PRODUCT MANUAL

SYNTOUCH BIOTAC® SP
TACTILE SENSOR

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TERMS AND CONDITIONS OF USE

Limited warranty, license and technical support

Using SynTouch sensors signifies the unconditional acceptance of the Limited Warranty and License found at syntouchinc.com/sensor-documents.

The fee to purchase SynTouch sensors does not include technical support from SynTouch or repairs to the sensors other than what is provided by the limited warranty. SynTouch will respond to requests for technical support or repairs in the manner and for the fee that SynTouch deems appropriate at its sole discretion. All requests for technical support or repairs must be submitted in writing to info@syntouchinc.com.

Safety precautions

The BioTac SP sensor contains a chemical fluid. Individuals using the sensor are wholly responsible for learning how to use, store and dispose of the fluid safely and in full compliance with their workplace's safety and health guidelines and regulations. SynTouch provides a Material Safety Data Sheet (MSDS) that explains the potential safety and health risks associated with the fluid.

THE BIOTAC® SP TACTILE SENSOR ("BIOTAC SP")

Hardware

The BioTac SP consists of a rigid core surrounded by an elastic skin filled with a liquid to give compliance like the human fingertip (Figure 1).

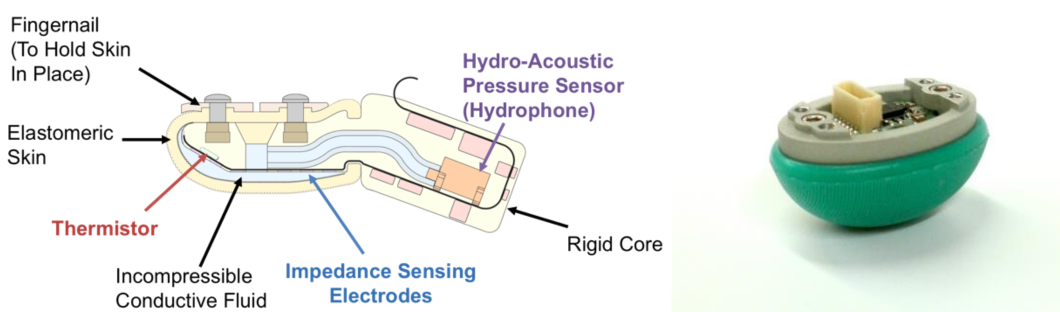

Figure 1 – L: The original BioTac schematic, R: BioTac SP

The curved, deformable nature of both the BioTac SP skin and biological fingertips provides mechanical features that are desirable for the manipulation of objects. The BioTac skin has texture and tackiness like human skin. The BioTac detects the same of cutaneous sensory information as human fingers: forces, micro vibrations, and temperature. The bone-like core of the BioTac contains all sensors; the skin does not contain sensors.

The three sensory modalities of the BioTac are made possible by three separate sets of transducers:

- As forces are applied to the skin, the skin and fluid deform. Changes in impedance as the fluid deforms are detected by an array of electrodes on the surface of the BioTac core.
- As objects slide across the surface of the BioTac, they generate vibrations that are detected by a hydro-acoustic pressure transducer inside the core.

- As objects of different thermal conductivity come into contact with the core, the heat that flows from the BioTac into the object produces thermal gradients that are detected as a change in temperature of the thermistor in the BioTac SP tip.

Raw data collected from the BioTac SP include:

- Voltages on impedance sensing electrodes
- Absolute fluid pressure (DC Pressure)
- Dynamic fluid pressure = vibration (AC Pressure)
- Temperature (DC Temperature)
- Heat flow (AC Temperature)

Signal processing of these data enables the BioTac SP to do many things that humans can do by touch, such as:

- Determine point of contact
- Estimate tri-axial forces
- Estimate the radius of curvature of a contacted object
- Discriminate edges, corners, and flat surfaces
- Sense initial contact, with a remarkably high sensitivity
- Detect slip
- Discriminate objects based on their texture
- Discriminate object based on their compliance
- Discriminate objects based on their thermal properties

These sensory modalities tend to be synergistic for tasks such as identifying objects or maintaining a stable grasp. For example, information about texture and slip can be derived from vibrations of skin ridges sliding over a surface, but only if the forces on the skin are known and well-controlled. Similarly, information about the material composition of an object can be inferred from the rate of heat transfer from a heated finger to the object, but only if the location and force of contact are known and controlled.

Software

The BioTac SP includes at no additional cost several software programs and programming libraries to help with the development of custom applications. These include graphical user interfaces to visualize and record data (Windows), software libraries for LabVIEW, and C-Libraries to support various hardware interfaces. Supported hardware includes the Cheetah SPI USB Host Adapter (LabVIEW: Windows, C-Libraries: Linux, Windows, OS X) and PEAK-System Technik's PCAN-PCI Card (C-Libraries: Real Time Linux). Community developed and maintained, software libraries for Willow Garage's Robotic Operating System, ROS, as well as others are available, open source. Available for download at syntouchinc.com/software.

