

# SpikeGadgets

*Modular Stacking Headstage*



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## Modular Stacking Headstage



### Introduction

The Modular Stacking Headstage (MSH) is a modular and scalable head-mounted electrophysiology system for simultaneously recording up to 1024 channels of neural data. This is achieved by combining the MSH processor unit with stackable 128-channel recording modules that allow for channel count configurations between 128 and 1024 channels, in 128-channel increments.

The MSH supports recording in 2 modes: 1) In tethered mode, the MSH connects to the Main Control Unit (MCU) via HDMI, and up to 1024 channels of data can be streamed on the local computer via Trodes. 2) In untethered mode, the MSH operates under battery power and records up to 512 channels of data to the removable onboard micro SD storage. In untethered mode, the headstage is controlled via a radio frequency (RF) signal transmitted by the control unit (MCU or Logger Dock). The RF signals sent by the control unit are also used to sync the neural data with any event data recorded to the local computer via the control unit.

The MSH achieves high channel count while maintaining a lightweight and compact design by connecting to implanted electrode arrays via high-density zero-insertion force (ZIF) connectors on the stackable recording module boards, referred to as Probe Boards. This does however mean that the MSH is intended to stay on the animal for the duration of the implant as ZIF connectors have limited robustness to daily connecting/disconnecting of implanted arrays.

## Specifications

<b>Channel Count</b>	Scalable 128 to 1024 channels
<b>Intended Experimental Applications</b>	Freely-moving tethered or untethered recording
<b>Connector to Electrode Array/Probe</b>	2x Hirose 71-pin ZIF connectors (FH43B-71S-0.2SHW) per Probe Board
<b>Sampling Rate</b>	30KHz and 20KHz supported
<b>Bit Depth (ADC's)</b>	16-bit and 12-bit supported
<b>Input-referred Noise</b>	2.4-2.8 $\mu$ V RMS (as reported by Intan)
<b>Connector to MCU</b>	Micro HDMI
<b>Input Range</b>	$\pm$ 5 mV
<b>Dimensions</b>	
Length	29.5mm
Width	36.4mm
Height	55.7mm
<b>Weight</b>	16.40g + 1.48g per 128-ch Probe Board
<b>Battery Life</b>	Varies based on battery capacity.
<b>Sensors</b>	3-axis accelerometer, 3-axis-gyro
<b>Radio synchronization range</b>	10-20 meters

## MSH H70 vs. H80

As of 2023, two product versions of the MSH exist; H70 & H80. The primary distinguishing difference between these headstage versions is the size of the probe board Hirose connector used for board stacking and connecting to the headstage. In this case, the 70 and 80 refers to the connector pin count. These headstage versions are functionally similar, but an adaptor board is required for cross-compatibility.

The headstage version can also be identified using the ref/ground board. The H80 uses a ref/ground board equal in size to the Probe Boards (Fig. 2), the H70 uses a shorter board.

When using the H70→H80 adaptor to connect H70 probe boards to an H80 headstage, grounding should still be done using the H70 ref/ground board. When using the H80→H70 adaptor all grounding should be done using the adaptor board.

## Headstage Functions

### Headstage Processor Unit

The MSH utilizes an integrated processor (FPGA) to achieve scalability, flexibility and modularity. The processor flexibly communicates with up to 8 128-channel Probe Boards simultaneously, combining their output into one high-speed data stream. In tethered recording mode, this allows for real-time streaming of up to 1024 channels of data simultaneously via a single cable tether.

In untethered data-logging mode, this allows up to 512 channels of data (recorded at 20KHz, 12-bit) to be written directly to onboard micro SD storage. The lower untethered channel count is due to the write speed restrictions of micro SD storage.



**Figure 1** | MSH with open module bay. 8 128-channel Probe Boards (green) and 1 reference board (black).

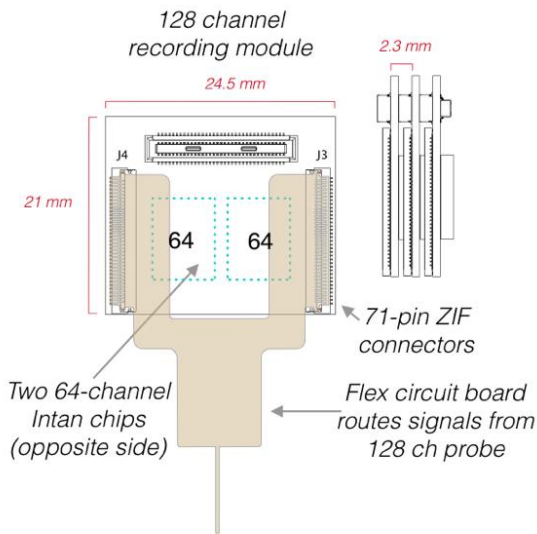
### 128-channel Probe Boards

Each 128-channel Probe Board is equipped with 2 Intan Technologies RHD2164 64-channel digitization and amplification chips optimized for neural recording. This allows neural signals to be recorded at 30KHz with a resolution below  $1\mu\text{V}$  and 2.4-2.8 $\mu\text{V}$  RMS typical input-referred noise.

Up to 8 Probe Boards can be stacked via daisy-chaining (see below) and are connected directly to the headstage's processor unit. A reference/grounding board must also be included in the stack.

**Figure 2** | 128-channel Probe Boards. Probe Boards are equipped with ZIF connections to electrode arrays on one side (upper left), with dual 64-channel Intan chips on the other (lower left). 1 to 8 Probe Boards can be stacked to meet channel-count needs (upper right). The reference board (bottom right) connects all boards in the stack to a single reference, tied to ground.





