DSI Guidelines for Biopotential Applications

Applications involving sampling of electrical signals like ECG and EEG require telemetry implants with adequate technical specifications to accurately acquire and analyze data. The purpose of this document is to provide definitions of key terms and clearly outline what telemetry implants are appropriate for certain applications.

Important principles covered by these guidelines:

- Only signal frequency content within the specified channel bandwidth of the telemetry implant is acquired accurately
- In certain transmitters with multiple biopotential channels, channel #1 is not recommended for ECG if EEG is being sampled by another channel
- Delta EEG wave and therefore sleep cannot be properly acquired by certain telemetry implants

Definitions:

Channel Bandwidth:

- The frequency range between the lowest and highest attainable frequency, measured in Hertz (Hz)
    - For DSI products, this focuses on the range of frequencies for which the reported signal amplitude remains within an error power band of 3 dB
- The two values of a published channel bandwidth indicate the low and high frequencies where the response has fallen by no more than 3dB
    - 3dB is the “half-power” point where signal power (dB) has fallen to 50% or where the amplitude (Volts) has dropped to 70.7%
    - 3 dB is an accepted standard in physics and electrical engineering (see Appendix A)

Nominal Sampling Rate:

- Nominal implant sampling rate: The rate at which data points are sampled by the implant. Higher sample rates enable accurate response to higher signal frequencies, but at the cost of shorter battery life
- Aliasing: Arises when a signal is discretely sampled at a rate that is insufficient to capture the changes in the signal (see Appendix B)

Nyquist Sampling Theorem:

- Definition: The sampling frequency should be at least twice the highest frequency contained in the signal to avoid aliasing
- For DSI implants, we choose to sample sometimes higher than a factor of 2. We typically sample 4-5x higher than highest targeted frequency content

Software Sampling Rate:

- The rate at which the raw data is reconstructed in the application software (e.g. Ponemah) for plotting and feature extraction
- Higher software sample rates (relative to nominal sampling rate of implant) will include more points along an interpolated representation of the raw telemetry data
- Interpolation: or upsampling, is the insertion of additional data points between points collected via the nominal sampling rate of the implant
- Interpolation allows for a more continuous representation of the physiological data, but it cannot increase the accuracy of the signal reconstruction
- Select a software sampling rate that is at least equal to the nominal implant sampling rate

Best Practices per Application Type

Best Practices - ECG sampling:

- Input voltage range must accommodate full amplitude of ECG signal
  - The recommended input voltage for mouse ECG is ±2.5 mV, rat is ±5 mV, large animal is ±10 mV
  - These input range thresholds are recommended to avoid cutting ECG signal above these levels, this phenomenon may result in less precise ECG interval calculations
- For the following implants, it is not recommended to use channel #1 for ECG, EMG, or EOG, if you also desire to sample EEG in the other available biopotential channels: 4ET, HD-X02, HD-S02, F20-EET, and F40-EET
  - Channel #1 is not recommended because its negative lead is connected to the internal ground reference of the implant. As a result, if a high amplitude signal type (e.g. ECG) is collected on Channel #1, a small ECG signal artifact may be seen in the other channels.

Best Practices – EEG sampling:

- DSI's recommends the use of IROX EEG screws (Appendix C) if you desire to use a single biopotential channel telemetry implants or the D70-CCTP to record EEG.
  - These implants were designed to work best with ECG, the lowest attainable frequency is 3 Hz for EEG recordings if not used with IROX screws
- Source input impedance is most consistent across multiple cortical recordings by anchoring the biopotential electrodes to screws and making contact with the dura (See Appendix C)
  - EEG electrodes have a higher source impedance than ECG electrodes because the contact area between electrode and target tissue tends to be smaller than ECG electrodes
    - Impedance: the measure of the opposition that a circuit presents to a current when a voltage is applied
  - The source impedance of EEG electrodes is inversely proportional to the electrode contact between the target tissue and electrode material; a high source impedance may attenuate the lower EEG frequencies
- Input Voltage Range
  - Rodents: recommended input voltage range of ±1.25 mV or ±2.5 mV to keep noise levels low
  - Large Animals: recommended input voltage range of ±2.5 mV to keep noise levels low