CARE AND HANDLING

Special care should be taken when using the BioTac SP to ensure its long life and stable performance.

- Skin changes and bracket removal: Return the BioTac SP to SynTouch for skin changes or bracket removal.

> ➢ *The screws connecting the BioTac SP bracket to the sensor should NOT be removed by the customer. Doing so may cause BioTac SP fluid to leak into the core of the sensor, causing corrosion and potentially shorting electronics. Because of this the BioTac SP skin may NOT be changed by the customer.*

- Maximum Force: The BioTac SP is rated at forces up to 250N and should not be used in a robotic gripper using more force. Higher forces can cause strain on the neck of the BioTac SP that could damage the integrated electronics or break the BioTac SP.
- Skin leaks: Under normal usage the skin should not leak. If leaks are noticed disconnect, the sensor, clean any BioTac SP fluid, and notify SynTouch. Do NOT attempt to use the sensor before hearing back from SynTouch.
- Shock: The BioTac SP is not designed to be resistant to severe shock. Do not drop the BioTac SP on hard surfaces or swing a robotic hand with BioTac sensors installed into hard objects as this could cause a fracture.
- Storage: Store the BioTac SP in dry conditions and keep the electrical connectors coated with dielectric grease, if the sensor will be stored without usage for durations of 1 month or more.

> ➢ *The BioTac SP is NOT water resistant and should not be rinsed in water.*

Skin replacement

> ➢ *The BioTac SP skin may NOT be replaced or reinflated by anyone other than SynTouch. If the skin becomes damaged, contact SynTouch at **info@syntouchinc.com**. Skins may only be replaced or refilled by SynTouch. Attempting to remove the BioTac SP bracket, replace the skin, or refill the BioTac SP will void the limited warranty and may cause the sensor to fail.*

ELECTRONICS AND OUTPUT

The integrated electronics of the BioTac SP contains all sensory transducers, signal conditioning, and analog-to-digital conversion electronics to enable digital transmission of the sensor data (Figure 2).

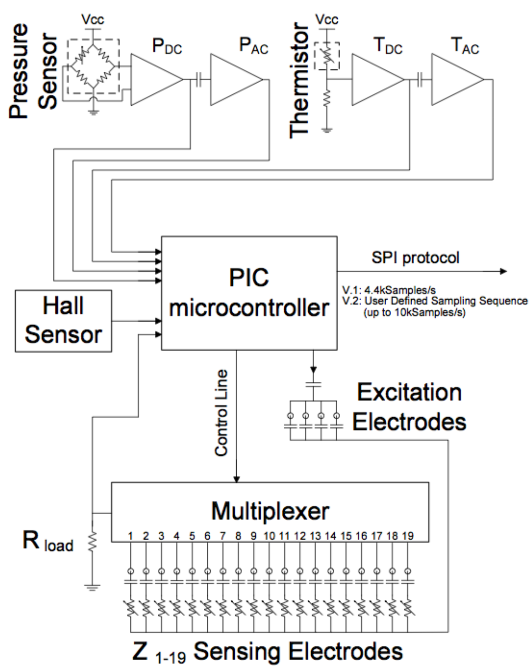

Figure 9 - Electrical schematic of the BioTac SP

Sensor output

The BioTac SP contains three classes of sensors: impedance sensing electrodes, static and dynamic fluid pressure, and temperature and thermal flux. Details of the acquisition and summary of performance of the three main sensor types are provided below:

Sensory Modality	Symbol	Range	Resolution	Frequency response
Impedance	E_n	0 - 3.3V	3.2 mV	0 - 100 Hz
Fluid Pressure	P_{DC}	0 - 100 kPa	36.5 Pa	0 - 1040 Hz
Microvibration	P_{AC}	+/-0.76 kPa	0.37 Pa	10 - 1040 Hz
Temperature	T_{DC}	0 - 75 C	0.1 C	0 – 22.6 Hz
Thermal Flux	T_{AC}	0 - 1 C/s	0.001 C/s	0.45 – 22.6 Hz

Table 1 – BioTac SP Sensory Transducer Sampling Details

- Impedance between each electrode and 4 common excitation electrodes is measured in a voltage divider with reference to a 10kΩ load resistor (R_{load}). For each sampling, the electrode of interest is connected by the multiplexer and a short 3.3V pulse is sent from the excitation electrodes through the fluid to the sensing electrode. As the impedance over the sensing electrode increases, the measured voltage decreases. This voltage (V_n) is digitized with 12-bit resolution (E_n: 0-4095). The exact impedance (Z_n) can be determined from the voltage divider equation as:

$$impedance_n = \left(\frac{3.3\,V}{V_n} - 1\right) 10\;k\Omega = \left(\frac{4095\,bits}{E_n} - 1\right) 10\;k\Omega$$

