



Bennu NP 1.0/2.0 Headstage Manual



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Bennu Headstage



Figure 1 | Bennu Neuropixels Headstage with cone assembly 1.0 (left) and 2.0 (right).

Introduction

Overview

The SpikeGadgets Bennu headstage is designed to optimize the power and density of Imec's Neuropixels 1.0 or 2.0 probes with the power and modularity of SpikeGadgets' products. The headstage records neural signals from up to three Neuropixels probes simultaneously, with 2880 selectable neural channels.

The headstage can operate in 2 modes: 1) tethered live streaming mode, where up to 1152 of the available 2880 channels across three probes can be selected and livestreamed to your computer using the Main Control Unit (MCU) 2) untethered data-logging mode, where up to 400 channels across three probes can be selected and the data is recorded locally to a microSD card on the headstage. Recording (start, stop, pause) is initiated in datalogging mode with either the MCU and RF transceiver or the Logger Dock.

Versions

The Bennu headstage comes in two versions: one that is compatible with the Neuropixels 1.0 probes (all versions except NHP) and one that is compatible with the Neuropixels 2.0 probes. The difference between these two versions is the probe cone (illustrated in Figure 1 above) and the firmware. Users may switch versions of the Bennu headstage they are using by purchasing additional cones for the probe version they are using and contacting support@spikegadgets.com or their lab's private support channel to request the new firmware.

