



BioTac® Product Manual

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Table of Contents

1	Introduction to Technology	3
2	Engineering Support.....	5
3	Available Software	6
4	Care and Handling	7
4.1	Skin Replacement and Fluid Filling Procedure.....	7
4.1.1	Preparation of Approved Filling Syringe	7
4.1.2	Install Skin.....	8
4.1.3	Inject BioTac Fluid.....	9
4.1.4	Remove Air from Skin	10
5	Sensor Electronics	13
5.1	Sensor Output.....	13
6	Sensor Performance Considerations	16
6.1	Maximum Loading and Saturation	16
6.2	Skin Wear Rate.....	16
6.3	Break-In Period of Skin	16
6.4	Calibration and Converting to Engineering Units	17
6.5	Accounting for Signal Drift.....	17
7	Electrical Connections.....	18
7.1	Flex Circuit Pinout.....	18
7.1.1	Flex Circuit Connector.....	19
7.1.2	BioTac Electrical Adapter	19
7.1.3	Built In 6-pin connector	21
7.2	Power Requirements	22
8	SPI Communication Protocol 2.3 and later	23
8.1	Overview	23
8.2	SPI Configuration.....	23
8.3	Command Types	24
8.3.1	Sampling command.....	25
8.3.2	Data Resend command	27
8.3.3	Set/Write and read command.....	27
9	Sampling sequences.....	29
9.1	Default Sampling Sequence.....	29
9.2	Alternate Sampling Sequences	30
9.2.1	Default with Hall.....	30
9.2.2	All Channels (24 Samples/frame):	30
9.2.3	Electrodes Only	31
9.2.4	AC/DC Pressure	31
9.2.5	Single Channel and Other Sampling Sequences	31
Appendix A.	BioTac SPI protocol V1.1.....	32
Appendix B.	Materials.....	36
Appendix C.	Legal	37
9.2.6	PURPOSE.....	38
9.2.7	CUSTOMER SUPPORT AND SERVICE	38
9.2.8	CUSTOMER FEEDBACK	38
9.2.9	TAXES AND TARIFFS.....	38
9.2.10	SAFETY AND HEALTH ACKNOWLEDGEMENTS.....	38

1 Introduction to Technology

This manual describes the performance and function of SynTouch's BioTac® tactile sensor. The biomimetic design consists of a rigid core surrounded by an elastic skin filled with a liquid to give compliance similar to the human fingertip (Figure 1). The curved, deformable nature of both the BioTac and biological fingertips provides mechanical features that are desirable for the manipulation of objects. The skin of the BioTac possesses texture and tackiness similar to the properties of human skin.

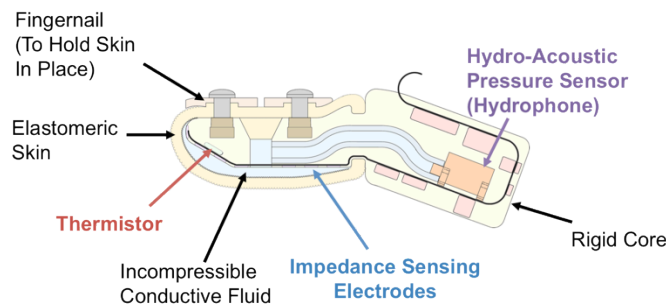


Figure 1 - The BioTac.

The BioTac is the first tactile sensor capable of detecting the full range of cutaneous sensory information that human fingers can detect: forces, microvibrations, and temperature. Note that all of these sensory functions have been incorporated into the bone-like core of the device; there are no sensors in the skin itself. The skin has been designed to be an easily replaced, low-cost, molded elastomeric sleeve. Because the sensors, electronic circuitry, and connections are protected inside the rigid core, the BioTac is uniquely robust.

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 tip.

Raw data collected from the BioTac 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 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

For tasks such as identifying objects or maintaining stable grasp, these sensory modalities tend to be synergistic. 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.

2 Engineering Support

SynTouch provides engineering support for troubleshooting and installation assistance with various platforms. Additional technical support can be purchased to aid with implementing new communication protocols, design and production of mechanical or electrical adapters, or generation of novel signal processing tools. Contact SynTouch at support@syntouchllc.com for additional details.

3 Available Software

SynTouch provides various software and programming libraries to help with the development of custom applications using the BioTac. These software are provided free of charge to all customers as a development tool. The latest versions of these software and their documentation are provided on our website at www.syntouchllc.com under the products tab.

Software provided by SynTouch includes various graphical user interfaces to visualize and record data (Windows) as well as software libraries for LabVIEW, and C-Libraries to support various hardware interfaces. As of the writing of this document, 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). Software libraries for Willow Garage's Robotic Operating System as well as other platforms and hardware are currently under development.

4 Care and Handling

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

- **Maximum Force:** The BioTac is rated at forces up to 50N and should not be used in a robotic gripper using more force. High forces can cause strain on the neck of the BioTac that could damage the integrated electronics or break the BioTac.
- **Skin Leaks:** Applying high shear forces around the neck of the BioTac where the skin mates with the core can result in small leaks. It is best to avoid contacting the skin in these areas.
- **Shock:** The BioTac is not designed to be resistant to severe shock. Do not drop the BioTac on hard surfaces or swing a robotic hand with BioTacs installed into hard objects as fracture from this impact could occur. Be particularly careful when handling the bare core without a skin.
- **Flex Circuit:** Do not bend the Flex Connector at sharp 90-degree angles. The Flex Connector is designed to bend at these angles but cannot handle many cycles without potential damage. Instead allow the flex circuit to bend naturally with a radius of at least 1/8 in (3.175mm),
- **Storage:** Store the BioTac in dry conditions and keep the electrical connectors coated with dielectric grease. The BioTac is water resistant and can be rinsed in water, however, it is not designed to operate while submerged or with a wet connector.

4.1 Skin Replacement and Fluid Filling Procedure

Always follow standard procedures for the following:

- Removal or Replacement of skin
- Filling with BioTac fluid
- Applying dielectric grease
- Removal of Air Bubbles

4.1.1 Preparation of Approved Filling Syringe

- Use the included BioTac filling syringe, needle and depth stop and fill with approximately 3cc of approved BioTac fluid.

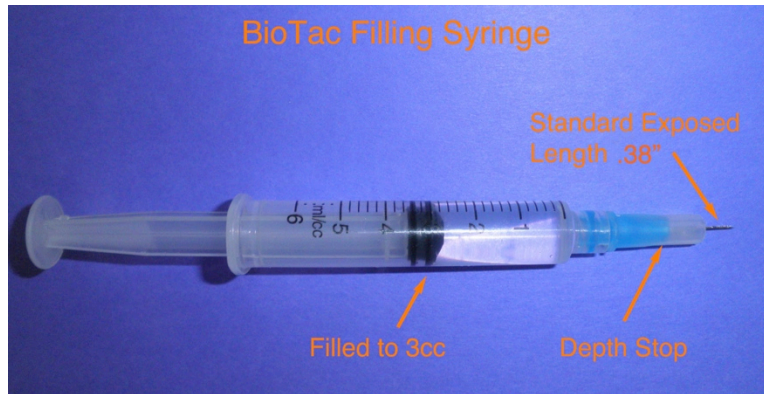


Figure 2 – Assembled BioTac filling syringe

- Hold syringe with tip facing up and remove any air by pressing plunger until no air bubbles can be seen at tip. Place syringe on clean surface ready for use. Note: wear surgical gloves for this & all of the following operations to keep hands clean.

4.1.2 Install Skin

- Use the filling syringe to place a few drops of BioTac fluid onto core and then spread fluid onto core surface with gloved fingers.

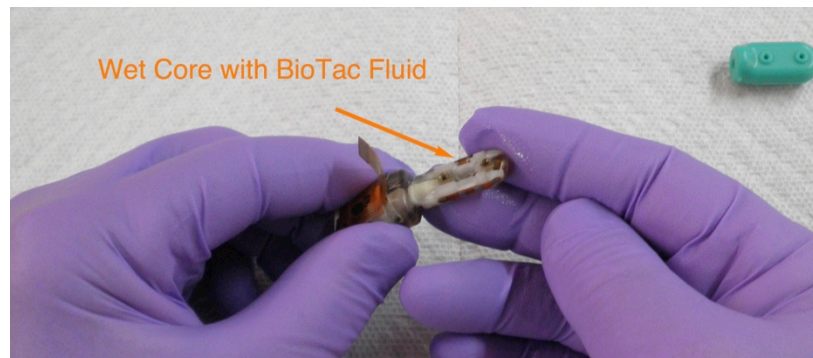


Figure 3 – Wetting of the core with BioTac Fluid

- Slip the BioTac skin onto the core.