- Fluid pressure is measured with a piezo-resistive pressure transducer with a range of 0-100kPa (15psi with reference to atmospheric pressure). The transducer output is biased in the positive direction to prevent negative saturation and amplified with a gain of 10 and a low-pass anti-aliasing filter at 1040Hz to produce the DC pressure signal (P_{DC}). A second stage includes a band-pass filter of 10-1040Hz and an additional gain of 99.1 to produce the high-resolution AC pressure vibration signal (P_{AC}). Both are sampled with 12-bit resolution for the range of 0-3.3V. Both AC and DC pressure can be estimated with the following equations (see Application Notes below):

$$fluid\ pressure = \left(P_{DC} - offset\right)\, 0.0365\ {}^{kPa}\!/_{bit}$$

$$dynamic\ pressure = \left(P_{AC} - offset\right)\, 0.37\ {}^{Pa}\!/_{bit}$$

➢ **The pressure transducer used in the BioTac SP is not thermally compensated and can drift slightly in response to changes in temperature. Due to the fabrication of the BioTac SP, mechanical strains applied to the core are coupled to the pressure transducer and can cause small fluctuations in sensor output.**

- Temperature is measured with a thermistor voltage divider with reference to a 30kΩ resistor and a 10V supply. The resistance of the thermistor is given as: 0.6444 exp(4025°K/T) in units of ohms. The absolute temperature (T_{DC}) has a low-pass anti-aliasing filter at 22.6Hz and unity gain buffer. Dynamic temperature (T_{AC}) is measured with a band-pass filter of 0.25-22.6Hz and an additional gain of 98. Both are sampled with 12-bit resolution for the range 0-3.3V. Both absolute temperature and dynamic temperature can be estimated with the following equations:

$$temperature = \frac{4025}{\ln\left(\frac{155183 - 46555\, T_{DC}/4095bits}{T_{DC}/4095bits}\right)} °C - 273.15°C$$

$$dynamic\ temperature = \frac{-41.07}{\ln\left(\frac{155183 - 46555\, T_{AC}/4095bits}{T_{AC}/4095bits}\right)} °C$$

PERFORMANCE

Maximum loading and saturation

The saturation force is the point at which the device output no longer varies with applied force. The saturation force for each electrode voltage is based on the skin properties, electrode configuration, fluid pressure and measurement circuitry. The saturation of the electrode impedance occurs above 250N, at which point the electrode voltage goes approximately to zero. Due to the non-linearity of the impedance circuit, higher-resolution is afforded at lower forces, while higher forces have a reduced resolution. The DC pressure also responds linearly to low forces before the skin comes into contact with the core; this measurement saturates at about 2N.

- *The maximum recommended force applied to the BioTac SP should not exceed 250N.*

This assumes a 250N force applied to the tip while loading against a relatively large flat surface. Lower forces with sharper objects will result in higher local pressures that could result in skin puncture and should also be avoided.

Generally, the BioTac SP has a similar resistance to damage as the human finger. Large forces, heavy impacts, and sharp objects that would cause harm to the biological finger may also damage the skin or core of the BioTac SP. Common sense should be used to avoid these situations.

Skin wear

The skin's wear rate will depend upon usage and environmental conditions. To retain human-like compliance for grip, the hardness of the elastomer skin was kept low and near human skin (Shore A 26). However other properties of the elastomer have been maximized (tensile strength, elongation % at break) to minimize wear. In most applications the skin and fingerprints should last for more than 100 hours of use. Care should be taken to avoid intentionally sliding the BioTac SP over abrasive materials that could increase the wear rate of the skin and fingerprints. Wearing of fingerprints has a substantial impact on the loss of sensitivity to texture-related vibrations.

➢ *If a BioTac SP skin needs replacement, do not try to replace the skin. Instead contact SynTouch to arrange for the skin to be replaced.*

Calibration and conversion to engineering units

Calibration is the method by which the sensor's electrical output is related to an engineering unit, such Newtons or Pascals. The BioTac SP is a highly non-linear device susceptible to drift (like the human fingertip) so it is generally not recommended to be used in this fashion, although these equations are provided for convenience and to give a sense of magnitude. The recommended use of the sensor output is to use the raw data output for various signal-processing algorithms. If it is still desired to convert to engineering units, direct values can be obtained through the equations in the previous section or through other analytical or machine learning methods. Frequent calibration is recommended if this approach is used.

