Sentimo Wireless Biosensor, 16 Channel, 9-axis IMU

1 Features

- **16** Wireless EMG Probes
- **4** Simultaneous sampling inputs on 4 Amplifier Units (APU)
- **150hz 9-Axis** IMU on each APU
- Real Time Raw Data & 3D IMU Visualization
- Long Range support mode:
  - **150ft/50m** Single APU
  - **65ft/20m** 4 APU network
- Extreme High Sample Rate
  - **500 Hz** to **16 Khz** available in device settings
- Hardware Low-Pass Filtering
- Software Filtering
- Small formfactor APU
  - 21.50mm x 31.5mm x 11.5mm
  - 9.5g weight
- **8 Hour** Battery Life
- Bluetooth Low Energy 5.4 SOC
  - Software Packet Synchronization
  - Lost Packet Recovery
  - High Throughput Network support
- Internalized signal optimization
  - **94 dB** Common Mode Rejection Ratio
  - **88 dB** Power Supply Rejection Ratio
  - **79 dB SNR** at **4 Khz**
- Ungrounded Support
  - Low Drift Internal Reference Voltage
  - Patient Ground Lead Support
- **16 & 24 Bit** Configurable Resolution EMG

2 Applications

- Bioengineering
- Mechatronics
- Biorobotics
- Neurology

3 Description

The Sentimo Wireless Biosensor is a 16-channel EMG system, with 4 Portable Amplifier Units (APU)s in a network. Each APU is capable of 4-Channel, 16khz, 24-bit, simultaneous sampling; offering wide dynamic range, and automatically applying unused specifications to improve signal quality when device needs are reduced.

Individual APU's can be configured to optimize for Higher Sample Rates, Higher Signal to Noise Ratios, Better Dynamic Ranges, or Improved Power Efficiency: making the Sentimo System ideal for a wide variety of EMG systems without having to calibrate Phase/Offset/Gain/Filtering Optimization. (Manual device control and optimization guidelines are provided for interested parties in this document)

The Sentimo System is offered with both pinch and standard DIN terminated leads, along with varying lengths and 4, 3, 2, or 1 lead support.

The Sentimo System also offers an optional additional Trigger Unit with Single-Channel BNC input Isolated at up to +/-20V, and an echo output at +/- 5V. The Trigger Unit reports TTL timestamps over USB and translates them to flags in the UI.

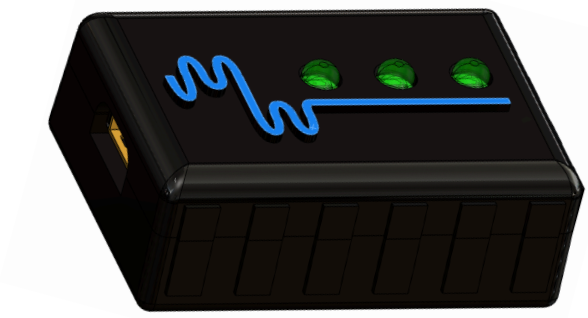

Figure 1.0: Sentimo Amplifier Unit (APU)

An **IMPORTANT NOTICE** in this datasheet addresses contraindications regarding product use in Critical Care, or on At-Risk individuals. Unsupported device usage which may result in **personal injury** or **death**.

