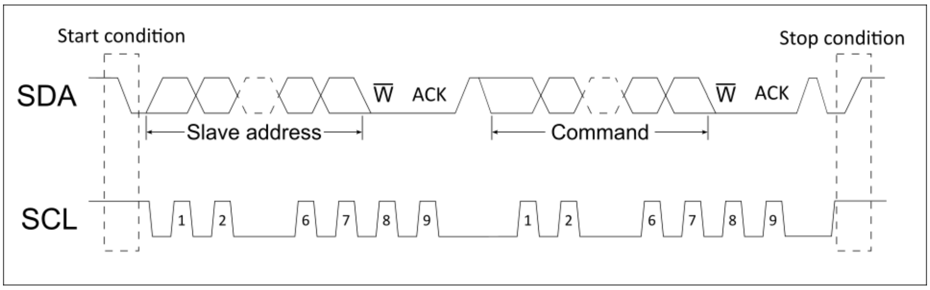
I^{2}C is an open drain communication system, so line capacitance must be minimized, and appropriate pull-up resistors must be present on both SCL and SDA for reliable operation. The pull up resistors should tie the SCL and SDA lines to V_{CC}.

When using the I^{2}C interface, the sensor behaves as an I^{2}C slave with clock stretching enabled. If the sensor requires more time to respond to commands, it will hold the SCL line low (for a maximum time of 40 milliseconds).

The default sensor I^{2}C address is 0x57.

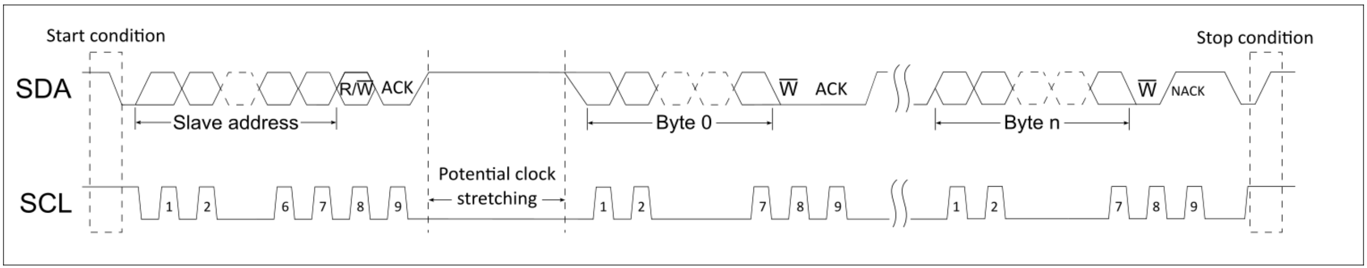
The Command Phase and Data Exchange Phase are performed as separate I^{2}C transactions.

7.5.1 Command Phase



During the command phase, the sensor is selected by transferring the slave address (default 0x57) followed by a command byte.

7.5.2 Data Exchange Phase



In the data exchange phase, the sensor waits for a read/write transaction of the appropriate number of bytes. After the host initiates a transaction by sending the slave address, the sensor may hold the SCL line low (clock stretching) to allow time for the sensor to be ready.

During this phase, it is the responsibility of the host to ensure the correct number of bytes are exchanged.

7.5.3 Active Mode Read

The recommended way to read data from a sensor running in Active mode is to monitor the interrupt pin (INT) to determine when new data have been acquired. The INT pin will be set HIGH when new data are available to be read.

During Active mode, the host reads data from the sensor as per the Data Exchange Phase (with no Command Phase required).

If the host attempts to read data faster than the 'Active Frequency', the sensor will hold the SCL line low (clock stretching) until the data are ready to be read.