Accounting for signal drift

Like human fingertips, the BioTac SP is better at providing information about changes than absolute values. The recommended use of the sensor output is to use the raw data for various signal-processing algorithms. Moreover, absolute signal levels will drift slightly with changes in temperature, inflation volumes, and skin wear. The BioTac SP fluid blend has been optimized to reduce the effects of fluid diffusion through the skin that might affect impedance sensed by the electrodes. In developing algorithms utilizing BioTac data, incorporate a function to account for signal drift that will occur in their application and/or conditions of use. In general, these effects are not dramatic, but it is important to be aware of the potential occurrence of these changes. When the BioTac is not in contact with external objects, it is recommended the sensor be tared to account for any offset.

ELECTRICAL CONNECTIONS

The BioTac SP comes in two different versions for electrical connections and can be reconfigured by SynTouch if needed.

Flexible circuit model

The following pinout is used in the BioTac SP Flexible Circuit Model:

Pin number	Function	Description
1	N.C.	Not Used
2	SCLK	SPI, clock
3	SS	SPI, Chip select
4	MOSI	SPI, Master out slave in
5	GND	Power (input)
6	MISO	SPI, Master in slave out
7	3.3-5V	Power (do not exceed 5.5V)
8	N.C.	Not Used

Table 2 – BioTac SP Flex Circuit Pinout

- *BioTac SP fluid is electrically conductive by design and can damage electrical components and corrode electrical leads. Care should be taken to ensure the BioTac SP fluid does not come into contact with electrical connections!!!*

Flexible Circuit Model Power Requirements

For optimal sensitivity, the noise of these power supplies should be less than 20mV.

- *Do not supply the BioTac SP with greater than 5.5V of voltage. This can cause damage to the electrical components, which could make the BioTac SP unusable.*

6-pin connector model

The 6-pin connector model of the BioTac SP is designed to use the same cabling and electronics as the original BioTac Sensor and can be connected to with a 6-pin connector to provide 5V power and SPI communication.

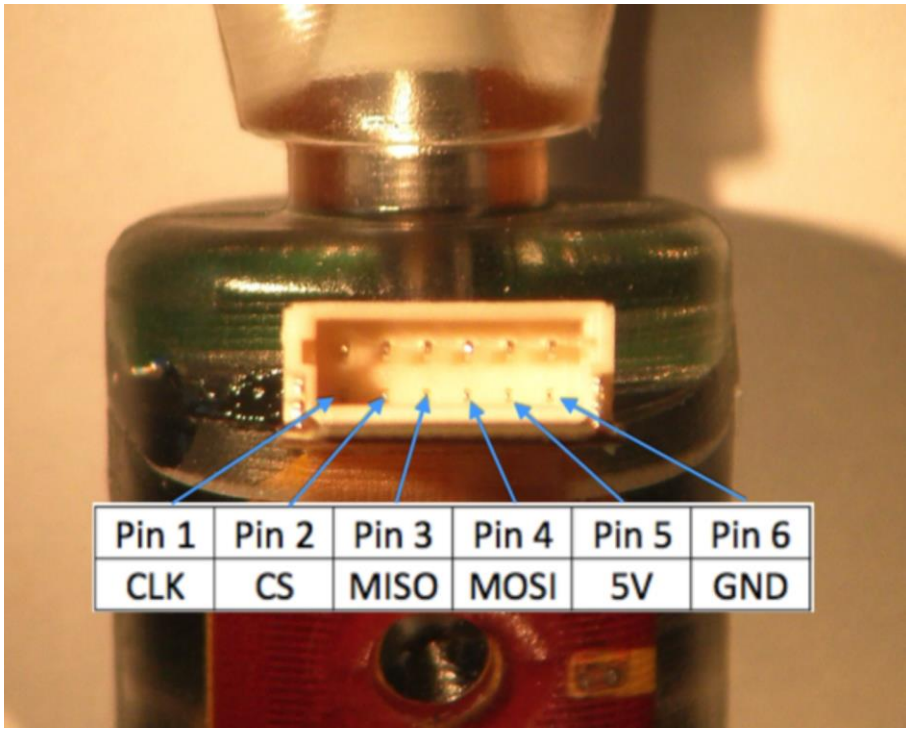

Figure 11 – BioTac SP 6-Pin Connector Pinout

- *Do not supply the BioTac SP with greater than 5.5V(volts) of power. This can cause damage to the electrical components, which could make the BioTac SP unusable and void the warranty.*

The 6-pin connector is designed to mate with the following connector:

Manufacturer	JST Sales America Inc
Manufacturer Part Number	SHR-06V-S
Digi-Key Part Number	455-1396-ND
Datasheet	http://www.jst-mfg.com/product/pdf/eng/eSR.pdf

Family	Rectangular Connectors - Housings
Connectors	Interconnects
Series	SH
Connector Type	Receptacle
Number of Positions	6
Pitch	0.039" (1.00mm)
Mounting Type	Free Hanging (In-Line)
Termination	Crimp

Table 5 – 6-Pin Connector Information

- *BioTac SP fluid is electrically conductive by design and can damage electrical components and corrode electrical leads. Care should be taken to ensure the BioTac SP fluid does not come into contact with electrical connections!!!*

6-Pin Connector Power Requirements

For optimal sensitivity, the noise of these power supplies should be less than 20mV.