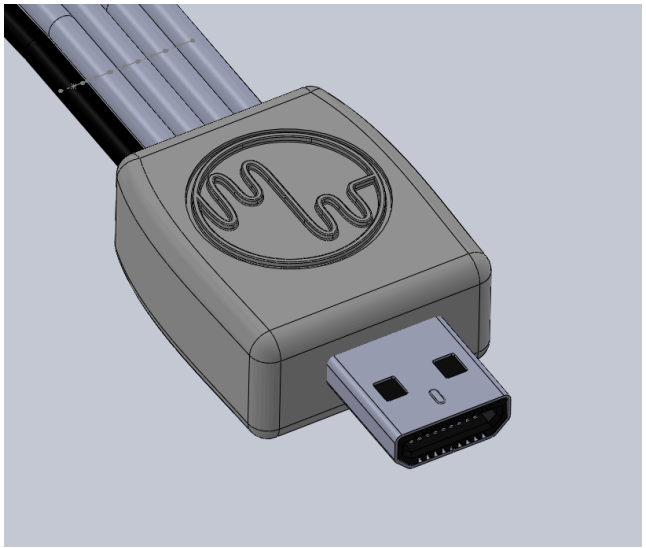

Figure 1.1: Sentimo Miniaturized Cable Header

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4.1 Contraindications

⚠ The Sentimo 16 lead Wireless IMU is a **RESEARCH ONLY System**, and should **NOT be used** for the standalone monitoring or care of individuals **at risk** or in **critical care**.

DO NOT USE on individuals with ANY implanted electronic devices. Examples of incompatible devices include: pace-makers, implanted cardiac stimulators, infusion pumps, or Oxygenators.
DO NOT USE on irritated skin or open wounds.
DO NOT USE in critical care applications.
CEASE USAGE should you become aware of **any** allergic response at electrode sites.

4.2 Technical Service and Support

For information and support, please visit our website:
impulsewellness.org
Email:
info@impulsewellness.org

4.3 Device Information

- Please keep the device **dry**. The external carrying case is water resistant, but liquid ingress may compromise safety and functionality of the device.
- **DO NOT connect to existing hdmi or micro hdmi devices**. The Sentino does NOT follow the micro-hdmi standard. Non-Approved devices are liable to **cause damage** to the Sentino Monitoring system.
- Connecting to high-frequency surgical equipment while using the Sentino EMG system may cause **burns** at the site of EMG contact.
- IW only guarantees the safety, and performance of the Sentino EMG system if assembly, modification, and repairs are carried out by **authorized technicians**, and the equipment is used in accordance with instructions herein.
- Device contains a Lithium-Polymer battery:
  - **DO NOT crush, burn, freeze, or mishandle the device**.
  - **Recharge ONLY USING the provided supplies and chargers.**
  - The Sentino EMG system should be stored and operated between **5 and 45 degrees Celsius.**
  - Device storage or operation outside of this range **may compromise functionality, safety, and integrity** of the device
- Replacement charging and power supply equipment can be found on ImpulseWellness.org
- Report any serious injury or incident with the device to info@impulsewellness.org
- This Integrated Circuit device can be damaged by Electrostatic Discharge.

Device operation near strong electrostatic, magnetic, or radioactive fields is discouraged
ESD damage can range from subtle performance degradation to complete device failure.

4.4 PC Minimum Specs

As the Sentimo system uses the latest in Bluetooth Technology, it is recommended to **use the included Bluetooth 5.4 Dongle**. Replacement Bluetooth 5.4 dongles can be found on impulsewellness.org

4.4.1 MAC operating system requirements

OS X 10.7.0 or later
Processor: 2.0GHz+ 64-bit
Memory: 4 GB RAM

Hard Drive: 4GB available space
Bluetooth 5.4 or later recommended

4.4.2 Windows PC Operating System Minimum Requirements

OS : Windows 10 x64, 11
Processor: Intel Core2 Duo E4500 (2 * 2200)
Memory: 4 GB RAM
Storage: 4GB available space
Bluetooth 5.4 or later recommended

4.4.3 Linux PC operating system requirements

Ubuntu 14.04, Mint 17
Processor: 2.0GHz+ 64-bit
Memory: 4 GB RAM
Hard Drive: 4GB available space
Bluetooth 5.4 or later recommended

5.0 Sentimo Amplifier Unit Advanced Features

The Sentimo system has similar user-interactions to existing wireless biofeedback systems, but replaces internal instrumentation amplifiers with advanced analog to digital converters to gather reliable high quality EMG data in a smaller package than alternatives.