Figure 4 – Installation of the skin by sliding onto the core

- Ensure that skin is seated well around neck area of core by slightly rotating skin back and forth over neck.
- Attach the nail using only the supplied screws (presently white or black Nylon). Screws must be snug but care must be taken not to over tighten (finger-tight is usually sufficient to prevent leaks).

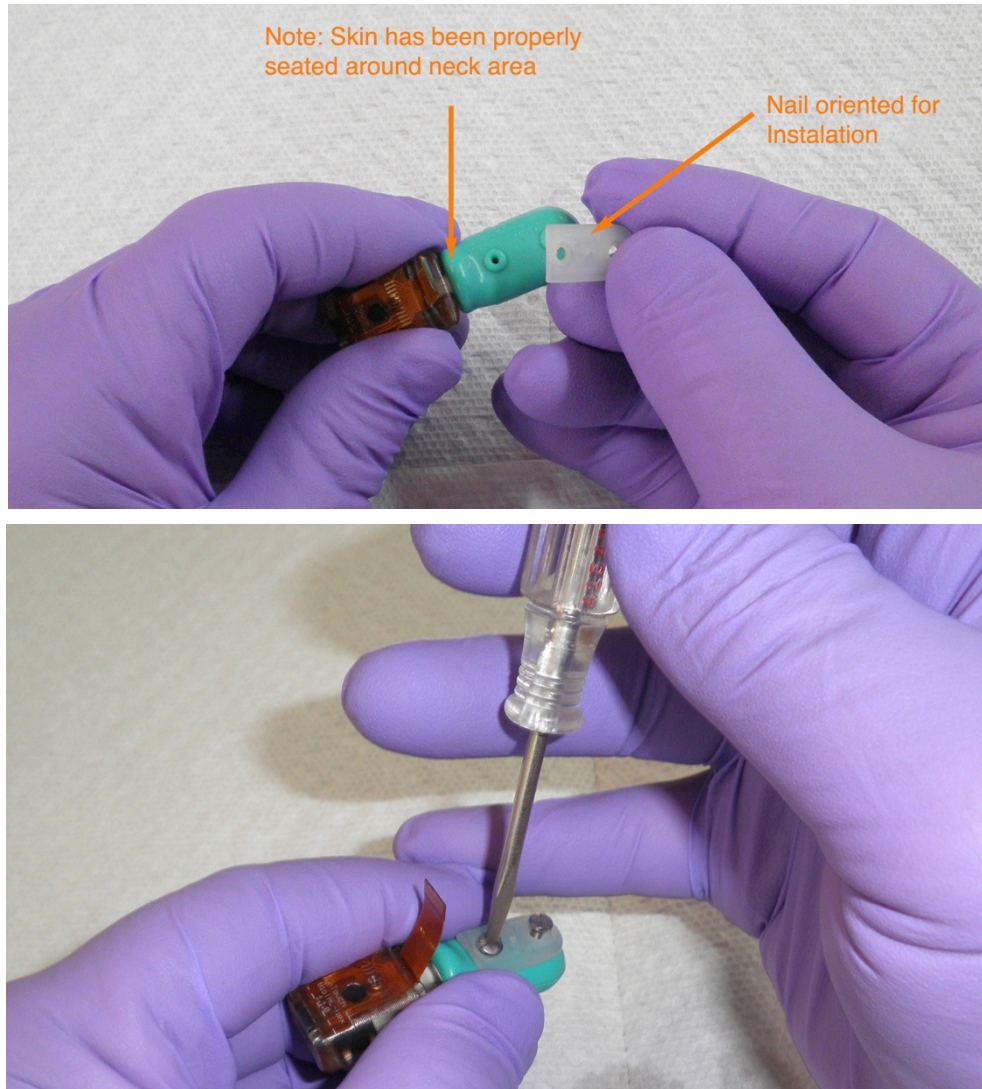


Figure 5 - Installation of the nail

4.1.3 Inject BioTac Fluid

- Hold filling syringe at right angles to nail. Insert needle into hole and push until the “Depth Stop” is in contact with the nail.

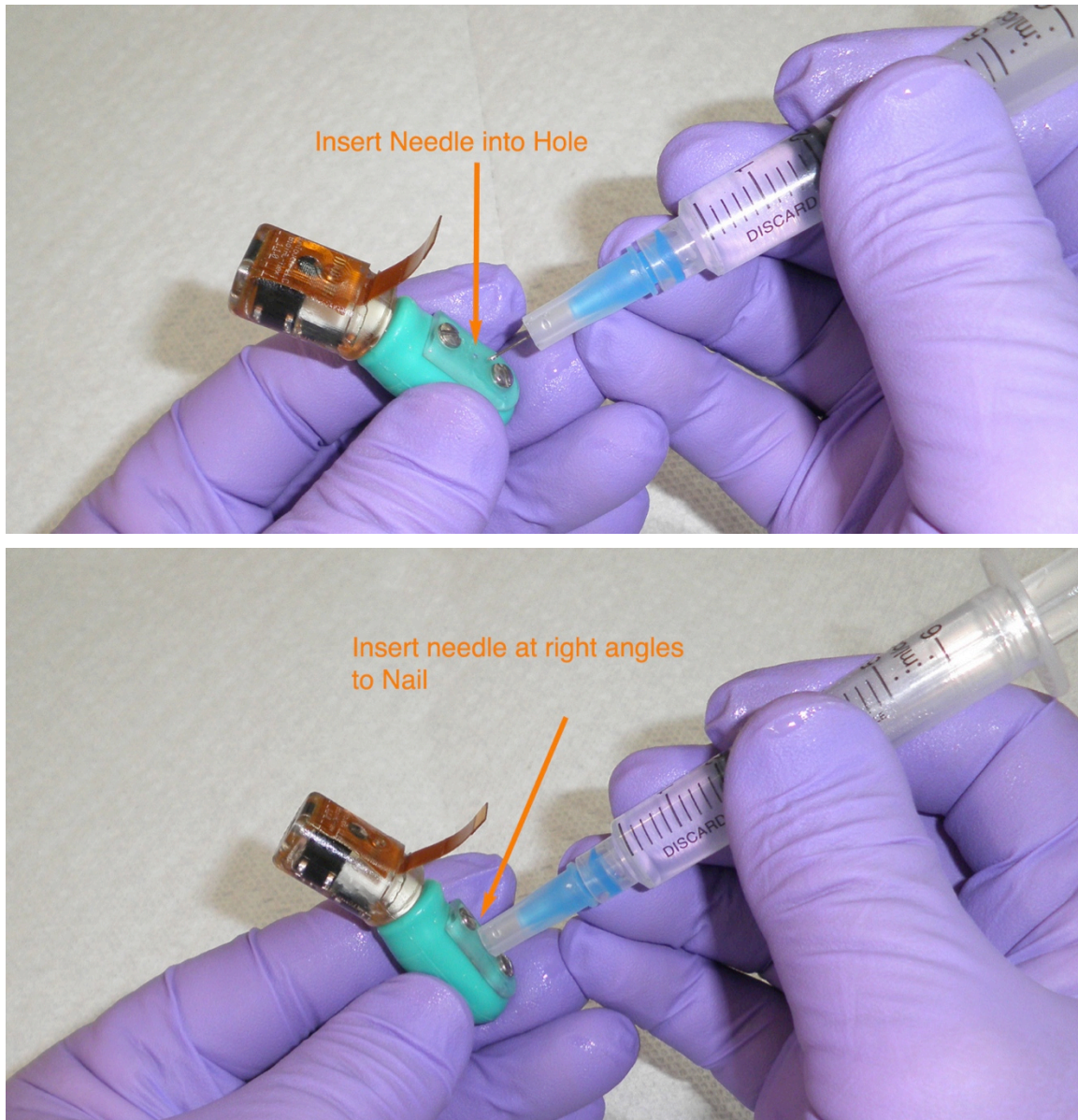


Figure 6 - Inflation of the BioTac

- Press plunger on filling syringe and inject fluid until skin has expanded and the fluid can be felt inside the skin by squeezing with thumb and finger.

4.1.4 Remove Air from Skin

- Hold BioTac in vertical position with fingertip pointing down.
- To remove air bubbles, squeeze lower portion of skin with thumb and finger of one hand while pinching “neck” area of skin with thumb and finger of other hand.