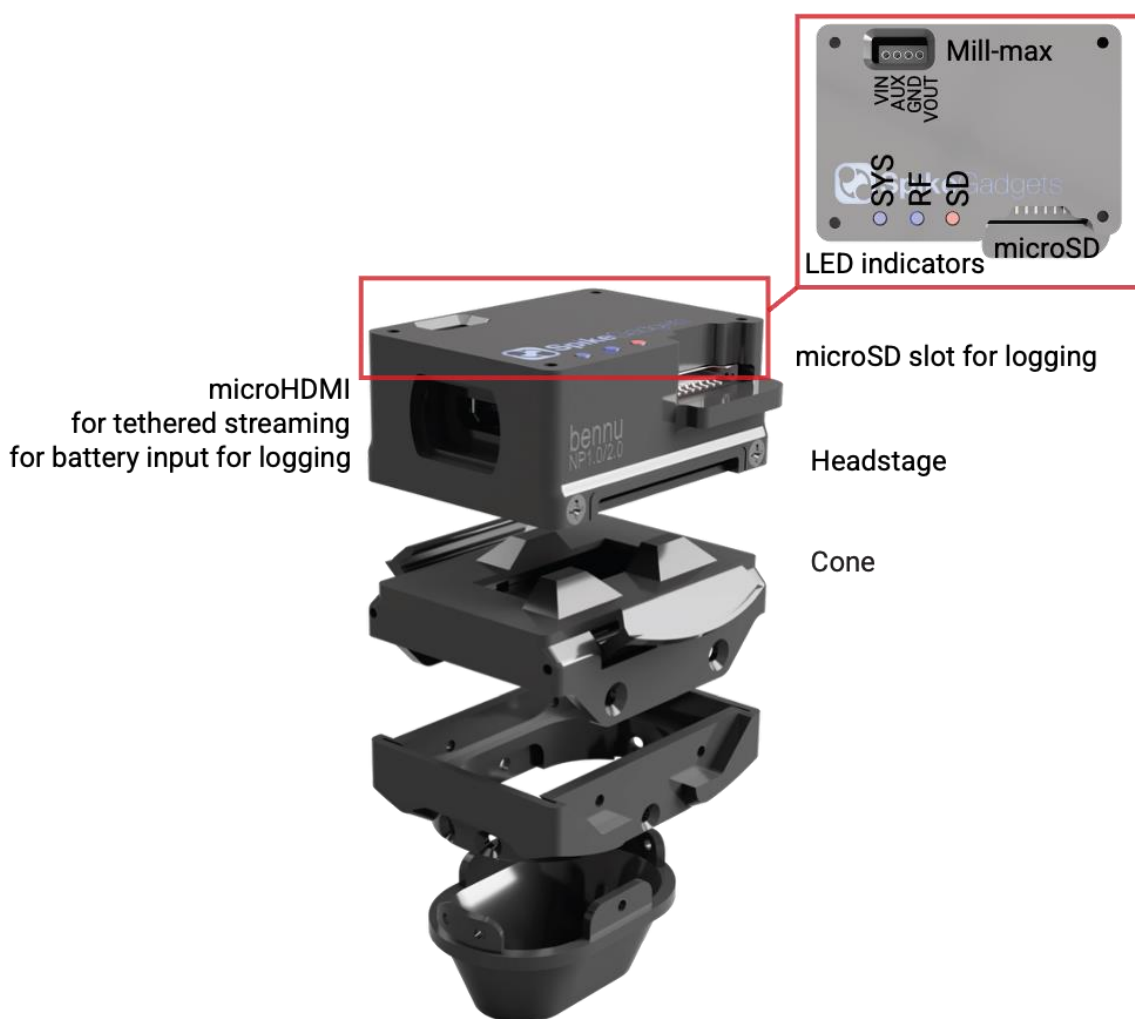


Figure 2 | Headstage and cone assembly

Setup

The Neuropixels headstage can be used with both the SpikeGadgets MCU as well as the Logger Dock, and requires the [Trodes application suite](#), which can be downloaded [here](#). See our Trodes wiki for more information about [Installing Trodes](#).

Please also familiarize yourself with the Neuropixels user manual before recording with this headstage. The manual can be found [here](#).

For additional information about Neuropixels 1.0 or 2.0 Probes and recording with them, please see the UCL Neuropixels training course [here](#).

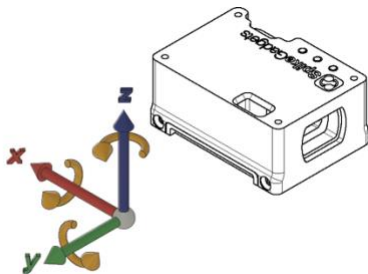
Important note: The Bennu requires at least one probe attached to operate. Without a probe, the device will remain in hardware error mode and cannot be used, including for testing purposes.

Neuropixels Headstage Specifications

Number of Neuropixels Probes (not included)	Up to 3
Compatible with	Neuropixels 1.0 probes (every version except NHP) OR Neuropixels 2.0
Channel count	
Selectable	(up to) 2880
Streamable (via tether)	1152 (across 3 probes) or 384/probe
Wireless data logging	400 (across 3 probes) or 384/probe
Weight (without probes)	
Headstage + cone	21g
Headstage+ cone + 400mAh battery	33g
Record time (with 400mAh battery, 1 probe)	~2-2.5 hours
Power consumption (1 probe)	160mA (1.0 Probes), 180mAh (2.0 Probes)
Dimensions- untethered recording (with cone)	
Length	33mm
Width	25mm
Height	52mm (incl. 1.0 Cone), 39mm (incl. 2.0 Cone)
Sampling rate	30 kHz
Bit depth	10-bit (1.0 Probes), 12-bit (2.0 Probes)
Connection to commutator	Micro HDMI
Sensors	Accelerometer, gyro
LED Array	3 LED

Onboard Sensors

The headstage has an integrated accelerometer and gyroscope. The diagram below shows the orientation of these sensors. The figure on the left is for the 4401 version of the Benu with the 4402 version on the right.



Surgery, Probe Connection and Assembly

Before beginning the implantation procedure, the cone should be disassembled to reveal the ZIF probe interface connectors. During implantation, the bottom portion of the cone can be further disassembled to make the probe implantation process easier. The cone portion of the Neuropixels headstage must be placed around the implanted Neuropixels probe(s) and attached surrounding the site of implantation. Before reattaching the cone top, the probes are connected to the cone's headstage interface by inserting the flexible probe connectors into the Zero Insertion Force (ZIF) connectors as shown in the image Fig.3.

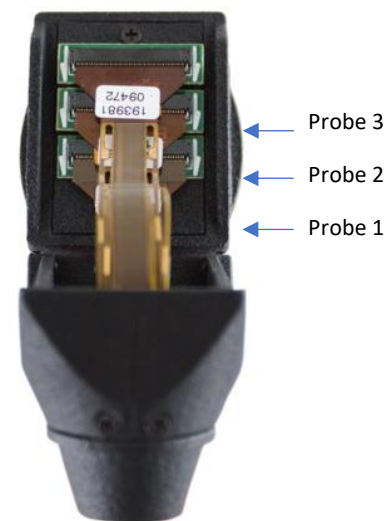


Figure 3 | Neuropixels 1.0 Probes connected to cone assembly via tiered zero insertion force (ZIF) connector interface.