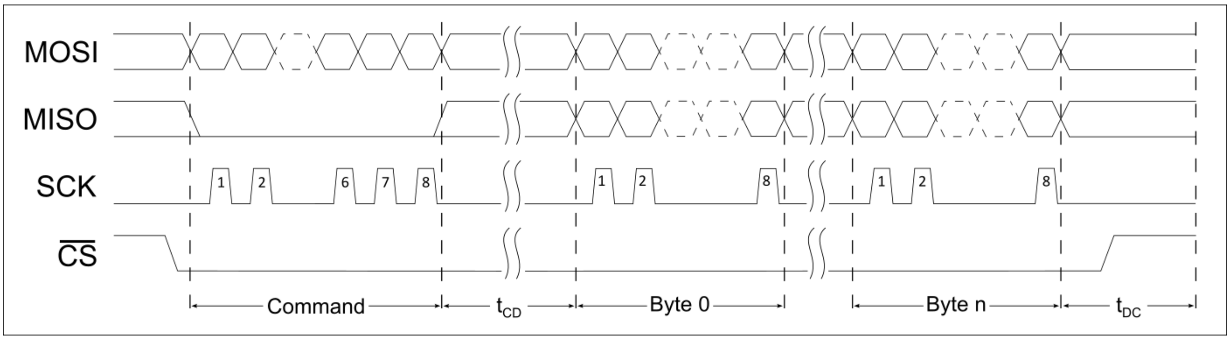
7.6 SPI Interface

This device uses SPI Mode 0 and supports SPI clock frequencies up to 3MHz.

SPI Mode	CPOL	CPHA	SCK Idle State	Data Sampling
0	0	0	LOW	Data sampled on rising edge and shifted out on the falling edge

7.6.1 Command and Data Exchange

The Command Phase and Data Exchange Phase are performed in the same transaction, i.e. without de-asserting.



To perform a successful SPI transaction, the host must:

- Set $\overline{CS}$ LOW to select the sensor.
- Send a single command byte (Command Phase).
- Wait for a duration of at least t_{CD} to allow the sensor to process and respond to the command.
- Read/write 1 or more bytes, depending on the command (Data Exchange Phase).
- Set $\overline{CS}$ HIGH to de-select the sensor.

Following a transaction, the host must wait for a duration of at least t_{DC} before beginning another transaction.

SPI Timing Parameters

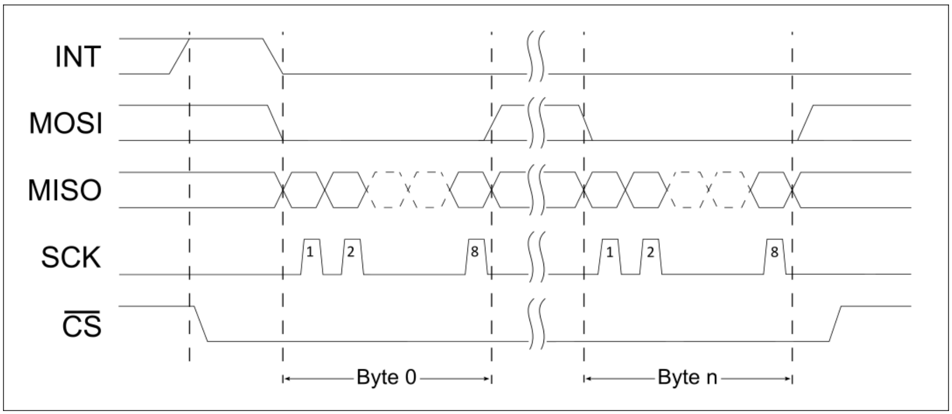
Parameter	Symbol	Min	Max	Units
Command to Data Time	t_{CD}	250	-	µs
Data to Command Time	t_{DC}	10	-	

7.6.2 Active Mode Read

The recommended way to read data from a sensor running in Active mode is to use the interrupt pin (INT) to synchronize transaction timing.

To perform a successful SPI transaction in Active mode, the host must:

- Wait for the INT pin to be set HIGH. This indicates the requested data has been acquired.
- Set $\overline{CS}$ LOW to select the sensor. The sensor will move the data into the SPI write buffer.
- Wait for the INT pin to be set LOW. This indicates the data is ready to be read.
- Proceed with the SPI transaction as normal, shifting out the number of bytes determined by the Set Active Data command.
- Set $\overline{CS}$ HIGH to de-select the sensor.



If the interrupt pin is not used, it is the responsibility of the host application to ensure that the frequency of read requests is no quicker than the data frequency set with the Set Active Frequency command. In addition, the host must wait 3 μs after asserting before initiating an SPI data transfer.