The system achieves high EMG clarity by utilizing the following methodologies:

- Over Sampling
- 3.2 Mhz Low Pass Filtering *(Always on)*
- SINC Filtering & SINC^3 Filtering which supports:
    - DC Blocking
    - High Pass Filtering *(Configurable)*
    - 50 or 60 Hz Filtering *(Configurable)*

The system achieves high 9-axis IMU clarity by utilizing the following methodologies:

- Internalized 9-axis IMU data calibration
- Linear Acceleration & Orientation Sample Rate Control
- Timestamp-Attached Sensor Reports

The system achieves consistent and high quality networking using the following methodologies:

- Bluetooth 5.4 SOC
- Proprietary lossless compression

5.1 Advanced EMG Hardware Capabilities

The Sentimo system utilizes a four-channel simultaneous-sampling delta-sigma ADC to offer high frequency muscle measurement across multiple sites.The Sentimo system relies on a programmable gain amplifier instead of a medical instrumentation amplifier, and functions at a much higher internal frequency than what is reported to the user: the system aims to produce an overabundance of samples, and apply advanced filtering and over-sampling of the information in real time to produce superior data to traditional EMG systems at a miniaturized form factor. This enables the Sentimo system to offer skilled technicians access to previously unheard of data rates, and their first opportunity to optimize the data processing methodologies used in their research without weeks of development effort.

5.1.1 Low Pass Filtering

A Low-Pass filter is placed on all input channels with a cutoff frequency of 3.2Mhz. This filter cannot be disabled, as typical EMG does not value signals greater than 1 kHz, and bioimpedance measurements have no benefit from exceeding 1Mhz. *(The Sentimo system does not currently support the broadcasting of bioimpedance information, please contact us if you require bioimpedance support.)*

5.1.2 DC Blocking/High Pass Filtering

An optional high-pass filter to eliminate any systematic offset or low frequency noise is available in the user interface. When experienced as a waveform, low frequency noise looks like the center point of the waveform slowly shifting up and down. This represents the slow fluctuation of electrical potential that happens naturally completely separate from EMG.
The functionality of the high-pass filter is performed as a transfer function in the Amplifier Unit's software. Accordingly, the Sentimo system provides presets, and allows a high degree of tuning for the High pass filtering when paired with the *EMGenius* software. The topology of the High Pass Filter may be found on Figure 5.1. The optimization of the High pass filter may be found in **Figure 5.6** under "**-3db Corner**"

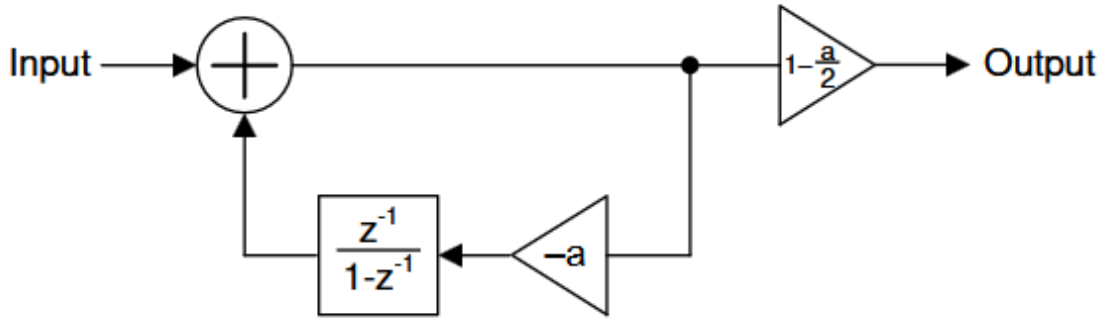

Figure 5.1: Embedded DC-Blocking Topology

5.1.3 SINC Filtering & SINC^3 Filtering

The Sentimo system has the capability to automatically select between parallel SINC and higher order SINC^3 filtering innately in hardware. The system will automatically select whether to use a SINC or a SINC^3 according to whether the higher order filter is supported at a selected user-setting. The differences between the SINC and SINC^3 filter are as follows:

- **Frequency Response:**
  The SINC^3 filter will have a steeper roll-off in the frequency domain compared to a basic SINC filter, providing a better separation between the desired pass-band signals, and the undesired and attenuated stop-band signal frequencies.
- **Notch Characteristics:**
  While all SINC filters create notches at integer occurrences of the output data rate, higher order filters (like SINC^3 filters) produce wider notches with greater attenuation than lower-order filters (SINC filter)
- **Settling Time:**
  After a fundamental change in input (Ex: A lead-off event, or a change in device-settings), the SINC^3 filter requires three conversion cycles to fully settle after a change in the input signal or configuration. That is to say: The SINC filter will come online and stabilize faster than the SINC^3 filter. The Sentimo system does account for this, and only switches into SINC^3 mode when aggregate quantities of data have been measured after power-on and lead connection.
- **Noise Performance:**
  Higher order SINC filters generally provide better noise rejection, particularly at high output data rates. The extreme high input data rate input of the Sentimo system exists as the justification for the unique SINC-filtering capabilities implemented.

The following Equation calculates the z-domain transfer function for the SINC^3 filter where Over Sample Rate is 1024 or lower:

$$\left|H(z)\right| = \left|\frac{1 - Z^{-N}}{N\left(1 - Z^{-1}\right)}\right|^{3}$$

Figure 5.2: Digital Filter Characteristic

The following Equation calculates the transfer function of a SINC^3 filter in terms of the continuous-time parameter ***f:***

$$H(f)\,| = \left|\frac{\sin\left[\frac{N\pi f}{f_{MOD}}\right]}{N \times \sin\left[\frac{\pi f}{f_{MOD}}\right]}\right|^{3}$$

Figure 5.3: Continuous Time Parameterized SINC^3 Filter Transfer Function

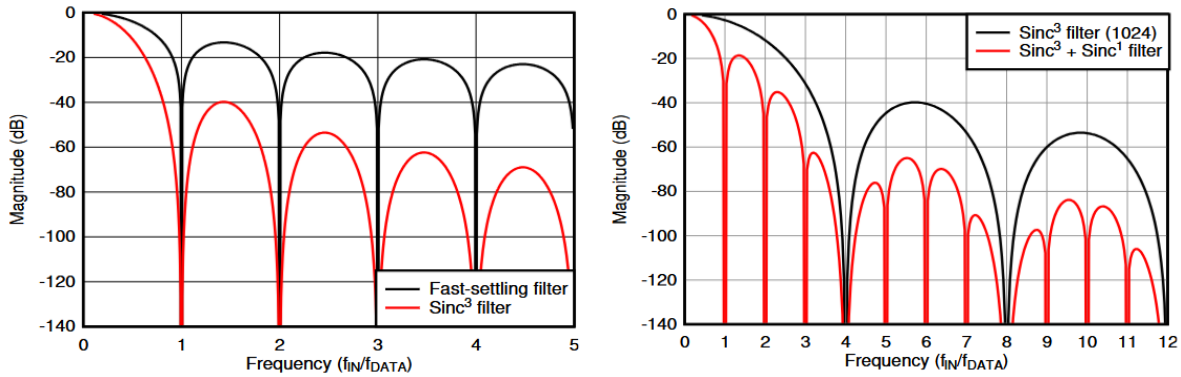

Figure 5.4: SINC/SINC^3 Digital Filter Response
Figure 5.5: Digital Filter response for Over Sample Rate of 1024 & 4096

5.1.4 50 Hz and 60 Hz Filtering

The on-board filtering does not include a dedicated 50/60 hz filter. The Sentimo system instead offers the user the capability to tune their SINC filter into a high quality band-gap filter using the following table which leverages the deep troughs present in SINC filters to align them with harmonic noise at 50 or 60hz:

DC BLOCK	-3dB Corner	PASS-BAND ATTENUATION		SETTLING TIME (SAMPLES)	
		50 Hz	60 Hz	SETTLED >99%	FULLY SETTLED
OFF	DC blockfilter disabled				
4	181 Hz	11.5 dB	10.1 dB	17	88
8	84.8 Hz	5.89 dB	4.77 dB	36	187
16	41.1 Hz	2.24 dB	1.67 dB	72	387
32	20.2 Hz	657 mdB	466 mdB	146	786
64	10.0 Hz	171 mdB	119 mdB	293	1585
128	4.99 Hz	43.1 mdB	29.9 mdB	588	3182
256	2.49 Hz	10.8 mdB	7.47 mdB	1178	6376
512	1.24 Hz	2.69 mdB	1.87 mdB	2357	12764
1024	622 mHz	671 udB	466 udB	4714	25540
2048	311 mHz	168 udB	116 udB	9430	51093
4096	155 mHz	41.9 udB	29.1 udB	18861	102202
8192	77.7 mHz	10.5 udB	7.27 udB	37724	204447
16384	38.9 mHz	2.63 udB	1.82 udB	75450	409156
32768	19.4 mHz	655 ndB	455 ndB	150901	820188
65536	9.70 mHz	164 ndB	114 ndB	301803	1627730

Figure 5.6: Advanced APU Filtering Characteristics

DC BLOCK in **Figure 5.6** represents the Coefficient **a^-1** value expressed in **Figure 5.1**. This Coefficient may be found in the *EMGenius* Software in EMG → Advanced Settings → DC Blocking cap

Disabling the **DC BLOCK** in the *EMGenius* software suite will disable High-Pass Filtering and the accompanying 50/60Hz Band-Gap Filtering Implementation.

5.1.5 Over Sampling

Internally, the Sentimo system runs at 64 kHz, with a moderate degree of inaccuracy. It is impossible, at current technology level (Bluetooth 5.4), to send 64 kHz 16 times on the same Bluetooth network. However, when many Samples are averaged together, the random noise attenuates massively, and the EMG signal becomes clear.

Up to **16,384 samples may be combined into each sample** to move from a 5.58 uVrms of noise, to just 0.42 uVrms of noise. This effect is strong enough that by sampling internally at 64 kHz (An 8Mhz master Clock produces this), **the Sentimo system is capable of outputting 4 Khz of EMG data at 128x gain, and a 79 db Signal to Noise Ratio.** And SNR only improves as the required data rate out of the Sentimo system is lowered. The table below can be used to comprehend the positive effects of Over Sampling.

			Dynamic Range (mV) / Gain / Max Noise (µVrms)							
			1200	600	300	150	75	37.5	18.75	9.375
Master Clock	DATA RATE	Over Sample Rate	1x	2x	4x	8x	16x	32x	64x	128x
8.192Mhz	250hz	16384	1.90	1.69	1.56	0.95	0.64	0.42	0.42	0.42
8.192Mhz	500hz	8192	2.39	2.13	2.13	1.29	0.86	0.57	0.57	0.57
8.192Mhz	1khz	4096	3.38	2.99	2.88	1.74	1.17	0.77	0.77	0.77
8.192Mhz	2khz	2048	4.25	3.91	3.79	2.27	1.52	1.00	1.00	1.00
8.192Mhz	4khz	1024	5.35	4.68	4.52	2.70	1.82	1.20	1.20	1.20
8.192Mhz	8khz	512	7.56	6.62	6.37	3.82	2.55	1.69	1.69	1.69
8.192Mhz	16khz	256	10.68	9.56	9.09	5.42	3.63	2.39	2.39	2.40
8.192Mhz	32khz	128	21.31	15.26	13.52	7.89	5.21	3.41	3.42	3.42
8.192Mhz	64khz	64	75.34	41.63	26.84	14.59	8.90	5.57	5.58	5.58

Figure 5.7: Over Sampling Maximum Noise (uVrms)

For more information about how to configure your Sentimo System, see **Section 11.0: Sentimo Quickstart Guide**

5.2 Advanced 9-Axis IMU Capabilities

The advanced IMU features in the Sentimo system are kept much simpler than EMG info. The Sentimo system relies on a standard self-calibrating low-latency inertial movement unit with an included Gyroscope, Magnetometer, and Accelerometer. The Calibration methodology of the in-built IMU is not accessible outside of the selected chipset, and thus cannot be exposed to EMGenius software users. Only the frequency of data transmission and the form in which you view the information are accessible in the EMGenius software.