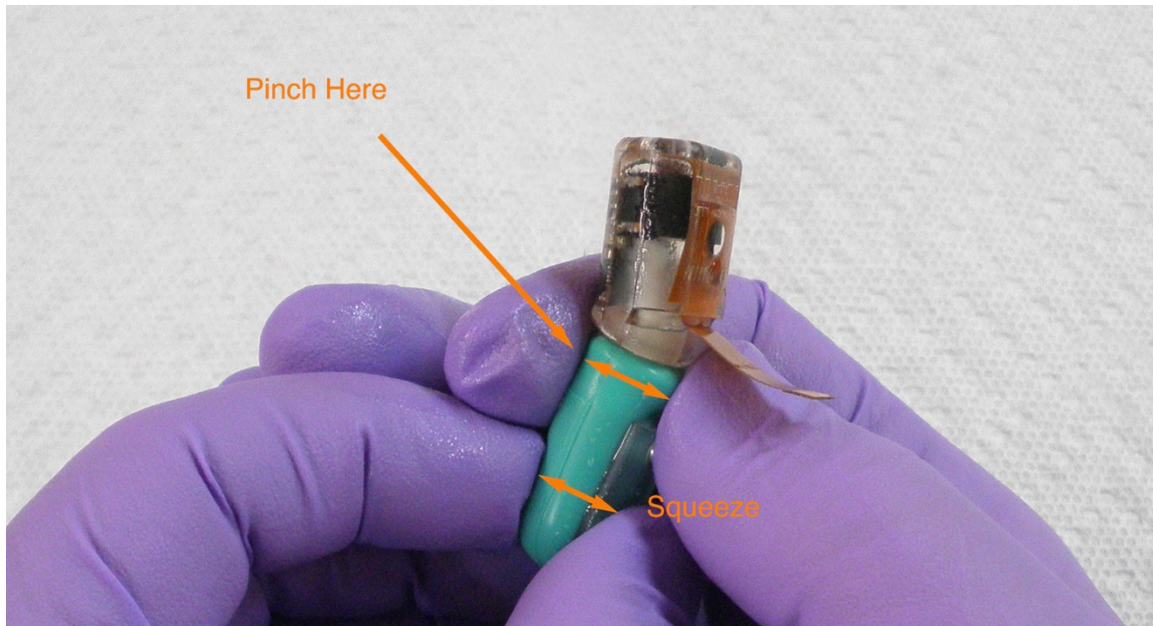


Figure 7 – Removal of air bubbles

- Air bubbles will be seen and/or heard coming from neck area.
- Remove as much air as possible and then repeat previous steps to inject BioTac fluid if necessary to purge all air. Fluid should be injected until skin has visibly expanded.
- In order to check that the correct amount of fluid has been injected, a measurement is taken using calipers across the finger between the nail (just behind the forward screw) and the bottom of the skin. The correct measurement is 15.1mm +/- 0.2mm. NOTE: When taking this measurement touch the skin but do not compress.

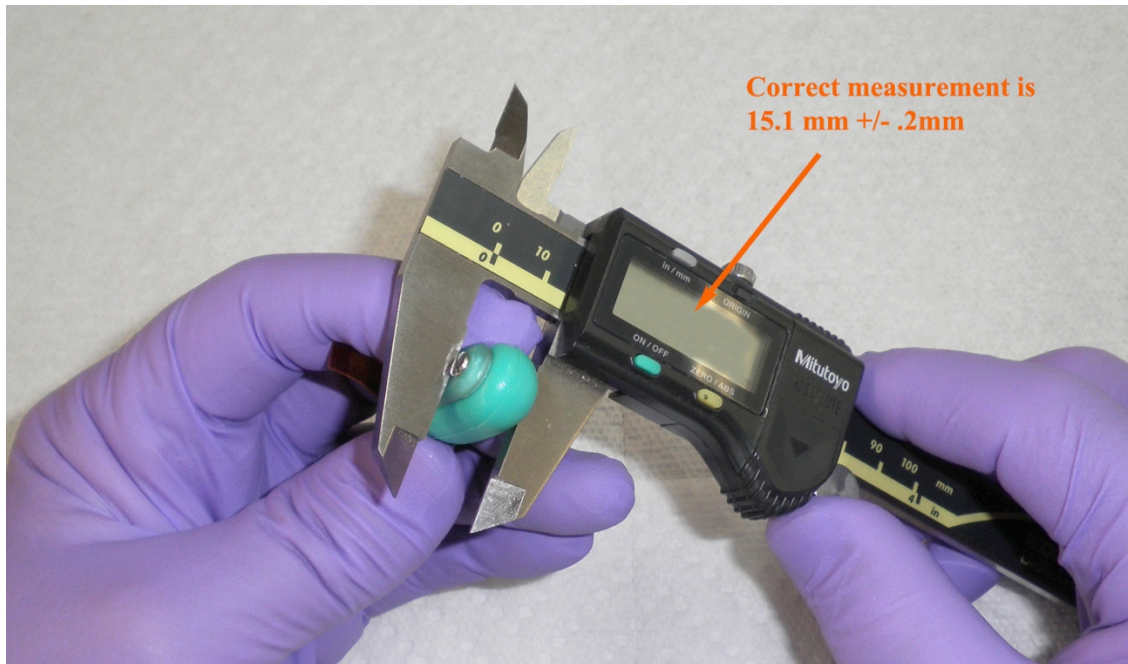


Figure 8 – Measurement of skin inflation

- If the measurement is too large, some fluid can be squeezed out of the neck using the previously described method.
- If the measurement is too small, more fluid can be injected with the syringe as previously described.
- Rinse BioTac under running, room temperature water, to remove any excess BioTac fluid.
- Dry BioTac by blowing with compressed air and then place on absorbent tissue.
- Coat the BioTac flexible circuit with grease to prevent corrosion.

➤ *Make sure to coat the electrical connector of the BioTac with grease to prevent corrosion if it happens to come in contact with BioTac Fluid.*

These procedures are described and illustrated in videos available on the SynTouch website (www.syntouchllc.com).

5 Sensor Electronics

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

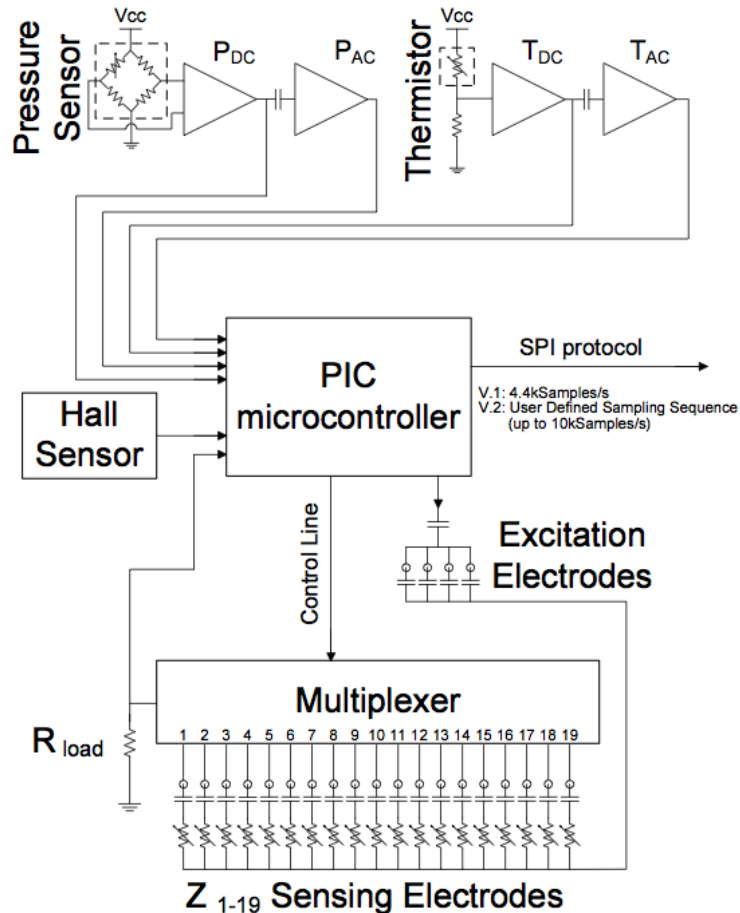


Figure 9 - Electrical schematic of the BioTac

5.1 Sensor Output

The BioTac contains three classes of sensors: impedance sensing electrodes, static and dynamic fluid pressure, and temperature and thermal flux. Some models of BioTacs (Version 2.3 and later) also include a Hall sensor used for integration with the Shadow Robot Hand. 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 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):

$$fluid\ pressure = (P_{DC} - offset) 0.0365\ kPa/bit$$

$$dynamic\ pressure = (P_{AC} - offset) 0.37\ Pa/bit$$

➤ **The pressure transducer used in the BioTac is not thermally compensated and can drift slightly in response to changes in temperature. Due to the fabrication of the BioTac, 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: $0.6444 \exp(4025^\circ K/T)$ 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:

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

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

6 Sensor Performance Considerations

6.1 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 50N, 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 should not exceed 50N.*

This assumes a 50N force applied to the tip while loading against a relatively large flat surface. This precludes damage to the neck at the bend from excessive torque. Lower forces with sharper objects will result in higher local pressures that could result in skin puncture and should also be avoided.