Application Summary

Species	Signal Type	Applications	Telemetry Implant
Mouse	Electrocardiogram (ECG), Electroencephalogram (EEG), or Electromyogram (EMG)	ECG waveform acquisition, Heart Rate Variability (HRV), Sleep[1], Seizure, Affective Disorders, Neurodegenerative Disorders, and Movement Disorders	ETA-F10, HD-X11, ETA-F20*
Mouse	EEG, EMG	Sleep, Seizure, Affective Disorders, Neurodegenerative Disorders, and Movement Disorders	HD-X02, F20-EET
Rat	ECG, EMG, or EEG	ECG waveform acquisition, Heart Rate Variability (HRV), Sleep[1], Seizure, Affective Disorders, Neurodegenerative Disorders, and Movement Disorders	CTA-F40, HD-S11, HD-S21, CTA-D70*
Rat	EEG, EMG	Sleep, Seizure, Affective Disorders, Neurodegenerative Disorders, and Movement Disorders	HD-S02, F40-EET, F50-EEE
Rat	Nerve Activity	Isolated sympathetic nerve activity	F50-W-F2
Large Animal Models	ECG, EMG, or EEG	ECG waveform acquisition, Heart Rate Variability (HRV), Sleep[1], Seizure, Affective Disorders, Neurodegenerative Disorders, and Movement Disorders	M01, M11, L11, L21, D70-PCTR, D70-PCT*, D70-PCTP*, D70-CCTP*
Large Animal Models	EEG, EMG	Sleep, Seizure, Affective Disorders, Neurodegenerative Disorders, and Movement Disorders	L03, L04, D70-EEE

[1] Specialized IROX screw electrodes are required to ensure waveforms below 3 Hz are measured, critical for measuring slow wave sleep.
*New purchases of these implant models are not available in certain countries; check with your DSI sales representative for local availablity

Implant Specifications

Implant Family	Implant Model	# of Biopotential Channels	Input Voltage Range	Biopotential Channel Bandwidth (Hz)	Biopotential Channel Nominal Sampling Rate (Hz)	Signal Type
PhysioTel	ETA-F10, ETA-F20, EA-F20	1	±2.5 mV	1-200	1000	ECG, EMG, EEG[1]
	CTA-F40, CA-F40, CTA-D70	1	±10 mV	1-200	1000	ECG, EMG, EEG[1]
	F50-W-F2	1	±0.5 mV	50-1000	5000	Nerve activity
	F20-EET, F40-EET	2	±1.25 mV	1-50	240	EEG, EMG (ECG[2])
	F50-EEE, D70-EEE	3	±2.5 mV	1-100	500	ECG[2], EEG, EMG
	4ET	4	±2.5 mV	1-100	400	ECG[2], EEG, EMG
	D70-PCT, D70-PCTP, D70-PCTR	1	±10 mV	1-100	500	ECG, EMG, EEG[1]
	D70-CCTP[$]	2	±10 mV	1-100	500	ECG, EMG, EEG[1]
PhysioTel HD	HD-X02	2	±1.25 mV	0.5-80	300	EEG, EMG (ECG[2])
	HD-S02	2	±1.25 mV	0.5-100	375	EEG, EMG (ECG[2])
	HD-X11	1	± 2.5 mV	0.1-200	600	ECG, EMG, EEG[1]
	HD-S11	1	±5 mV	0.1-145	600	ECG, EMG, EEG[1]
	HD-S21	1	±5 mV	0.1-145	450	ECG, EMG, EEG[1]
PhysioTel Digital	L11, L21	1	Programmable ±2.5, 5, 10, 20^ mV	0.1-100	448	ECG, EMG, EEG[1]
	L03	3	Programmable (Ch. 1-2) ±2.5, 5, 10, 20^ mV	0.5-100	500	EEG, EMG, ECG
	L04	4	Programmable (Ch. 1-2) ±2.5, 5, 10, 20^ mV	Ch. 1-3: 0.5-100 Ch. 4: 0.5-50	Ch. 1-3: 375 Ch. 4: 185	EEG, EMG, ECG
	M11, M01	1	±10 mV	0.1-100	448	ECG, EMG, EEG[1]

[1] Specialized IROX screw electrodes are required to ensure waveforms below 3 Hz are measured, critical for measuring slow wave sleep.
[2]If there is a need to record ECG, EMG, or EOG with these devices, channel 1 should not be used; (Note that signal railing in the ECG may occur in mice and rats at high R wave amplitudes using implants with input voltages that equal ±1.25 mV)
Dependent on electrode input impedance (to learn more, visit the section: "Best Practices – EEG Sampling")
^ 20 mV input voltage may be selected when solid tip lead placement results in ECG amplitude exceeding 10 mV

Appendix

A. 3dB explained:

Voltage vs Power when using dB

The -3dB point is also known as the "half power" point. In voltage it may not make not make tons of sense as to why we use ($\sqrt{2}/2$), but lets look at an example of what it means in the sense of power.