Initialization and Startup

When a two-way capable headstage is powered on, all 3 status LEDs will blink white simultaneously. This indicates the headstage has completed initialization and is now in the active state. The headstage status LEDs will now report system readiness to record using the following color-coded indications:

LED Color	System Status LED	RF Status LED	SD Status LED
Blue	Hardware OK	Connection to Dock OK	SD card ready
Yellow		Waiting for RF communication from Dock	SD card not enabled for recording
Red	Hardware error detected; contact Support	-	No SD card detected OR SD card error

All LED must show a blue indication before a recording can be initiated. Once this occurs, the LEDs will stay on briefly, then turn off to conserve power.

Note: Logger system statuses are displayed hierarchically. This means that status issues must be resolved sequentially as follows: Hardware Status issues must be addressed before Wireless Status can be addressed, and Wireless Status must be OK before an SD Status issue can be resolved.

In practical terms, this means that if the Wireless Status LED is yellow (waiting for RF signal), enabling your SD card will not cause the SD Card status LED to change until the Wireless Connection is established.

Recording Indications

When a recording is started, all status LEDs will flash white (4x) simultaneously to indicate the Start command has been received. Status LEDs remain off for the duration of the recording. Status LEDs will flash white (2x) again when the Stop command is received. LEDs will remain off unless a hardware or SD cards state change is detected.

For more information, see *Tethered recording and wireless logging via 2-way radio link*, the wiki ([link](#)) and Fig2.

Batteries and Charging for Untethered Recording

The Bennu headstage requires an external battery for untethered datalogging. A compatible 400mAh battery along with the battery adaptor is included in the datalogging bundle which can be purchased from SpikeGadgets. The Bennu may be powered via other sizes of rechargeable 3.7V Lithium-ion batteries with a 2-pin JST-PH connection (we typically order from Sparkfun). Attempting to power the headstage using a different battery type is not recommended and can result in damage to the headstage or connected probes.

The battery is connected to the headstage via the magnetic battery adaptor which is included with your headstage order. The HDMI battery adapter included with the purchase of a datalogging bundle is also compatible with the Satori datalogger.

Batteries can be charged using either the [SpikeGadgets Battery Charger](#), or a 3rd party charging device. When charging batteries with any device, it is important that the selected charge rate setting does not exceed the battery specification (e.g. a 400mAh battery should be charged using a 400mAh charge setting or lower). Charging at a rate below the battery spec will result in a longer charge time but will still fully charge the battery.

Probe Configuration

Imec Calibration (1.0 Probes only)

Before a probe can be used it must be programmed with the probe-specific configuration files from Imec that are provided with each probe. This can be done by connecting your headstage to the MCU via HDMI and using the SpikeGadgets probeConfig command line script (**Windows and USB compatible only**)(Fig.4), which can be downloaded [here](#).

To use the probeConfig application:

1. Connect the probe to your headstage in the slot you intend to use when recording.
2. Connect your Neuropixels Headstage via HDMI to your MCU.
3. Move the probe configuration file from Imec and the probeConfig.exe executable to the same directory.
4. Open the command line and run the probeConfig script. When calling the script, the probe slot being configured must be specified (e.g. "probeConfig 1" to configure the probe in slot 1, "probeConfig 2" to configure the probe in slot 2, etc.).