- *Do not supply the BioTac SP 5V input with greater than 5.5V(volts) of power. This can cause damage to the electrical components, which could make the BioTac SP unusable.*

SPI COMMUNICATION PROTOCOL 2.3 AND LATER

Overview

During regular data acquisition the master sends a 2-byte request for a particular sensor channel measurement and then pauses the clock while each sensor on the bus simultaneously acquires a 2-byte (12 bit) datum. The master then selects each sensor in sequence and drives the SPI clock so that each slave transmits its datum to the master when its chip select is activated.

See Appendix A for SPI protocol V1.1 in which a single BioTac SP collects a preset sequence of data from its sensors for transmission as a buffer when queried by the host.

SPI configuration

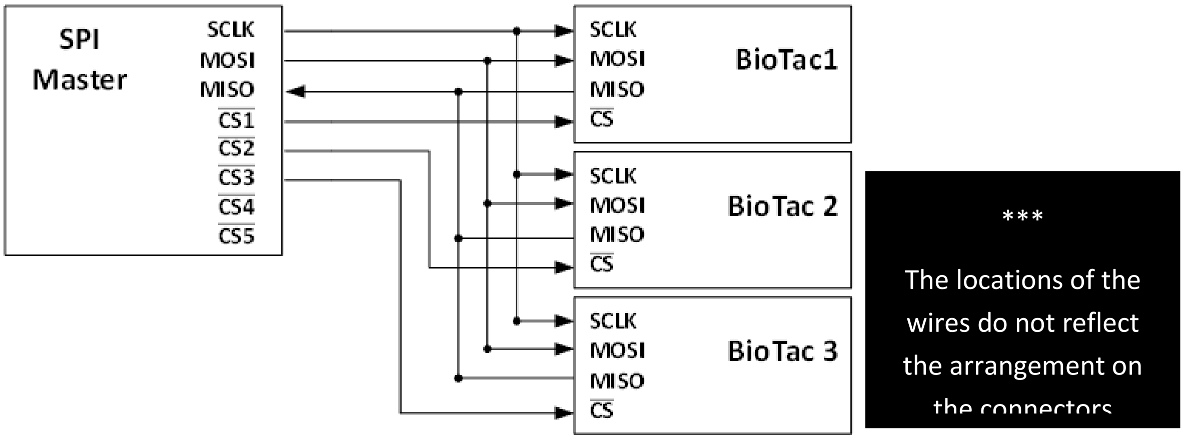

Figure 12 - SPI Connection Overview

SPI communication details

- Word Structure: 2-byte words (16 bits)
- Clock rate: 500kHz-10MHz
- Clock priority: idle low
- Clock phase: first edge
- MISO is changing at negative edge of SCLK; master should sample the signal from MISO line during positive edge and NOT sample the MISO line during negative edge of SCLK.
- BioTac SP samples MOSI line around positive edge; master should change the signal at negative edge and NOT change the signal at positive edge.

	MISO	**MOSI**
Signal update	-ve clock edge	-ve clock edge
Signal sample	+ve clock edge	+ve clock edge

Table 6 - Timing of SPI signal update and sample

Command types

There are four types of basic commands between the host controller and individual BioTac SPs:

- Sampling command
- Resend command
- Parameter Set/Write command
- Parameter Read command

	bit#	First Byte 7	6	5	4	3	2	1	0	Second Byte 7	6	5	4	3	2	1	0
Sampling	0b	1	S	S	S	S	S	S	P	X	X	X	X	X	X	X	X
Resend	0b	0	1	0	1	0	0	0	0	X	X	X	X	X	X	X	X
Set/Write	0b	0	1	0	0	0	0	0	0	N	N	N	N	V	V	V	P
Read	0b	0	1	1	0	0	0	0	1	N	N	N	N	V	V	V	P
										Subset				Variables			

0b: indicating the command is sent as binary code

0/1 : command type

SSSSSS: sampling channels number (0~63)

Figure 13 – SPI Communication Protocol Command Types and Structure

While SPI supports full duplex transmission, the current version of SPI protocol is designed to communicate in half duplex with two-byte commands being sent from the host and 2xn bytes of response from the BioTac SPs.