As a general rule of thumb, the BioTac 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. Common sense should be used to avoid these situations.

6.2 Skin Wear Rate

The skin's wear rate will depend upon usage and environmental conditions. In an effort 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 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.

6.3 Break-In Period of Skin

When replacing the BioTac skin with a new one, a modest break-in period of 1-2 hours before calibration and testing is beneficial in achieving accurate results. This will help to lessen the effects of drift due to stress relaxation and fluid absorption in the silicone elastomer. Conditioning is required for newly shipped sensors, and for sensors that have not been used or inflated for a length of time.

To accelerate the conditioning of a new skin, massage the skin gently by squeezing and applying forces in all directions, it is recommended that the skin

be slightly over-inflated for this step. You will notice the resting DC pressure drop slightly in response to skin relaxation and fluid absorption during the break-in period.

6.4 Calibration and Converting to Engineering Units

Calibration is the method by which the sensor's electrical output is related to an engineering unit, such as Newtons or Pascals. The BioTac 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.

6.5 Accounting for Signal Drift

Similar to human fingertips, the BioTac 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. Further, absolute signal levels will drift slightly with changes in temperature, inflation volumes, and skin wear. The BioTac's 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, we suggest that users incorporate a function to account for signal drift that will occur in their particular application and/or conditions of use. In general, these effects are not dramatic, but it is important that users are aware of the potential for these changes to occur. When the BioTac is not in contact with external objects, it is recommended the sensor be tared to account for any offset. This practice is also necessary after skin replacement and refill, as there may be small variations in fluid volume/pressure.

7 Electrical Connections

The BioTac flexible circuit supports two different types of electrical pinnouts from the connectors leaving the BioTac. Version numbers BT-2P-02.3.1 and earlier have a 12-pin flexible circuit lead containing all SPI lines and programming pin connectors, while versions BT-2P-02.4.0 and later have the flexible circuit connector as well as a 6-pin connectors with SPI and power connections.

➤ **BIOTAC FLUID IS ELECTRICALLY CONDUCTIVE BY DESIGN AND CAN DAMAGE ELECTRICAL COMPONENTS AND CORRODE ELECTRICAL LEADS. CARE SHOULD BE TAKEN TO ENSURE THE BIOTAC FLUID DOES NOT COME INTO CONTACT WITH ELECTRICAL CONNECTIONS!!!**

7.1 Flex Circuit Pinout

Each BioTac has a 12-lead flexible circuit that exits the device on the dorsal side. This consists of 4 power lines (12V, 5V, 3.3V and GND), 4 SPI lines (CLK, MOSI, MISO, SS), 3 programming lines (/MCLR, PGD, PGC), and one auxiliary line (TP). During normal SPI use the 3.3V power line is not required. A pinout of the flexible circuit is shown in the table below. Pin 1 is marked with a white dot.

Pin number	Function	Description
1	12V	Power (input)
2	GND	Power (input)
3	3.3V	Power (output), NOTE: Do not connect to power supply! This pin just for programming and testing
4	5V	Power (input)
5	/MCLR	Programming pin
6	TP	Test point.
7	PGD	Programming pin
8	MOSI	SPI, Master out slave in
9	MISO	SPI, Master in slave out
10	PGC	Programming pin
11	SS	SPI, Chip select
12	SCLK	SPI, clock

Table 2 – BioTac Flex Circuit Pinout

➤ **It is not advised to develop custom hardware to interface directly with the BioTac flexible circuit. Instead, it is recommended that customers use the supplied BioTac Electrical Adapter Board. If custom electrical components are advised, please heed all advisory notes in this section.**

➤ **Do not supply the BioTac 5V power supply with greater than 5.5V of voltage. This can cause damage to the electrical components, which could make the BioTac unusable.**

7.1.1 Flex Circuit Connector

The BioTac flexible circuit has been designed to mate with the following connector:

Manufacturer	Hirose Electric Co Ltd
Manufacturer Part Number	FH33-12S-0.5SH(10)
Digi-Key Part Number	HFS12CT-ND
Datasheet	http://www.hirose.co.jp/cataloge_hp/ef_58013009.pdf
Family	FFC, FPC (Flat Flexible)
Connectors	Board Mount
Series	FH33
Connector Type	Bottom Contacts
Number of Positions	12
Pitch	0.020" (0.50mm)
FFC, FCB Thickness	0.30mm
Mounting Type	Surface Mount, Right Angle
Termination	Solder
Locking Feature	Flip Lock

Table 3 – Connector J1A Information

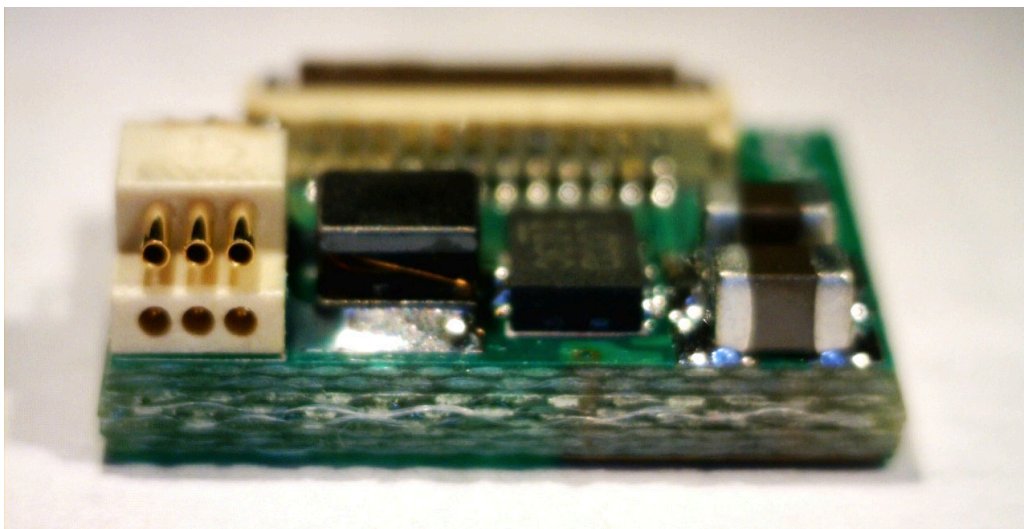
7.1.2 BioTac Electrical Adapter

The BioTac Electrical Adapter is designed to mate with the flex circuit of the BioTac, and a 6-pin connector (Omnetics) that supplies 5V power and ground as well as the 4 SPI communication lines.

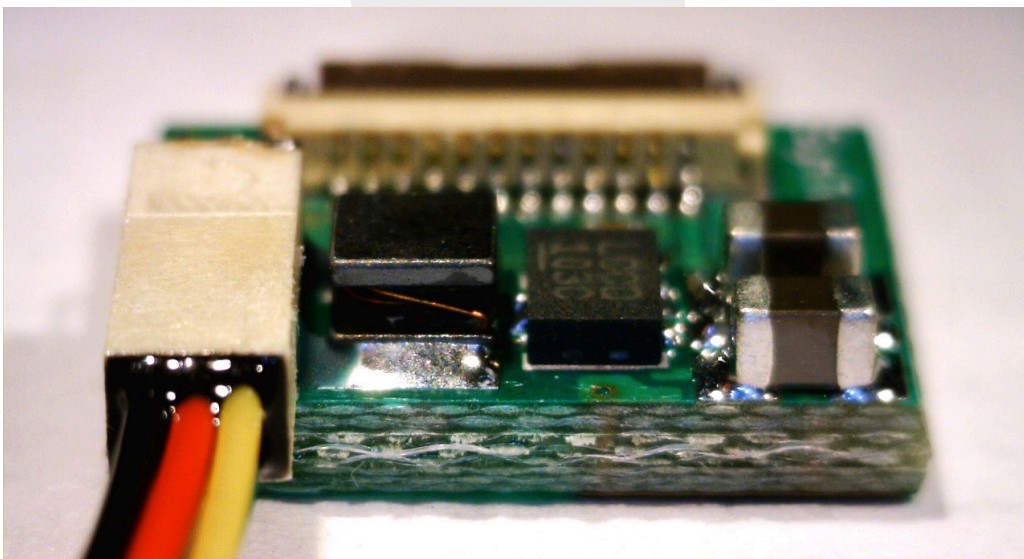
When attaching the flexible circuit, lift up the flap on the J1A connector, then carefully insert the flexible circuit before lowering the flap to hold the flexible circuit in place.