5.2.1 Internalized 9-axis IMU data Calibration

The Sentmo system will only broadcast calibrated intelligent IMU data in real time. However, data calibration is done relative to some real world comprehension of where the system is facing. For your comprehension of the Sentimo system, a mapping of the APU onto a standard X, Y, and Z coordinate plane is provided below:

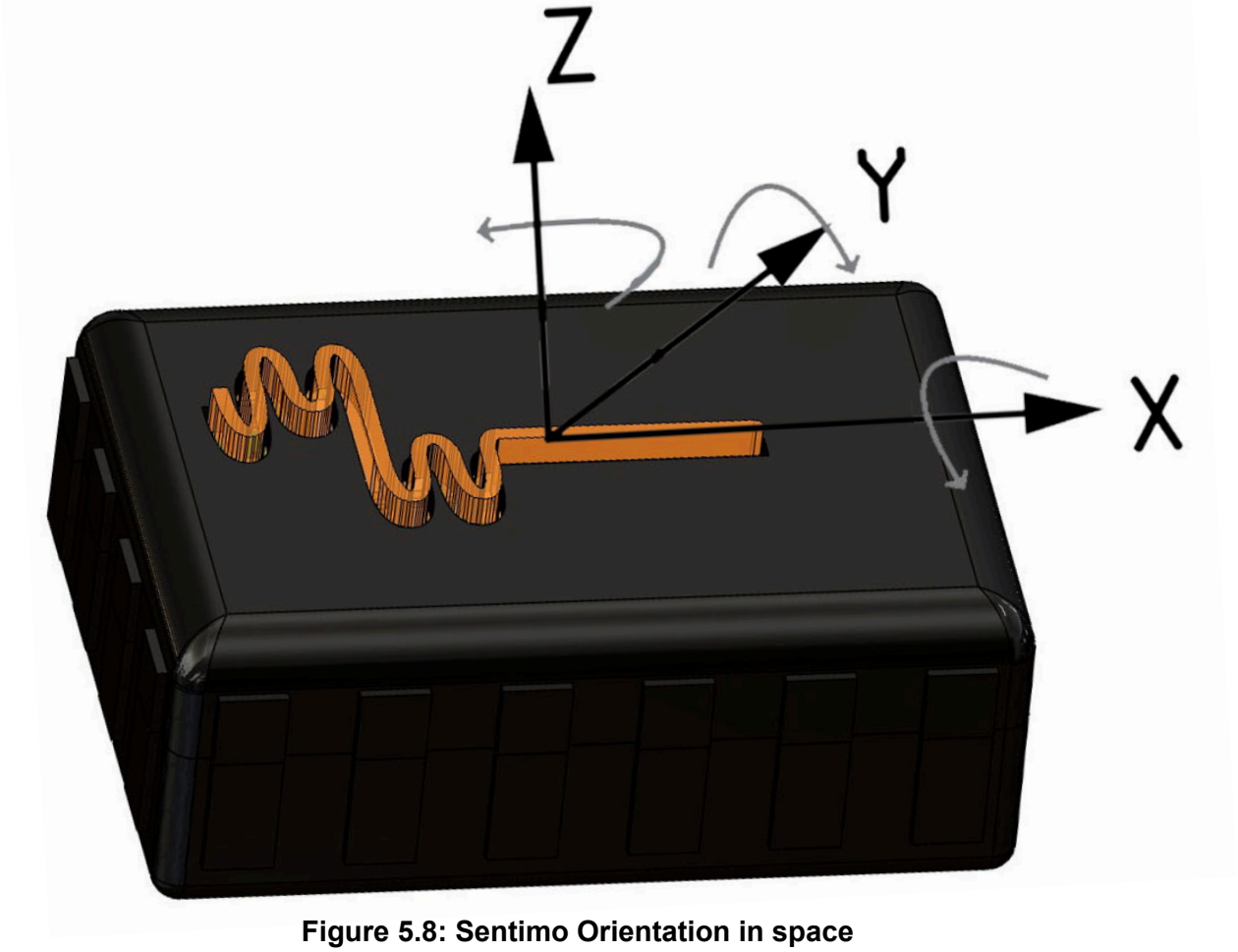

Figure 5.8: Sentimo Orientation in space

5.2.2 Sensor Report Optimization

The Sentimo system exposes direct control of the frequency and form of the IMU information directly to the user. All reports sent from an APU will be time-stamped and synchronized with accompanying EMG data. However, whether information is displayed to the user in a real time 3d graphic, or in the separated readings in the X, Y, & Z planes is up to the user. Orientation & Linear Acceleration measurements are made available to users, but Magnetometer readings are internalized and automatically applied to Gyroscope calibration.

5.3 Advanced Network Capabilities

The Sentimo system implements Bluetooth 5.4. It may take a few seconds upon power on, or scanning to synchronize your bluetooth device to the Bluetooth 5.4 network, this is normal. The Sentimo system supports a 4 second backlog of bluetooth data, and will attempt to reconnect and send all 'missed' data over the *EMGenius* software system upon reconnection. It is not unusual for the Sentimo system to periodically lose packets, and automatically catch up in the user interface in real time. The Sentimo system has a data processing delay equivalent to that of a BLE network, averaging **approximately 10ms**. It is worth noting that the IW logo is placed to accurately show users the location and approximate direction BLE signals exit the device.

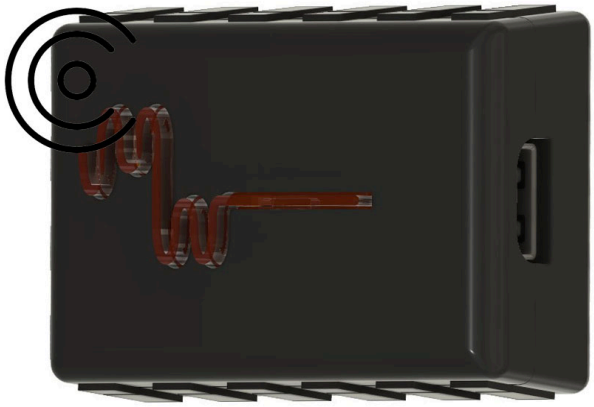

Figure 5.9: Sentimo Metal Broadcast Region

Large Metal Objects encompassing and blocking bluetooth broadcast from propagating
Other **Extreme High Frequency** Data transmission systems functioning in the local area