5. The script will read the probe ID, then look for a probe calibration file that matches the probe ID in the same directory as the probeConfig script. If found it will apply the configuration data to the probe. If not found it will ask if the probe should be configured using default calibration data instead.
6. Repeat the process if configuring multiple probes.

```
$ probeConfig 1
Sending get probe id command...
Found probe: Probe ID 18408410302
Probe configuration values found on probe. Overwrite with new values ? (yes or no) yes
Looking for calibration file 18408410302_ADCCalibration.csv... found it!
Sending set probe settings command... success!
Writing probe configuration data to probe 18408410302
Continue? (yes or no) yes
Sending probe programming command... success!
```

Figure 4 | Example output from running the probeConfig program to calibrate a probe

Trodes

Creating a Neuropixels Workspace

1. From the Trodes main menu, choose "Create/Edit Workspace," then select "From Scratch." This will open the Workspace editor.
2. From the Workspace editor, under "Hardware Configuration" select "Amplifier/probe technology: Neuropixels 1.0 probes or Neuropixels 2.0 probes" (Fig.5)
3. Select the number of probes you are using from the dropdown menu (1,2 or 3).
4. If an Environmental Control Unit (ECU) is connected to the system, the ECU device should be added under "Hardware Devices." To do this, select "ECU" from the "Select Devices" dropdown menu, then click "+Add Device" (Fig.5).
5. If using the accelerometer and gyro sensor data from the headstage add this from the Auxiliary Display tab.
6. Click "Open."

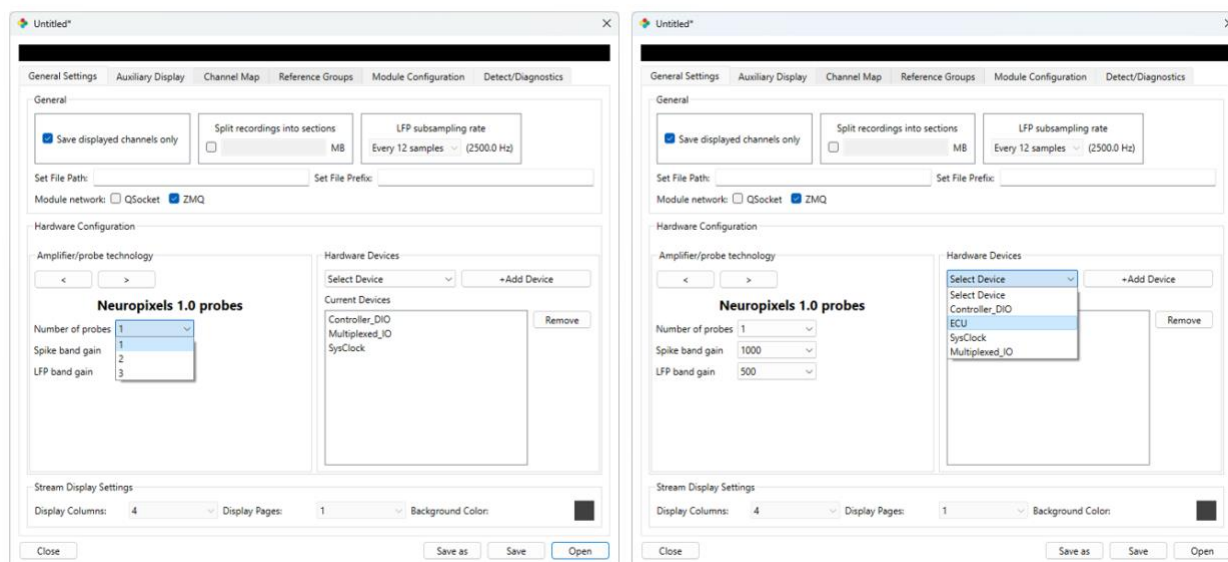


Figure 5 | Workspace probe selection dropdown menu (left), and selecting ECU from the Hardware Devices dropdown menu (Right)

Selection Tool Interface

Each Neuropixels probe is limited to recording 384 distinct channels simultaneously. For tethered live streaming recordings, this means that a maximum of 1152 channels can be recorded simultaneously across 3 probes. For untethered recording, a maximum of 400 channels can be selected and recorded across 3 probes, with a maximum of 384 channels from any one probe. Channels are selected using the Neuropixels interface in the Trodes GUI.

To open the Neuropixels interface in Trodes, open your Neuropixels Workspace, then select Connection > Specific Source Control > Neuropixels from the dropdown menu.

Probe Selection

Choose the probe you would like to format using the "Probe Selection" dropdown menu (Fig.6). Probes will be numbered chronologically, not by slot number. For example, if probes are in slot 2 & 3, the probe in slot 2 will be labeled "Probe 1," and the probe in slot 3 will be labeled "Probe 2."