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8 Command List

Command	**Code (Hex)**	**Description**	**Write (bytes)**	**Read (bytes)**
Reserved	0x00	Reserved.	-	-
NOP	0x01	No operation. Returns 0xAA.	-	1
Get Status	0x02	Retrieve device status.	-	1
Get Data	0x03	Read calibrated force and temperature data.	-	28
Get Temperature	0x04	Read device temperature.	-	4
Get Version	0x06	Read the device version.	-	32
Set Active Frequency	0x09	Set the acquisition frequency used when running in Active mode.	4	-
Get Active Frequency	0x0A	Read the current acquisition frequency.	-	4
Set Active Data	0x0B	Configure which data are to be acquired when running in Active mode.	4	-
Get Active Data	0x0C	Read which data are currently configured to be acquired in Active mode.	-	4
Enter Active	0x0D	Enter Active mode.	-	1
Bias Sensor	0x0F	Bias the sensor.	-	1
Set I^{2}C Address	0x10	Set a new I^{2}C Address for this device. The new address will take affect after a reset.	1^	1
Who Am I	0x11	Retrieve hardware ID.	-	32#
Set Comms Mode	0x13	Set the communication interface for this device (I^{2}C/SPI).	1^	1
Other Commands		Reserved. Do not use	*Reserved*	*Reserved*

** All values are little endian.*
^ Flash write commands should be followed by a 100ms delay.
 # Null terminated string.

9 Command Descriptions

9.1 NOP

Command: 0x01
Rx size: 1 byte

This command returns 0xAA. This command can be used to verify communication with the device.

9.2 Get Status

Command: 0x02
Rx size: 1 byte

Reads the error status from the device. The status is a single unsigned byte:

Status	Code (Hex)	Description
Out Of Range	0x01	Attempt to access an out-of-range memory address.
Memory Allocation Error	0x02	Memory allocation failed. Insufficient internal memory.
OK	0xAA	No error. Sensor is operating as expected.
Bad Calibration	0xFD	There is a problem with the calibration on the device.
Error	0xFE	Generic error.
Status Unknown	0xFF	Device status is unknown.

9.3 Get Data

Command: 0x03
Rx size: 28 bytes

The sensor will collect and process 3D force and temperature data. All processed data are transmit as 32-bit floating-point values. Data are sent in the following order:

Starting Byte	Description
0	Force applied in the X axis
4	Force applied in the Y axis
8	Force applied in the Z axis
12 – 23	Reserved
24	On-board temperature

Note: After receiving the Get Data command, the sensor takes approximately 300µs to sample 3D force and temperature data. The SCL line will be held low by the sensor during this time.

9.4 Get Temperature

Command: 0x04
Rx size: 4 bytes

The sensor will sample and transmit the on-board temperature as a single 32-bit floating-point value.

9.5 Get Version

Command: 0x06
Rx size: 32 bytes

The sensor transmits its firmware version as a 32-byte null-terminated string.

9.6 Set Active Frequency

Command: 0x09
Tx size: 4 bytes

The command is used to define the data processing rate in Active mode. By default, the sensor will collect and process pillar data at 1000 Hz. The minimum active frequency is 25 Hz.

The sensor expects to receive a 32-bit unsigned integer to set the active frequency.

9.7 Get Active Frequency

Command: 0xA
Rx size: 4 bytes

The sensor transmits the current Active frequency as a 32-bit unsigned integer.

9.8 Set Active Data

Command: 0xB
Tx size: 4 bytes

This command is used to set which data are to be processed and transmitted during the Active state. The sensor expects a 32-bit bitfield in the following format. All values are set to 0 after a reset.

Active Data Bitfield

Bit number	Data
31-16	Reserved
11	Force applied in the X axis
10	Force applied in the Y axis
9	Force applied in the Z axis
8-6	Reserved *
5	On-board temperature
4-0	Reserved *

** Setting Reserved fields can cause erroneous data and communication issues.*

9.9 Get Active Data

Command: 0x0C
Rx size: 4 bytes

The sensor will transmit the active data bitfield. See ‘Set Active Data’ for details regarding the active data bitfield. The data are transmitted as a 32-bit unsigned integer.