5.3.1 Broadcast Range limitations

The Sentimo system has been tested for a +3 dBm transmit power at the antenna, and is capable of supporting a **minimum 65ft/20m broadcast range**. The Sentimo system supports a secondary BLE functionality if used as an individual unit, and has been tested in this **Low Frequency** mode to support **ranges up to 150ft/50m.** As is the objective of the Sentimo system, the Amplifier Unit's goal is to give researchers and technicians the ability to optimize the limits and capabilities of their unit. Successful Broadcasting Range will **automatically improve** as researchers reduce EMG & IMU broadcast frequencies or move from a 4 device network to a single device & receiver network.

6.0 System Contents

The Sentimo system's Portable Amplifier Unit has the following Enclosure:

- 21.50mm x 31.5mm x 11.5mm
- 9.5g weight

- Medical-grade polycarbonate shell

A complete Sentimo System should include:

- 4 Sentimo Portable Amplifier Units
- 4 Cables of Selectable Length & Termination
- A 5V DC Barrel jack connector for charging
- A USB Bluetooth 5.0 Dongle for PC interfacing
- 1 bag of 50 disposable electrode stickies
- 1 bag of 50 device stickies
- *Optional* External Trigger Unit

Figure 6.0: Sentimo Ruggedized Charging Case

7.0 System Charging:

The Sentimo System comes with a built-in internal fuel gauge, which will display the remaining device battery in the EMGenius Software. Portable Amplifier Unit LIPO batteries are tested to 500 charge/discharge cycles, and are for **8 hours of device life,** and a **15-minute charging time**.
Upon plugging in a device into the Ruggedized Portable Carrying case, the Case light will turn orange to indicate charging has begun. Upon the device becoming fully charged, the status light will turn green to indicate a fully charged device. The Sentimo Portable Amplifier Unit is completely capable of being charged without power being on the device. Therefore, the charging case LED showing 'Orange' is the only indicator necessary for Sentimo Charging.