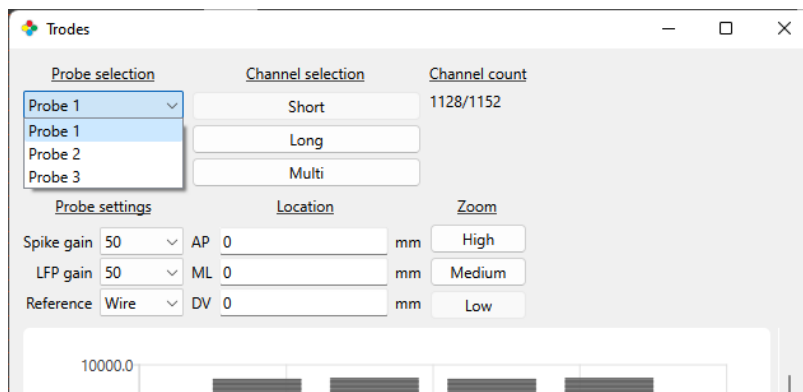


Figure 6 | Neuropixels interface Probe Selection menu

Channel Selection

The Channel Selection menu allows you to select a total of 384 channels per probe for a total of 1152 channels across 3 probes for tethered recordings, or a total of 400 channels for untethered recordings.

The GUI will always list the *absolute* total channel count for detected probes regardless of recording type (tethered or untethered). For untethered recording, the actual maximum recordable channels is 400.

NOTE: Trodes version 2.5.0 AND MCU firmware 3.20.7 or later should be used when recording with the Neuropixels Bennu headstage. In previous versions of Trodes an error can occur during data extraction that causes LFP channel IDs to become scrambled following export. The error occurs when using the Trodes Export Utility to extract LFP band data from a recording where all 384 available probe channels were not assigned for a given probe. This error does not impact the integrity of the recorded data; only the channel ID mapping of the exported data band. Contact SpikeGadgets support if you need assistance updating your devices.