The 6-pin Omnetics connector can be attached to connect the electrical adapter to other hardware such as the Cheetah SPI MultiBioTac board or CAN-BUS Adapter. Pay careful attention to the alignment of these pins.

➤ *Do not supply the BioTac 5V power supply with greater than 5.5V of voltage. This can cause damage to the electrical components, which could make the BioTac unusable.*



GND	5V	SCK
SS	MOSI	MISO



Black (GND)	Red (5V)	Yellow (SCK)
Brown (SS)	Orange (MOSI)	Green (MISO)

Figure 10 – BioTac Electrical Adapter Connections (Versions 2.1-2.3)

The electrical adapter board is designed to mate with the following connector:

Manufacturer	Omnetics Connector Corporation
Manufacturer Part Number	PZN-06-AA
Datasheet	http://www.omnetics.com/polarized-nano/horizontal/
Series	Polarized Nano (PZN)
Number of Positions	6
Pitch	0.025" (0.64mm)
Mounting Type	Surface Mount, Right Angle
Termination	SMT Horizontal, solder

Table 4 – Omnetics Connector Information

7.1.3 Built In 6-pin connector

BioTac versions BT-2P-02.4.0 come with built in electronics that handle the function of the previous electrical adapter board and can be connected to with a 6-pin connector to supply 5V power and SPI communication.

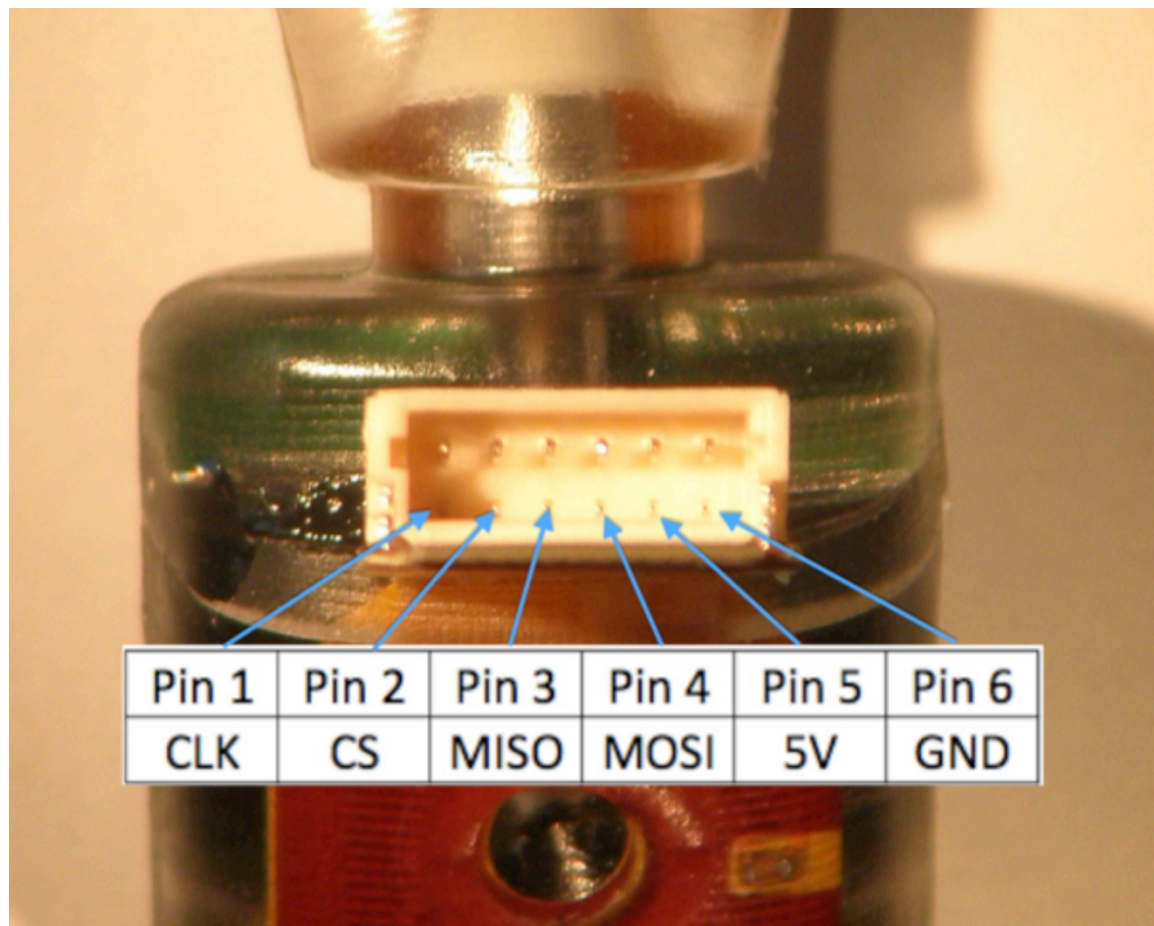


Figure 11 – BioTac 6-Pin Connections (Versions 2.4 and later)

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

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

7.2 Power Requirements

The BioTac requires a 12V and 5V power supply for SPI communication. For optimal sensitivity, the noise of these power supplies should be less than 20mV. As an alternative, if clean power is not available, the BioTac can be supplied with an adapter board that only requires the four SPI lines, 5V power and ground. Power signals are conditioned with this board to provide appropriate output and are designed to work sufficiently with USB power supplies.

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

8 SPI Communication Protocol 2.3 and later

8.1 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 BioTac on the pus simultaneously acquires a 2-byte (12 bit) datum. The master then selects each BioTac 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 collects a preset sequence of data from its sensors for transmission as a buffer when queried by the host.

8.2 SPI Configuration

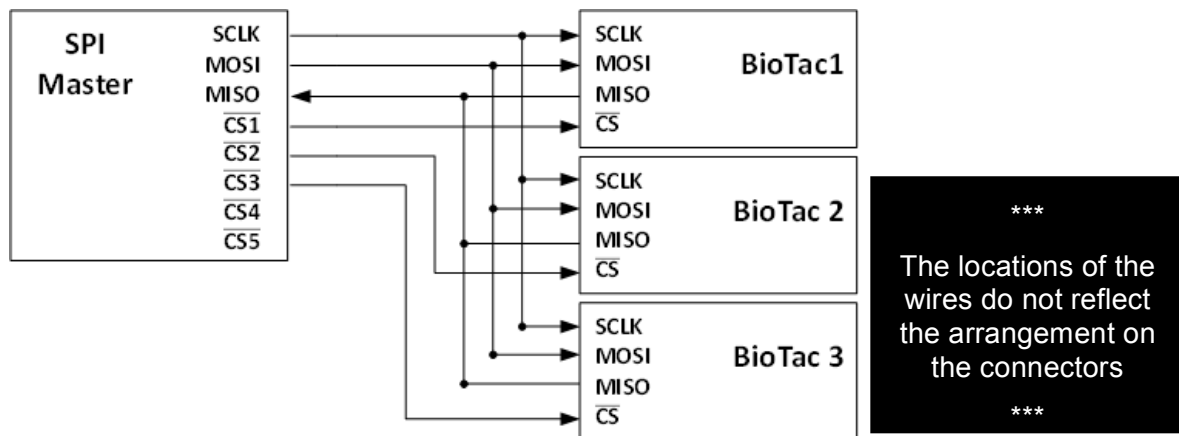


Figure 12 - SPI Connection Overview

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 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

8.3 Command Types

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

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

		First Byte								Second Byte							
	bit#	7	6	5	4	3	2	1	0	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)

NNNN: subset number (0~15)

VVV: variable number (0~7)

P: parity check (odd parity)

X: ignored

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 BioTacs.