9.10 Enter Active

Command: 0x0D
Rx size: 1 byte

This command is used to place the sensor in Active mode. The sensor transmits a 1-byte unsigned integer to indicate if the transition to Active mode was successful:

Response	Meaning
0xAA	Enter Active mode was successful
0xFE	Enter Active mode failed. Check active data bitfield.

The sensor enters active mode after the one-byte response is read.

After entering Active mode, the sensor continuously acquires the force and temperature data that were requested by ‘Set Active Data’ at the ‘Active Frequency’. The host can read the corresponding number of bytes to retrieve the latest data. All force and temperature values are 32-bit floating-point values.

When in Active mode, the host should only *read* from the sensor. Active mode will exit automatically and return to Idle mode when any command is issued.

The host should read 4 bytes for every valid bit in the Active Data Bitfield. Data are transferred in the order listed in this bitfield. See Set Active Data for more details.

The host can read at any desired rate, but will only read the latest sampled data. There is no on-board buffering; unread data are discarded.

9.11 Bias Sensor

Command: 0x0F
Rx size: 1 byte

This command is used to bias the sensor. The sensor collects 3D force data to calculate bias constants.

Biasing the sensor is akin to taring a weighing scale, it sets a baseline from which to calculate readings. This command should be run with no force applied to the pillars to calculate accurate bias constants. This command must be run at least once to receive valid force data.

The sensor sends a 1 byte response indicating if biasing was successful. A response of 0xAA indicates success.

9.12 Set I^{2}C Address

Command: 0x10
Tx size: 1 byte
Rx size: 1 byte
Modifies flash memory ^

This command is used to permanently change the I^{2}C address for the device. The data phase for this command has two transactions. The first is a Tx phase with a size of 1 byte where the sensor expects a 7-bit I^{2}C address (LSB at bit 0). An Rx phase follows, with a read size of 1 byte where the sensor transmits the new I^{2}C address as it was received/stored on-board.

A reset is required for the new address to take effect.

^ See section 7.3 Flash Write Commands for timing requirements for this command.

9.13 Who Am I

Command: 0x11
Rx size: 32 bytes

This command is used to read the sensor's hardware details. The sensor transmits 32 bytes in the form of a null terminated string. All 32 bytes must be read from the sensor.

9.14 Set Comms Mode

Command: 0x13
Tx size: 1 byte
Rx size: 1 byte
Modifies flash memory ^

This command is used to permanently change the communication interface for the device. The data phase for this command has two transactions. The first is a Tx phase where the host sends the desired communication interface (I^{2}C = 0x00, SPI = 0x01). An Rx phase follows, with a read size of 1 byte where the sensor transmits the new communication interface as it was received/stored on-board.

Communication Interface	Tx phase data byte
I^{2}C	0x00
SPI	0x01

A reset is required for the new communication interface to take effect.

^ See section 7.3 Flash Write Commands for timing requirements for this command.

The communication interface may also be changed using Interface Bootstrapping.

10 Important Notes

10.1 Communication Check

The 'NOP' command can be used to check communication with the sensor and ensure the sensor is transmitting as expected. The 'Set Active Frequency' and 'Get Active Frequency' commands can be used to ensure that data are being transmitted to the sensor at the rate expected.

10.2 Address Collision

To use multiple sensors on the same I^2C bus, the 'Set I^2C Address' command can be used to assign new addresses to sensors. Other sensors may be held in reset to avoid collisions during I^2C address assignment.

10.3 Data Exchange Phase

The correct number of bytes must be exchanged in each phase, otherwise the sensor may enter a non-responsive state. This can be seen when the response to any command is all 1's or the sensor does not respond at all. Reset the sensor to restore communication.

11 Revision History

Date	Revision	Changes
24 May 2024	1	Described changes available from firmware version 1.1.0 ▪ Added SPI communication interface; ▪ Added SPI timing diagrams; ▪ Updated Pinout; ▪ Revised section 7 Communication; ▪ Expanded interrupt description; ▪ Added command *Set Comms Mode* to Command List; ▪ Flash write commands now require only 30ms between writing command and reading response (previously 100ms); ▪ The 'Bias' command now includes a data exchange phase. Updated diagrams and description to indicate this; ▪ 'OK' status code changed from 0x00 to 0xAA

12 Resources

[1] C3DFBS library for a host micro-controller: https://github.com/contactile/c3dfbs