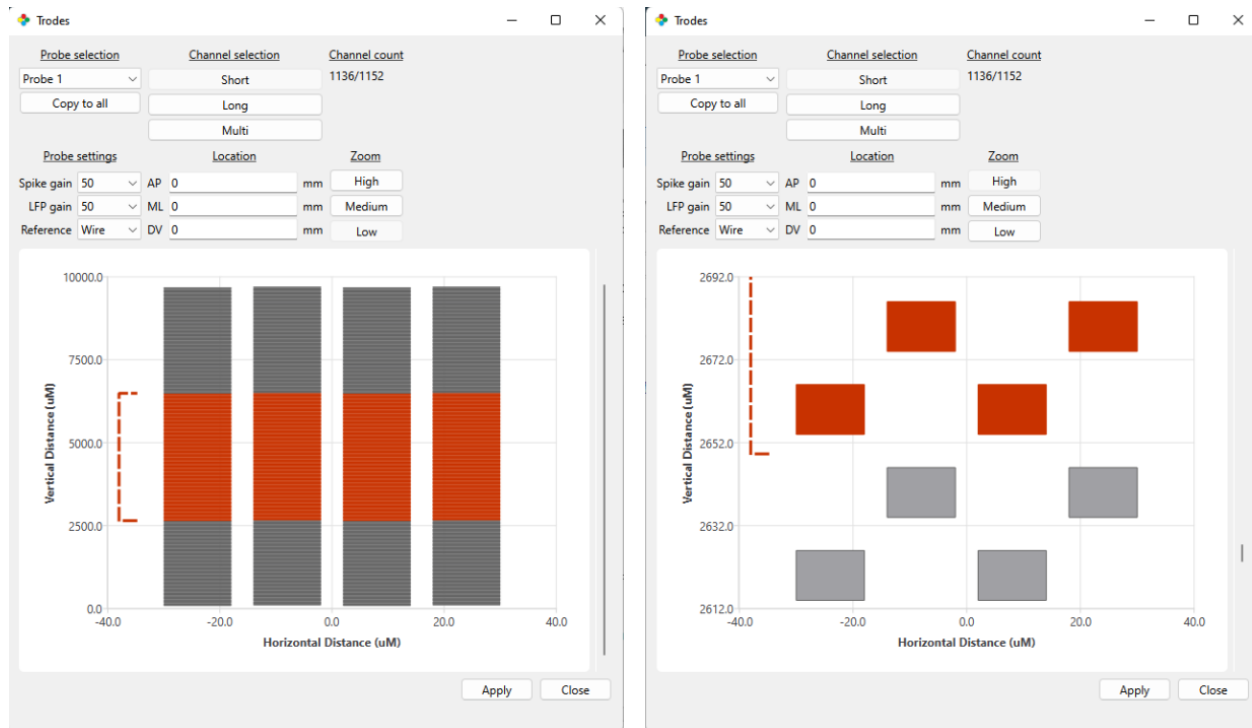


Figure 7 | Short Channel Selection viewed in low and high zoom. Probe contacts are referenced from the pointed tip of the probe shank (0,0). This makes it possible to use the implantation coordinates as the origin when determining contact location in the brain.

Channel Selection modes:

- **Short** - Selects exactly 384 consecutive channels across the probe. The placement of these channels along the probe shank can be adjusted by moving the red dashed range bracket to the left of the channel schematic.
- **Long** - Selects 384 channels in alternating fashion (every other channel is activated). This covers an area twice as large, with half the density of the short selection method. This density is roughly equivalent to that of a tetrode.
- **Multi** - Allows for custom selection of channels. When High zoom is selected in Multi selection mode, individual channels can be turned ON/OFF within a selected range. Custom channel range is selected using the brackets preloaded in the top left of the selection pane. Simply drag one of these brackets to the desired position and set the bracket range by right-clicking the bracket. *NOTE: bracket range is expressed in microns.*

Multi-channel selection patterns may also be copied to the other probes being used by selecting, "copy to all," under Probe Selection.