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

8.3.1 Sampling command

8.3.1.1 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 BioTacs 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 BioTacs. During this time the CS lines should be disabled.**

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

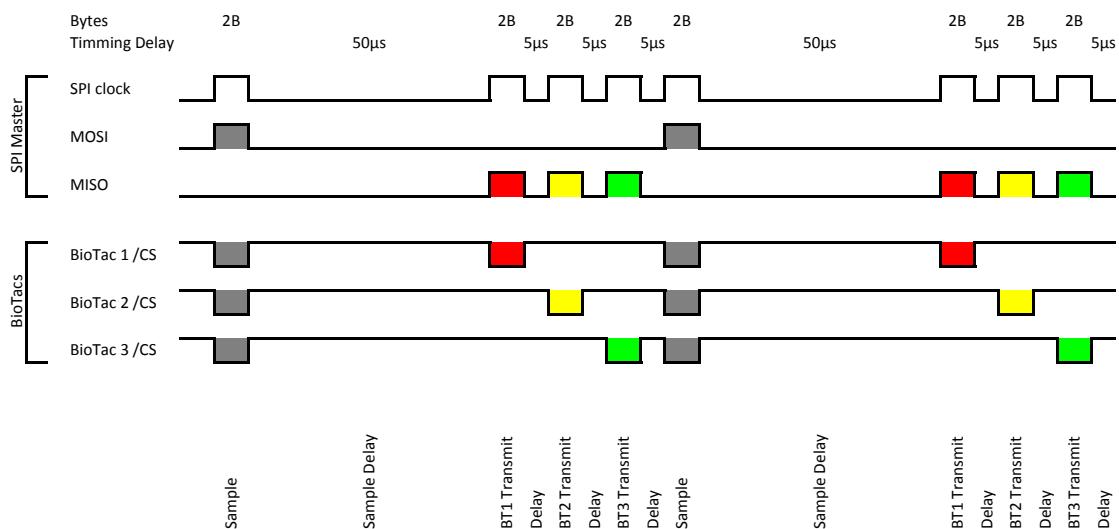


Figure 14 - Recommended Sampling Sequence for 3 BioTacs

8.3.1.2 Detailed Sampling Commands

Description	Index	1 st 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	
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	

Table 7 – Sampling Commands

8.3.1.3 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.

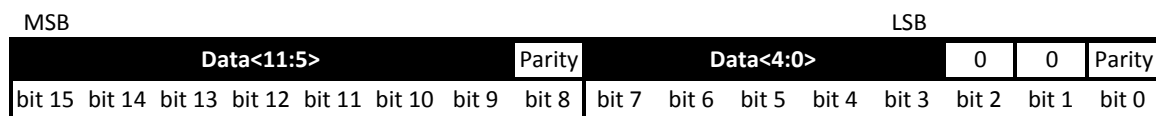


Figure 15 – Sampling Command Response Format

8.3.1.4 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.

8.3.1.5 Error Handling

Sampling Errors	BioTac 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 firmware or unavailable

Table 8 – Sampling Error Responses

8.3.2 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 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. If the data resend command is sent before the BioTac has been sent a sampling command the BioTac will ignore the resend request.

8.3.3 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 responds with 2x bytes.

Group index		Subset name	Function
1	NNNN=0001	Information	BioTac general parameters
6	NNNN=0110	CPU	BioTac 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

8.3.3.1 Error Handling

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

Table 11 - Read/Write Error Codes

9 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.

9.1 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 (44 Samples/frame):

P_{AC} , E1, P_{AC} , E2, P_{AC} , E3, P_{AC} , E4, P_{AC} , E5, P_{AC} , E6, P_{AC} , E7, P_{AC} , E8, P_{AC} , E9, P_{AC} , E10, P_{AC} , E11, P_{AC} , E12, P_{AC} , E13, P_{AC} , E14, P_{AC} , E15, P_{AC} , E16, P_{AC} , E17, P_{AC} , E18, P_{AC} , E19, P_{AC} , P_{DC} , P_{AC} , T_{AC} , P_{AC} , T_{DC}

Bandwidth:

Data: 16 bits/ch/BioTac, 704 bits/frame/BioTac

Communication Overhead: 704 bits/frame

3 BioTacs sampled at 4.4kHz: 281.6 kB/s

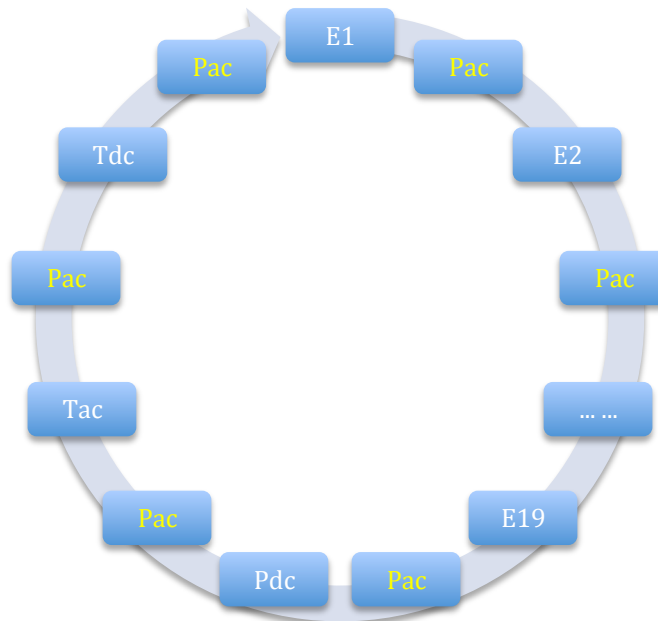


Figure 16 – Recommended Default Sampling Sequence

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

Sensor type	Numbers of sensor	Sampling rate	Signal bandwidth
Electrode	19	100Hz per electrode	50Hz
AC Pressure (P_{AC})	1	2200Hz	1100Hz
DC Pressure (P_{DC})	1	100Hz	50Hz
AC Temperature (T_{AC})	1	100Hz	50Hz
DC Temperature (T_{DC})	1	100Hz	50Hz

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

9.2 Alternate Sampling Sequences

9.2.1 Default with Hall

This sampling sequence is for BioTacs versions 2.3 and later with integrated Hall Sensor. However, the default sampling sequence is recommended if the Hall Sensor will not be used. The recommended sampling rate for this sequence is 4.6kHz.

Sequence (46 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} , P_{DC} , P_{AC} , T_{AC} , P_{AC} , T_{DC} , P_{AC} , Hall

Bandwidth:

Data: 16 bits/ch/BioTac, 736 bits/frame/BioTac

Communication Overhead: 736 bits/frame

3 BioTacs sampled at 4.6kHz: 294.4 kB/s

9.2.2 All Channels (24 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 2.4kHz, 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} , Hall, 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}

Bandwidth:

Data: 16 bits/ch/BioTac, 704 bits/frame/BioTac

Communication Overhead: 704 bits/frame

3 BioTacs sampled at 2.4kHz: 153.6 kB/s

3 BioTacs sampled at 240Hz: 15.3 kB/s

9.2.3 Electrodes Only

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

Sequence (19 Samples/frame):

E₁, E₂, E₃, E₄, E₅, E₆, E₇, E₈, E₉, E₁₀, E₁₁, E₁₂, E₁₃, E₁₄, E₁₅, E₁₆, E₁₇, E₁₈, E₁₉

Bandwidth:

Data: 16 bits/ch/BioTac, 704 bits/frame/BioTac

Communication Overhead: 704 bits/frame

3 BioTacs sampled at 1.9kHz: 121.6 kB/s

Sequence:

9.2.4 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, 704 bits/frame/BioTac

Communication Overhead: 704 bits/frame

3 BioTacs sampled at 4.4kHz: 281.6 kb/s

9.2.5 Single Channel and Other Sampling Sequences

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

Appendix A. BioTac SPI protocol V1.1

In the legacy V1.1 SPI communication protocol a BioTac samples data internally and transmits buffered data upon request in the following frame format. The size of data buffer inside BioTac is 30 frames and the buffer is a circular buffer; BioTac can keep up to 300ms of data, after 300ms if the data hasn't been sent out to master, the oldest frame of data will be over written new frame of data. The same frame structure is maintained during the entire communication from BioTac to FTDI chip and to PC.

There are three kinds of frame structure:

First data frame	New data transmission, only occurs once after BioTac is power on or is been reset
Data frame	New data transmission
Null data frame	If master acquires more data frame after all new data has been sent completely, BioTac starts to send out null data frame per single SPI communication. The null data frame will ve removed when PC is processing the data before displaying and storing the data.