- **While listening to the responses from the BioTac SP the host should write 0x0001 to the MOSI lines to avoid errors.**

Sampling command

Description

The sampling command is a 2-byte command from the host. Only the first byte is processed and the second byte is ignored. Upon receiving the 2-byte command from the host, all BioTac SPs with an active slave select during the command simultaneously and independently sample the requested channel specified by the 6-bit command SSSSSS (63 possible channels) and load the value into a 2-byte buffer.

- **NOTE: A minimum of 50µs delay is required between the sampling command and response from the BioTac SPs. During this time the CS lines should be disabled.**

After the minimum delay of 50µs individual BioTac SPs can be queried for this 2-byte buffer by enabling the CS and CLK line to each BioTac SP for two bytes. This buffer must be read before sending a new sampling request. A sample of the recommended communication structure is outlined below:

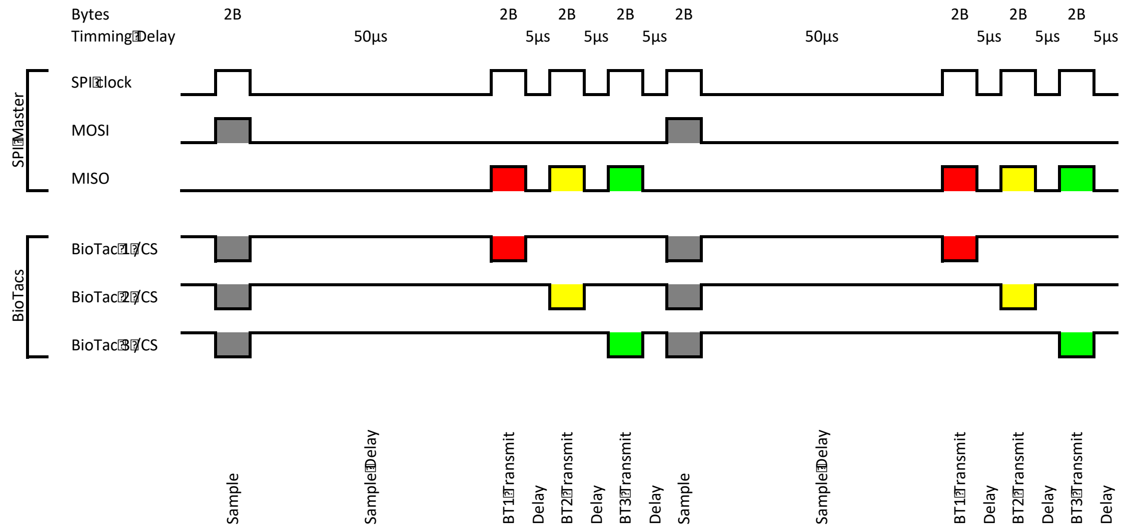

Figure 14 - Recommended Sampling Sequence for 3 BioTac SPs

Detailed Sampling Commands

Description	Index	1st Byte command	Return (bytes)	Note
Pac	**0**	0b10000000	2	
Pdc	**1**	0b10000011	2	
Tac	**2**	0b10000101	2	
Tdc	**3**	0b10000110	2	
Hall Sensor	**15**	0b10011110	2	Only on specific models
Version 1.1 Streaming Protocol	16	0b10100001	92 x #Frames	See Appendix for details of SPI V1.1 Protocol
Get Electrode #1 data	**17**	0b10100010	2	
Get Electrode #2 data	**18**	0b10100100	2	
Get Electrode #3 data	**19**	0b10100111	2	
Get Electrode #4 data	**20**	0b10101000	2	
Get Electrode #5 data	**21**	0b10101011	2	
Get Electrode #6 data	**22**	0b10101101	2	
Get Electrode #7 data	**23**	0b10101110	2	
Get Electrode #8 data	**24**	0b10110000	2	
Get Electrode #9 data	**25**	0b10110011	2	
Get Electrode #10 data	**26**	0b10110101	2	
Get Electrode #11 data	**27**	0b10110110	2	

Description	Index	1st Byte command	Return (bytes)	Note
Get Electrode #12 data	**28**	0b10111001	2	
Get Electrode #13 data	**29**	0b10111010	2	
Get Electrode #14 data	**30**	0b10111100	2	
Get Electrode #15 data	**31**	0b10111111	2	
Get Electrode #16 data	**32**	0b11000001	2	
Get Electrode #17 data	**33**	0b11000010	2	
Get Electrode #18 data	**34**	0b11000100	2	
Get Electrode #19 data	**35**	0b11000111	2	
Get Electrode #20 data	**36**	0b11001000	2	
Get Electrode #21 data	**37**	0b11001011	2	
Get Electrode #22 data	**38**	0b11001101	2	
Get Electrode #23 data	**39**	0b11001110	2	
Get Electrode #24 data	**40**	0b11010000	2	

Table 7 – Sampling Commands

Response format

Signals from sensors are digitized as 12-14 bits of data; and split into two bytes (low byte and high byte) in the following format.