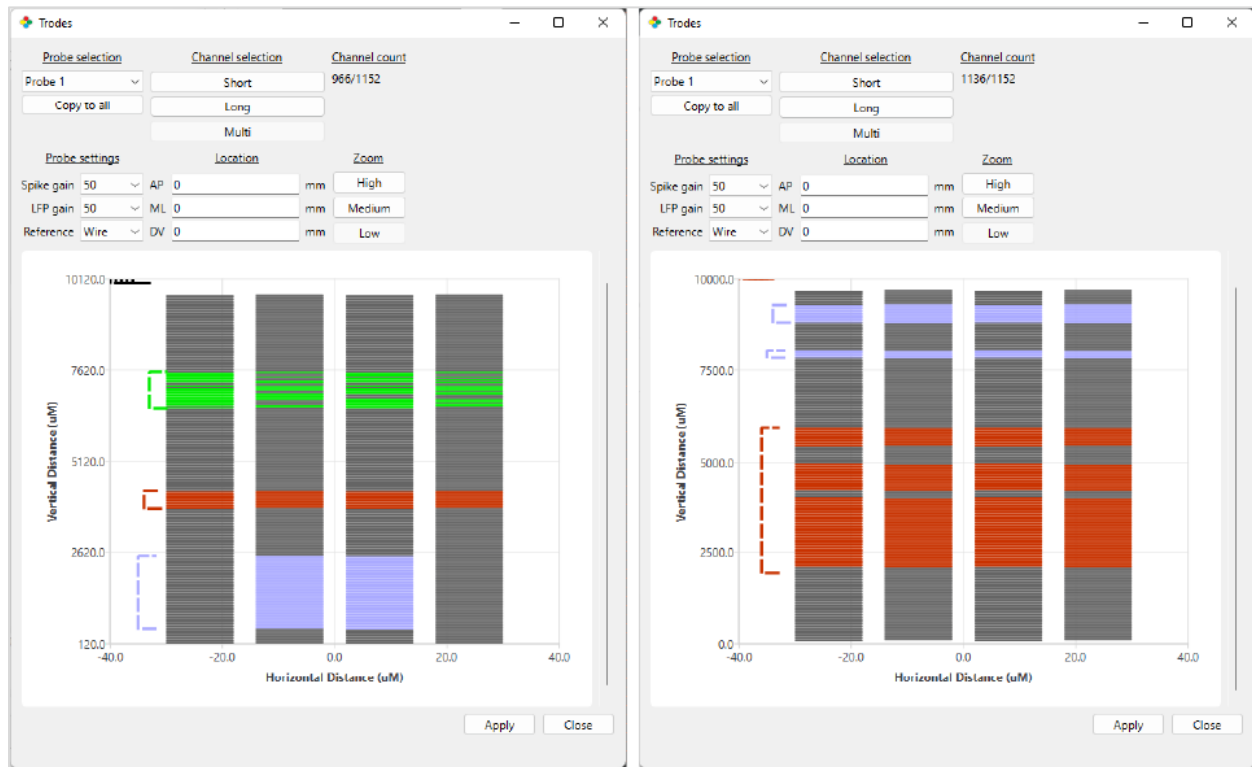


Figure 8 | Multi Channel Selection showing ranges of varying size with different custom channel selection schemes (left), and an example of output node overlap described below (right).

IMPORTANT NOTE: The Neuropixels probe array shank is comprised of 3 channel banks. These banks are connected to a finite number of output nodes, some of which are shared between multiple banks. This means that it is possible to select channels in 2 different banks that output to the same node. While the probe hardware is capable of this output scheme, it results in the voltage signals from both channels being combined. Because this combined channel data can be difficult to parse reliably, Trodes does not allow channels sharing an output node to be selected simultaneously. The right-hand image in Fig 8. above shows omission of overlapping output nodes/channels illustrated by gaps in red channel range resulting from outputs already occupied by purple channel ranges.

Probe Settings

Probe Settings is where reference and gain can be adjusted. Neuropixels probes acquire spike and local field potential (LFP) data streams simultaneously but independently. This makes it possible to set a different gain value for each stream. "Gain" refers to how much the signal is amplified before it is digitized, effectively determining amplitude resolution. The proper gain setting will depend on the amplitude of the signals being recorded, and should be determined by the user, but in general, Gain values between 1000-3000 for spike data and 100-1000 for LFP data are common.

*output signal = GAIN * (input voltage - reference voltage)*

Input voltage refers to the voltage at each electrode site. Reference voltage can come from one of three available sites. Neuropixels documentation states:

“The standard recording configuration is to short the external reference with the ground, and connect these to a saline bath (or agar) above the craniotomy for acute implants, or connect them to a skull screw for chronic implants.”

In Trodes this is referred to as the "wire" reference.

NOTE: Unless unique settings are required, it is highly recommended to use the same Probe Settings for reference and gain across all probes for consistency and clarity.

For more information about Neuropixels gain and referencing, see:

https://github.com/cortex-lab/neuropixels/wiki/Gain_settings

<https://github.com/cortex-lab/neuropixels/wiki/Referencing-and-Grounding>

Zoom

Adjusts channel display zoom. The High zoom setting allows individual channels to be viewed. When using High zoom **AND** Multi selection mode (discussed above), individual channels may be selected and de-selected.

Channel Formatting

Channel selections may be color coded by right-clicking any range marker and choosing “set color.” The length of the marker may also be changed in the multi-channel selection format by right-clicking the range marker.

Once the desired channels are selected, click “Apply” to save the configuration to your headstage. This will save the channel selections to the headstage itself for untethered recording or tethered streaming.

Tethered and wireless recording

For tethered recordings and wireless logging via 2-way radio link, please refer to the *Tethered recording and wireless logging via 2-way radio link documentation* ([link](#)).

Items Included with Shipment

Item	Description
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Neuropixels Logger Headstage	Neuropixels data logger with amplification, digitization, and SD data storage
Neuropixels headstage cone assembly	Neuropixels probe enclosure 1.0 or 2.0 cone assembly
Neuropixels cone cap	Protects cone electronics when headstage is not attached
45" HDMI A-D Cable (HDMI to micro HDMI)	HDMI tether for connecting headstage to MCU
30cm microHDMI to USB cable	Tether for pairing the Benu to Logger Dock (optional)

About SpikeGadgets

SpikeGadgets is trying something new. Our hybrid approach is to design and sell powerful hardware that interfaces with an open-source software platform supported by a large community of scientists and developers. Our goal is to support the efforts of the open-source community in a commercially-sustainable way.

Technical Support

If you would like technical support, please email us at support@spikegadgets.com.