A data frame contains 10ms information

A data frame is assembled by 92 bytes, including 1 byte of header, 44 data words (88 bytes), 2 bytes of synchronization number, and 1 byte of footer.

44 data words are composed by:

19 electrode data words

22 Pac data words

1 Pdc data word

1 Tac data word

1 Tdc data word

The one byte footers are all the same for all kinds of frames and each value is 0xEA (decimal: 234)

The one-byte header is 0x00 for the overall first frame and is 0xEA for all other frames.

First data frame

This frame only occurs once after BioTac is powered on or is been reset.

Byte Number	Length	Description	Value
Byte 1	1 byte	Header, read as 0x00 (Decimal: 0)	0
Byte 2~3	2 bytes	Data: Electrode #1, read as 0x0DDD	0~4095
Byte 4~5	2 bytes	Data: Electrode #2, read as 0x0DDD	0~4095
Byte 6~7	2 bytes	Data: Electrode #3, read as 0x0DDD	0~4095
Byte 8~9	2 bytes	Data: Electrode #4, read as 0x0DDD	0~4095
Byte 10~11	2 bytes	Data: Electrode #5, read as 0x0DDD	0~4095
Byte 12~13	2 bytes	Data: Electrode #6, read as 0x0DDD	0~4095
Byte 14~15	2 bytes	Data: Electrode #7, read as 0x0DDD	0~4095
Byte 16~17	2 bytes	Data: Electrode #8, read as 0x0DDD	0~4095
Byte 18~19	2 bytes	Data: Electrode #9, read as 0x0DDD	0~4095
Byte 20~21	2 bytes	Data: Electrode #10, read as 0x0DDD	0~4095
Byte 22~23	2 bytes	Data: Electrode #11, read as 0x0DDD	0~4095
Byte 24~25	2 bytes	Data: Electrode #12, read as 0x0DDD	0~4095
Byte 26~27	2 bytes	Data: Electrode #13, read as 0x0DDD	0~4095
Byte 28~29	2 bytes	Data: Electrode #14, read as 0x0DDD	0~4095
Byte 30~31	2 bytes	Data: Electrode #15, read as 0x0DDD	0~4095
Byte 32~33	2 bytes	Data: Electrode #16, read as 0x0DDD	0~4095
Byte 34~35	2 bytes	Data: Electrode #17, read as 0x0DDD	0~4095
Byte 36~37	2 bytes	Data: Electrode #18, read as 0x0DDD	0~4095
Byte 38~39	2 bytes	Data: Electrode #19, read as 0x0DDD	0~4095
Byte 40~83	2 bytes * 22 ¹	Data: AC Pressure (P_{AC}), read as 0x0DDD	0~4095
Byte 84~85	2 bytes	Data: DC Pressure (P_{DC}), read as 0x0DDD	0~4095
Byte 86~87	2 bytes	Data: AC Temp. (T_{AC}), read as 0x0DDD	0~4095
Byte 88~89	2 bytes	Data: DC Temp. (T_{DC}), read as 0x0DDD	0~4095
Byte 90~91	2 bytes	Synchronization number, read as 0xD4D4	0~65535
Byte 92	1 byte	Footer, read as 0xEA (Decimal: 234)	234

D: four (4) bits of data

¹ The multiplexed analog data are digitized every 227 μ s by the internal 12-bit ADC in the PIC (4.4 kHz sampling rate). Measurements of the vibrations P_{AC} at 2.2 kSamples/s are interleaved with the electrode impedances (Electrodes #n) and other sensor signals. Thus, the frame of sampling consists of 44 data words representing P_{AC} , Electrodes #1, P_{AC} , Electrodes #2, ..., P_{AC} , Electrodes #19, P_{AC} , P_{DC} , P_{AC} , T_{AC} , P_{AC} , and T_{DC} .

Data frames

Byte Number	Length	Description	Value
Byte 1	1 byte	Header, read as 0xEA (Decimal: 234)	234
Byte 2~3	2 bytes	Data: Electrode #1, read as 0x0DDD	0~4095
Byte 4~5	2 bytes	Data: Electrode #2, read as 0x0DDD	0~4095
Byte 6~7	2 bytes	Data: Electrode #3, read as 0x0DDD	0~4095
Byte 8~9	2 bytes	Data: Electrode #4, read as 0x0DDD	0~4095
Byte 10~11	2 bytes	Data: Electrode #5, read as 0x0DDD	0~4095
Byte 12~13	2 bytes	Data: Electrode #6, read as 0x0DDD	0~4095
Byte 14~15	2 bytes	Data: Electrode #7, read as 0x0DDD	0~4095
Byte 16~17	2 bytes	Data: Electrode #8, read as 0x0DDD	0~4095
Byte 18~19	2 bytes	Data: Electrode #9, read as 0x0DDD	0~4095
Byte 20~21	2 bytes	Data: Electrode #10, read as 0x0DDD	0~4095
Byte 22~23	2 bytes	Data: Electrode #11, read as 0x0DDD	0~4095
Byte 24~25	2 bytes	Data: Electrode #12, read as 0x0DDD	0~4095
Byte 26~27	2 bytes	Data: Electrode #13, read as 0x0DDD	0~4095
Byte 28~29	2 bytes	Data: Electrode #14, read as 0x0DDD	0~4095
Byte 30~31	2 bytes	Data: Electrode #15, read as 0x0DDD	0~4095
Byte 32~33	2 bytes	Data: Electrode #16, read as 0x0DDD	0~4095
Byte 34~35	2 bytes	Data: Electrode #17, read as 0x0DDD	0~4095
Byte 36~37	2 bytes	Data: Electrode #18, read as 0x0DDD	0~4095
Byte 38~39	2 bytes	Data: Electrode #19, read as 0x0DDD	0~4095
Byte 40~83	2 bytes * 22	Data: AC Pressure (P_{AC}), read as 0x0DDD	0~4095
Byte 84~85	2 bytes	Data: DC Pressure (P_{DC}), read as 0x0DDD	0~4095
Byte 86~87	2 bytes	Data: AC Temp. (T_{AC}), read as 0x0DDD	0~4095
Byte 88~89	2 bytes	Data: DC Temp. (T_{DC}), read as 0x0DDD	0~4095
Byte 90~91	2 bytes	Synchronization number, read as 0xDDDD	0~65535
Byte 92	1 byte	Footer, read as 0xEA (Decimal: 234)	234

D: four (4) bits of data

Total: 92 bytes/ frame

Sampling at 4.4kHz (100 frames/ s): 9.2kBytes/ s = 73.6kbps

Null data Frame

Byte Number	Length	Description	Value
Byte 1	1 byte	Header, read as 0xEA (Decimal: 234)	234
Byte 2~3	2 bytes	Null data, read as 0xFFFF	65535
Byte 4~5	2 bytes	Null data, read as 0xFFFF	65535
Byte 6~7	2 bytes	Null data, read as 0xFFFF	65535
Byte 8~9	2 bytes	Null data, read as 0xFFFF	65535
Byte 10~11	2 bytes	Null data, read as 0xFFFF	65535
Byte 12~13	2 bytes	Null data, read as 0xFFFF	65535
Byte 14~15	2 bytes	Null data, read as 0xFFFF	65535
Byte 16~17	2 bytes	Null data, read as 0xFFFF	65535
Byte 18~19	2 bytes	Null data, read as 0xFFFF	65535
Byte 20~21	2 bytes	Null data, read as 0xFFFF	65535
Byte 22~23	2 bytes	Null data, read as 0xFFFF	65535
Byte 24~25	2 bytes	Null data, read as 0xFFFF	65535
Byte 26~27	2 bytes	Null data, read as 0xFFFF	65535
Byte 28~29	2 bytes	Null data, read as 0xFFFF	65535
Byte 30~31	2 bytes	Null data, read as 0xFFFF	65535
Byte 32~33	2 bytes	Null data, read as 0xFFFF	65535
Byte 34~35	2 bytes	Null data, read as 0xFFFF	65535
Byte 36~37	2 bytes	Null data, read as 0xFFFF	65535
Byte 38~39	2 bytes	Null data, read as 0xFFFF	65535
Byte 40~83	2 bytes * 22	Null data, read as 0xFFFF	65535
Byte 84~85	2 bytes	Null data, read as 0xFFFF	65535
Byte 86~87	2 bytes	Null data, read as 0xFFFF	65535
Byte 88~89	2 bytes	Null data, read as 0xFFFF	65535
Byte 90~91	2 bytes	Null data, read as 0xFFFF	65535
Byte 92	1 byte	Footer, read as 0xEA (Decimal: 234)	234

The null frame is sent when there is no available buffer data to transmit.