MSB											LSB				
Data<11:5>							Parity	Data<4:0>					0	0	Parity
bit 15	bit 14	bit 13	bit 12	bit 11	bit 10	bit 9	bit 8	bit 7	bit 6	bit 5	bit 4	bit 3	bit 2	bit 1	bit 0

Figure 15 – Sampling Command Response Format

SPI Version 1 Communication Note

Sending a 0b10100001 command enters SPI Version 1.1 program loop, described in appendix A. To exit this loop, CLK must remain idle for 5 seconds.

Error Handling

Sampling Errors	BioTac SP Response	Description
Insufficient Sampling Delay (-)	0b10100101 00101101	There has been insufficient delay between the sampling command and response time (minimum delay is 50µs)
Channel Not Recognized (X)	0b10100101 01011000	The channel is not recognized by the BioTac SP firmware or unavailable

Table 8 – Sampling Error Responses

Data Resend command

The data resend command is a 2-byte command from the host. Only the first byte is processed and the second byte is ignored. Upon receipt of the data resend command, the BioTac SP responds with the previous 2 bytes of sampled data (this should be used in case of a parity error).

Chip select can be used to request a data resend from an individual BioTac SP. If the data resend command is sent before the BioTac SP has been sent a sampling command the BioTac SP will ignore the resend request.

Set/Write and read command

The set/write and read commands are a 2-byte commands from the host (with additional bytes in the case of set/write. Upon receiving the command the BioTac SP responds with 2x bytes.

Group index		Subset name	Function
1	NNNN=0001	Information	BioTac SP general parameters
6	NNNN=0110	CPU	BioTac SP CPU parameters
7	NNNN=0111	Internal sampling	Internal sampling mode parameters

Table 9 – Read/Write Function Subset Groups

Description	2nd byte Command	Return Bytes	rw	Details
NNNN = 0001				
General information subset	0b0001VVVP			
Flex version	0b00010000	2	r-	Format: M.N - ASCII (no parity)
Software version	0b00010011	4	r-	Format MMNN - ASCII (no parity)
Serial number	0b00010101	16	r-	Format ASCII (no parity)
NNNN = 0110				
CPU information subset	0b0110VVVP			
CPU speed	0b01100001	2	r-	0-65535 kHz (no parity)
NNNN = 0111				
Internal sampling information subset	0b0111VVVP			
Sampling frequency	0b01110000	2	r-	0-65535 Hz (no parity)
Sampling pattern	0b01110011	2 x n	r-	2 byte channel array: 0b 1SSSSSSP 00000001 x n Last Sample Ends in: 0b 1SSSSSSP 11111110

Table 10 - Read/Write Function Details

Error Handling

Set/Write Errors	BioTac SP Response	Description
Parameter is read-only (R)	0b10100101 01010010	Trying to write to a read-only parameter

Table 11 – Read/Write Error Codes

SAMPLING SEQUENCES

While the sampling sequence is configurable and controllable by the host by sending various sequences of sampling commands the following sequences are recommended by SynTouch to optimize the available bandwidth of sensory modalities and reduce the communication bandwidth.

Default Sampling Sequence

Vibrations signals are measured (P_{AC}) and interleaved with the electrode impedances (Electrodes #n) and other sensor signals (P_{DC}, T_{AC}, and T_{DC}). It is recommended that this sampling sequence is run at a minimum 4.4kHz to take advantage of the full bandwidth of P_{AC} and electrodes.

Sequence (54 Samples/frame)

P_{AC}, E_1, P_{AC}, E_2, P_{AC}, E_3, P_{AC}, E_4, P_{AC}, E_5, P_{AC}, E_6, P_{AC}, E_7, P_{AC}, E_8, P_{AC}, E_9, P_{AC}, E_{10}, P_{AC}, E_{11}, P_{AC}, E_{12}, P_{AC}, E_{13}, P_{AC}, E_{14}, P_{AC}, E_{15}, P_{AC}, E_{16}, P_{AC}, E_{17}, P_{AC}, E_{18}, P_{AC}, E_{19}, P_{AC}, E_{20}, P_{AC}, E_{21}, P_{AC}, E_{22}, P_{AC}, E_{23}, P_{AC}, E_{24}, P_{AC}, P_{DC}, P_{AC}, T_{AC}, P_{AC}, T_{DC}

Bandwidth

- Data: 16 bits/ch/BioTac SP, 864 bits/frame/BioTac SP
- Communication Overhead: 864 bits/frame
- 3 BioTac SPs sampled at 4.4kHz: 281.6 kB/s