First off, $P = V^2/R$, but lets assume R is a constant 1 Ω. Because of the constant 1ohm, we can remove it from the equation all together.

Lets say you have a signal at 6 V, its power would then be $(6\ \mathrm{V})^2 = 36\ \mathrm{W}$.

Now I take the -3dB point, $6\ \mathrm{V} \cdot \left(\frac{\sqrt{2}}{2}\right) = 4.2426\ \mathrm{V}$.

Now lets get the power at the -3dB point, $4.2426\ \mathrm{V}^2 = 18\ \mathrm{W}$.

So originally we had 36 W, now we have 18 W (which of course is half of 36 W).

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http://electronics.stackexchange.com/questions/6959/what-is-the-significance-of-3db

B. Nyquist Theorem Expanded

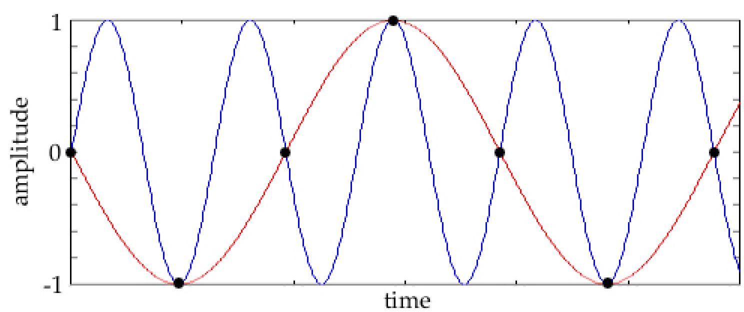

Figure 2.7 Undersampling: What happens if we sample too slowly for the frequencies we're trying to represent?

We take samples (black dots) of a sine wave (in blue) at a certain interval (the sample rate). If the sine wave is changing too quickly (its frequency is too high), then we can't grab enough information to reconstruct the waveform from our samples. The result is that the high-frequency waveform masquerades as a lower-frequency waveform (how sneaky!), or that the higher frequency is *aliased* to a lower frequency.

http://cmc.music.columbia.edu/musicandcomputers/chapter2/02_03.php

C. Recommended Surgical Accessories

Stainless steel mounting screws, screwdrivers, drill bits, and drill bit holders can be purchased from Plastics One.The length of the screw should be chosen so it makes contact with (but does not puncture) the dura matter, but does not contact/create pressure on the brain. This will depend on factors such as positioning and skull thickness. We recommend consulting published literature for recommendations of appropriate screw sizes per species, weight, and age of the subject. The below list are examples of sizes that have been used by DSI surgeons or clients successfully.

DSI EEG Screws

DSI Part Number	Model	Description
012011-001	EEG IROX Screws, Mouse	00-96 X 1/16, EEG, IROX screw, MOUSE, Pack of 50
012012-001	EEG IROX Screws, Rat	00-80 X1/16, EEG, IROX screw, RAT, Pack of 50
012013-001	EEG IROX Screws, LA-1	00-80 X 3/16, EEG, IROX screw, Large Animal-1, Pack of 50

Plastics One EEG Screws

Mice

Screw size: 0-96
Part number: 0-96 x 1/16
Drill bit part number: D#60
Drill bit holder part number DH-1
Screwdriver part number SD-96

Rats

Screw size: 0-80
Part number: 0-80 x 1/16
Drill bit part number: D#56
Drill bit holder part number: DH-1
Screwdriver part number: SD-80

Non-human Primates and Canines

Screw size: 0-80
Part number: 0-80 x 3/16
Drill bit part number: D#56
Drill bit holder part number: DH-1
Screwdriver part number: SD-80

Plastics One Inc.
Telephone: (1-540) 772-1166
Fax: (1-540) 777-5900
Website: www.plastics1.com (A list of international distributors can also be found here)