Appendix B. Materials

Part	Material	Weight	Remarks
Core	Epoxy Resin	7 g	Durable
Skin	Silicone Elastomer	2 g	Good Wear Properties
Nail	ABS-Like Plastic	0.5 g	
Screws	Nylon	-	
Fluid	1M Sodium Bromide dissolved in PEG-200/Water mixture	0.3 - 0.5 g	Nontoxic

Appendix C. Legal

BioTac® Warranty

1. The customer should check goods immediately after receipt for possible problems. Defective, damaged, or missing goods (hereafter: Defective Goods) are to be reported to SynTouch in writing within 5 working days. If a customer elects to not notify SynTouch about Defective Goods, or if a customer uses Defective Goods they waive all rights under this warranty.
2. Repairs or replacements of Defective Goods occur at the discretion of SynTouch. Discretion is not waived under any circumstances, including prior attempts to repair or replace Defective Goods.
3. Upon SynTouch acknowledging notice from a customer about Defective Goods, SynTouch has 90 days in which they may elect to resolve the issue by either: A) repairing or replacing the Defective Goods, or B) crediting the customer for the value of the Defective Goods.
4. The customer must provide access by shipping Defective Goods and all documentation about them to SynTouch. SynTouch may elect to send a representative to the customer, in which case the customer must provide access by enabling the representative to perform testing, repairs and replacements to Defective Goods. If a customer refuses to provide access they waive all rights under this warranty.
5. After receiving an acknowledgement about Defective Goods from SynTouch, if 90 days elapse without resolution of the issue, a customer has the right to a credit for the Defective Goods. To receive their credit a customer must return the Defective Goods along with a written description of the issues encountered, and a written description of efforts to resolve the issue.
6. No warranty claims will be accepted if it is determined that the cause was due to normal wear and tear, or damage caused by faulty or negligent maintenance, shipping with packaging other than the original packaging, modification, or use outside the specifications listed. Nor will warranty claims be accepted if it is determined that Damaged Goods have insignificantly reduced value or utility.
7. SynTouch is not liable for consequential or incidental damages during customer attempted repairs or any cost or expense of providing substitute equipment during periods of malfunction or pending repairs.
8. If any part of this Warranty is deemed unenforceable, all remaining parts remain in full effect.

Customer Service and Health and Safety Acknowledgements

9.2.6 PURPOSE

This document is intended as a written confirmation of the terms and conditions under which SynTouch LLC will provide Customer Service for our products to our customers. This agreement defines the services SynTouch LLC will provide to customer in conjunction with license of or purchase of SynTouch LLC products as well as Customer's notice and acknowledgement of any potential hazards, restrictions or limitations with regards to SynTouch LLC's products.

9.2.7 CUSTOMER SUPPORT AND SERVICE

Under this agreement, Customer seeks to receive, and SynTouch LLC agrees to provide customer service, in some cases for a fee, for Customer's purchased SynTouch LLC products.

Customer agrees and understands that some service options may be limited to normal business hours and days of the week. Customer agrees and understands that this agreement only covers their SynTouch LLC products and not any third-party product or modification. Customer understands that if it is determined that support and service are being used to support a third-party product or any modification or alteration to a SynTouch LLC product not authorized or approved in SynTouch LLC documentation, Customer may be charged and Customer agrees to pay for such service, at SynTouch LLC's sole discretion .

9.2.8 CUSTOMER FEEDBACK

Under this agreement, SynTouch LLC seeks to receive, and Customer agrees to provide, certain levels of customer feedback regarding Customer's purchased SynTouch LLC products.

9.2.9 TAXES AND TARIFFS

Customer shall be responsible for payment and satisfaction of all taxes applicable and/or tariffs, costs of import or costs of export related to purchasing, shipping or transporting materials for providing services under this agreement.

9.2.10 SAFETY AND HEALTH ACKNOWLEDGEMENTS

SynTouch LLC is concerned for your safety has communicated to Customer, and Customer understands, the following potential safety and health issues associated with SynTouch LLC Products:

1. **SHARPS WARNING** Many SynTouch LLC products use a standard insulin syringe with a 25 gauge needle in the operation of said products. Customer acknowledges

- a. that he or she has consulted with a SynTouch sales, marketing or development professional regarding whether his or her purchase uses such needles and therefore whether proper operation of that product involves a sharps hazard;
 - b. that Customer is wholly responsible for communicating such a hazard to any parties using his or her SynTouch LLC product, whether or not such use is under his or her supervision; and
 - c. that Customer is wholly responsible for proper storage and disposal of sharps and biomedical waste in conjunction with operation of his or her SynTouch LLC product and in compliance with applicable law.
2. **CHEMICAL WARNING** Many SynTouch LLC products use certain chemicals in their operations. Customer acknowledges:
- a. that Customer has been provided with the Material Safety Data Sheets (MSDS) for all SynTouch LLC products he or she has purchased, either with said purchase or through a request to a SynTouch LLC sales, marketing or development professional;
 - b. that Customer has read all MSDS for chemicals used in the appropriate SynTouch LLC products and understands the potential safety and health risks associated with such chemicals;
 - c. that Customer is wholly responsible for communicating such a safety and health risks to any parties using his or her SynTouch LLC product, whether or not such use is under his or her supervision;
 - d. that Customer will provide copies of the MSDS for chemicals used in the appropriate SynTouch LLC products to any parties who request them in conjunction with the Customer's SynTouch LLC products; and
 - e. that Customer is wholly responsible for proper storage and disposal of chemicals in conjunction with operation of his or her SynTouch LLC product and in compliance with applicable law.

Indemnification

Customer shall indemnify and hold harmless SynTouch LLC for all legal claims resulting from Customer's failure to reasonably communicate information in this agreement to parties using Customer's SynTouch LLC products, reasonably communicate information listed under above section Health & Safety Acknowledgements to parties using Customer's SynTouch LLC products or failure to take steps to account for responsibilities listed under above section Health & Safety Acknowledgements. SynTouch LLC shall indemnify and hold harmless Customer for all legal claims resulting from failure to respond in a reasonable time to requests made by Customer under above section Health & Safety Acknowledgements or for failure to provide full information requested in response to requests made by Customer under above section Health & Safety Acknowledgements. Procedure. In case any Claim is at any time brought against Syntouch LLC or Customer, the party obligated to provide such indemnification (the "*Indemnifying Party*") will defend such Claim, at the sole expense of the Indemnifying Party, using counsel selected by the Indemnifying Party but subject to the Indemnified Party's reasonable approval. If the Indemnifying Party fails to take timely action to defend such a Claim after having received written notice from the Indemnified Party of such failure, the Indemnified Party may defend such a Claim at the Indemnifying Party's expense. The Indemnifying Party will keep the Indemnified Party fully advised with respect to such Claims and the progress of any suits, and the Indemnified Party shall have the right to participate, at the Indemnified Party's expense, in any suit instituted against it and to select attorneys to defend it, which attorneys will be independent of any attorneys chosen by the Indemnifying Party relating to such Claim or related claim. The Indemnifying Party will not settle, compromise or otherwise enter into any agreement regarding the disposition of any Claim against the Indemnified Party without the prior written consent and approval of the Indemnified Party which shall not be unreasonable withheld.

GOVERNING LAW

This Agreement and the performance hereunder shall be governed by the laws of the State of California without regard to conflicts of law rules. The Parties agree on behalf of themselves and any person claiming by or through them that the sole and exclusive jurisdiction and venue for any litigation which may arise hereunder shall be an appropriate federal or state court located in the County of Los Angeles and the Parties hereby consent to the personal jurisdiction of such courts.

DISCLAIMERS AND LIMITATIONS

DISCLAIMER OF WARRANTIES. EXCEPT AS OTHERWISE PROVIDED IN THIS AGREEMENT, NEITHER PARTY MAKES, AND EACH PARTY HEREBY WAIVES AND DISCLAIMS, ANY REPRESENTATIONS OR WARRANTIES

REGARDING THIS AGREEMENT OR THE TRANSACTIONS CONTEMPLATED HEREBY, INCLUDING ANY IMPLIED WARRANTIES OF MERCHANTABILITY, FITNESS FOR A PARTICULAR PURPOSE OR NON-INFRINGEMENT OR IMPLIED WARRANTIES ARISING OUT OF COURSE OF DEALING, COURSE OF PERFORMANCE OR USAGE OF TRADE.

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