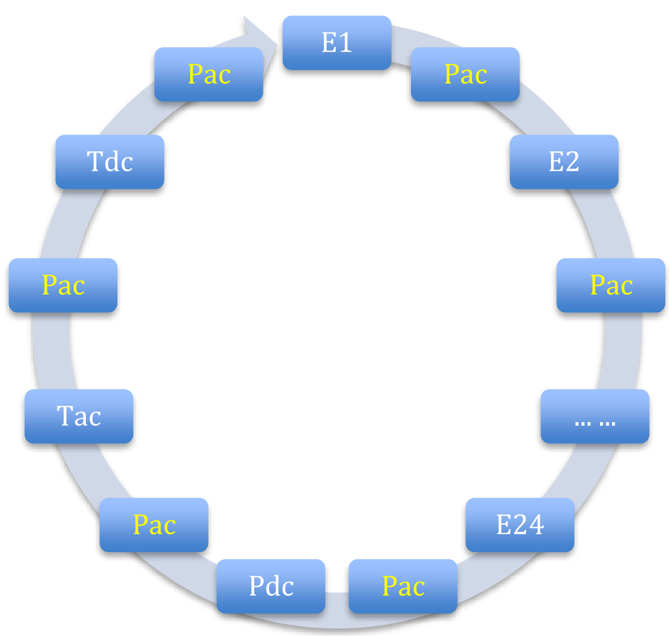

Figure 16 – Recommended Default Sampling Sequence

Using the recommended sampling rate of 4.4kHz, this permits for the following bandwidth:

Sensor type	Numbers of sensor	Sampling rate	Signal bandwidth
Electrode	24	73Hz per electrode	36.5Hz
AC Pressure (P_{AC})	1	2200Hz	1100Hz
DC Pressure (P_{DC})	1	73Hz	36.5Hz
AC Temperature (T_{AC})	1	73Hz	36.5Hz
DC Temperature (T_{DC})	1	73Hz	36.5Hz

Table 12 – Bandwidth and Sampling rate for Default Sampling Sequence at 4.4kHz

Alternate Sampling Sequences

All Channels (28 Samples/frame):

This sampling sequence is advised when high bandwidth vibration is not necessary. It reduces the sampling rate of P_{AC} to conserve bandwidth. Recommended sampling rate is 3.1kHz, however lower sampling rates can be used if desired. This is a preferred sampling pattern for a low-bandwidth standby mode when not interacting with objects. *NOTE: when using this sampling sequence P_{AC} is subject to aliasing.*

Sequence:

P_{AC}, P_{DC}, T_{AC}, T_{DC}, E_1, E_2, E_3, E_4, E_5, E_6, E_7, E_8, E_9, E_{10}, E_{11}, E_{12}, E_{13}, E_{14}, E_{15}, E_{16}, E_{17}, E_{18}, E_{19}, E_{20}, E_{21}, E_{22}, E_{23}, E_{24}

Bandwidth:

- Data: 16 bits/ch/BioTac SP, 448 bits/frame/BioTac SP
- Communication Overhead: 448 bits/frame
- 3 BioTac SPs sampled at 3.1kHz: 198.4 kB/s
- 3 BioTac SPs sampled at 310Hz: 19.8 kB/s

Electrodes Only

This sampling sequence is preferred for force extraction algorithms that make use of the BioTac SP electrodes, preferably for lighter forces. The recommended sampling rate is 1.9kHz.

Sequence (24 Samples/frame):

E_1, E_2, E_3, E_4, E_5, E_6, E_7, E_8, E_9, E_{10}, E_{11}, E_{12}, E_{13}, E_{14}, E_{15}, E_{16}, E_{17}, E_{18}, E_{19}, E_{20}, E_{21}, E_{22}, E_{23}, E_{24}

Bandwidth:

- Data: 16 bits/ch/BioTac SP, 384 bits/frame/BioTac SP
- Communication Overhead: 384 bits/frame
- 3 BioTac SPs sampled at 2.4kHz: 153.6 kB/s

AC/DC Pressure

This sampling sequence is preferred for high-resolution sampling of vibration signals and alternates between the P_{AC} and P_{DC} channels. The recommended sampling rate is 4.4kHz.

Sequence (2 Samples/frame):

P_{AC}, P_{DC}

Bandwidth:

- Data: 16 bits/ch/BioTac SP, 32 bits/frame/BioTac SP
- Communication Overhead: 32 bits/frame
- 3 BioTac SPs sampled at 4.4kHz: 281.6 kb/s

Single Channel and Other Sampling Sequences

The provided sampling sequences above are merely guidelines and users can customize their own sampling sequences or configure software to sample a single channel at any rate they prefer.