Power delivery for the Sentimo Portable Amplifier Unit is routed through cabling. In order for the Sentimo System to stay turned on, cabling **should not be unplugged** during use.

8.0 Cabling Options

The Sentimo unit has fully custom cabling which on one end terminates in micro hdmi and on the other terminates in one of the following:

- Din Connector Leads
- Pinch Style ECG Leads
- Button Style ECG Leads

Sentimo Unit Cabling currently Measures:

- **1.35mm** diameter Shielded Cables
- **14.25mm x 12.1mm x 6mm** Cable connector receptacles
- **TBA** cable weight

Sentimo Unit Cabling currently comes in the following Lengths:

- 6 inches, 1/2/3/4 channels
- 12 inches, 1/2/3/4 channels

Channel Number	Wire Color
GND	Black
1	White
2	Teal
3	Red
4	Green

Figure 7.0: Sentimo Cable Coloring Guide

9.0 LED FEEDBACK

Sentimo Portable Amplifier Units are keyed with separate LED colors to distinguish devices. These colors are configurable.
The following are **valid LED patterns** for the Sentimo System:

Charging Case:

- Solid Orange: **Charging** device plugged in.
- Solid Green: **Fully charged** device plugged in.
- OFF: **Unplugged** Sentimo or Charging case

Portable Amplifier Unit:

- LEDs Strobing: **Searching** for Bluetooth Connection
- LEDs Solid: **Paired** Device and sending data
- LEDs Rainbow: **Firmware updating**.
- LEDs off: **Unpowered** Device.

The Sentimo Portable Amplifier Units do not need to be powered on to charge.
Refer to Charging Case LEDs for Sentimo **Charging Status**.

10.0 External Trigger Unit

The Sentimo system has an optional **external Trigger Unit** known as "**Synthia**".
Synthia is connectable to the Computer running the EMGenius Software via USB.
Synthia is capable of taking in one isolated input (±20V) and outputting ±5V TTL signals over a locking BNC cable.

The **Synthia External Trigger Unit** passively listens to the BLE timing network for the Sentimo system, and upon receiving a TTL input signal greater than 3V, will send the current network timestamp to the **EMGenius frontend software** for placing a user flag.

11.0 Amplifier Unit Optimization Quick Guide

EMGenius Accessible Amplifier Unit Settings:

- Pre-Set Device Preferences for balancing Sample Rate Creation
- Dynamic Range (up to +/-9.375mV at 128x gain)
- 16-bit or 24-bit resolution
- 50Hz or 60Hz Hardware Notch Filter
- Optional Software High Pass Filter
- Optional Hardware 50 or 60 Hz Filter
- Sample Rate
- LED color

11.1 Advanced Settings

- **Master Clock**
  - This decides the frequency at which samples are taken internally to the device.
    Raising the Master Clock does the following:
    - Raises power consumption
    - Increase sample rate
- **Over Sample Rate**
  - This decides how many samples are averaged together before transmission.
    Raising the Over Sample Rate does the following:
    - Improves Signal to Noise Ratio **(See Figure 5.7)**
    - Lowers the final sample rate
- **DC Blocking Capacitor**
  - A DC-blocking capacitor: part of the High-Pass Filter and the 50/60 Hz Notch Filter
    - **Disabling** the DC Block **Disables** the High-Pass and 50/60 Hz Filters.
  - The DC blocking cap setting is set using the **F3dB point**: the point where half of the signal is attenuated by the High-Pass Filter.
    Raising the F3db does the following:
    - Attenuates noise lower than the point given. **(See Figure 5.6)**
  - **DC Blocking** is a **required** portion of enabling the High-Pass and 50/60Hz Filters.

For Quick Setup, the EMGenius Software Suite **allows users to define presets** so users can maintain their settings between sessions: **Devices --> Presets**