**Figure 3** | Schematic showing flexible printed circuit (FPC) mated to Probe Board ZIF connectors.

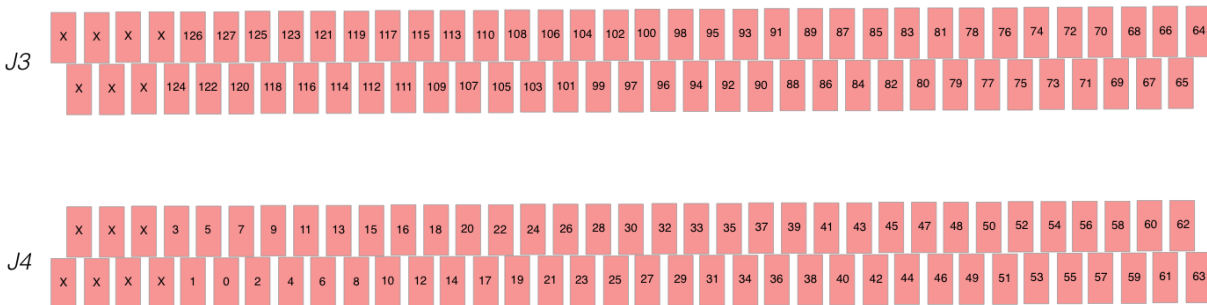
The MSH Probe Boards are designed for use with high-density silicon/polymer probes or arrays (including ECoG) to facilitate high channel count neural recording experiments across many channels or brain regions. Probes interface with the Probe Boards via a single-sided flexible printed circuit (FPC). In most cases the FPC must be custom designed by the experimenter to meet the needs of their specific experimental requirements.

MSH global hardware channel mapping is zero-based and can be determined using the channel mapping of the 71-channel Hirose ZIF connections on each Probe Board, where  $n$  is the channel ID shown in figure 4 below.

When stacking multiple Probe Boards, the global identity of a given channel can be found using the following equation:

$$\text{Hardware channel} = n + (128 * \text{the number of preceding Probe Boards in the stack})$$

Where  $n$  is the Probe Board channel as seen below.

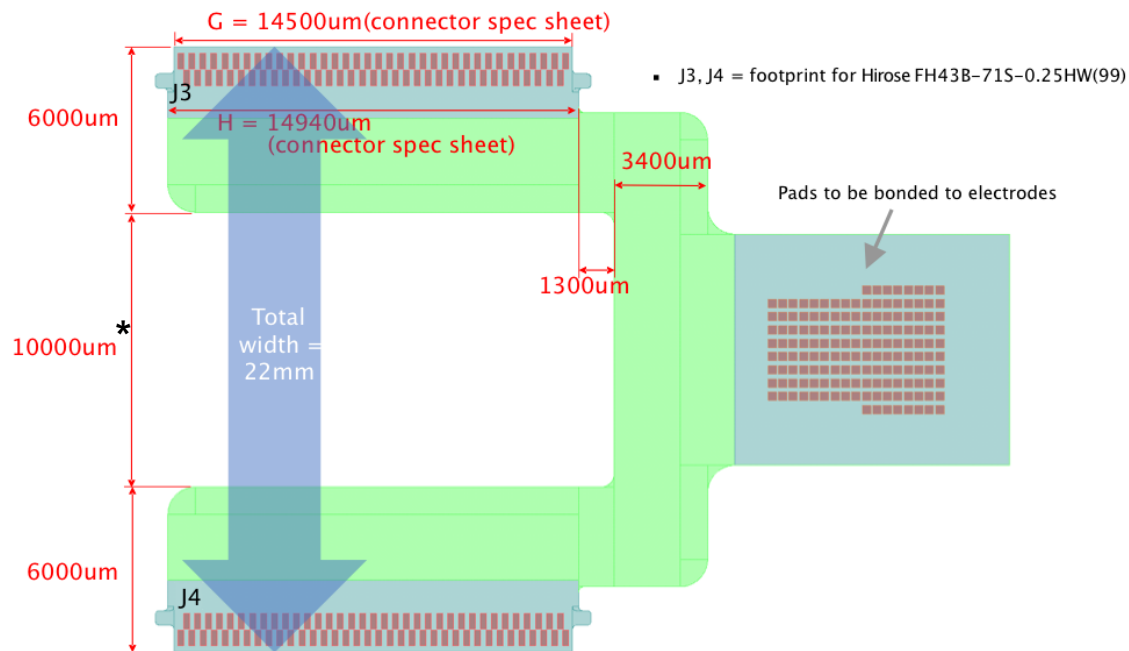


**Figure 4** | MSH Probe Boards channel mapping. Hardware channels are zero-based. J3 and J4 correspond to the 71-pin ZIF connectors shown in fig. 3 and fig. 4. Contacts are shown facing away, as if looking at the FPC while connected to the Probe Board ZIF connectors.

## Probe Interfacing

Recording probes/arrays are connected to the MSH Probe Boards using a flexible printed circuit (FPC) interface. For most applications this is achieved by bonding the probe/array contacts to a custom FPC that connects to the Probe Board ZIF connectors. Due to the myriad of available probes and application-specific configurations possible, SpikeGadgets does not offer FPC adaptors. The recommended “Y” shaped FPC layout can be seen in figure 5 below. For more detailed information about ZIF connector contact layout requirements, see the Hirose [datasheet](#) for the FH43B series connector.

**NOTE:** FPC traces should be routed to maintain a “Y” shaped board as seen in Figs. 3 & 4. This minimizes potential EM field effects caused by Probe Board componentry.



**Figure 5** | Expanded view of single-sided FPC dimensions and contact orientations. FPC shown with contact pads facing away, as in the schematic show in fig. 2.

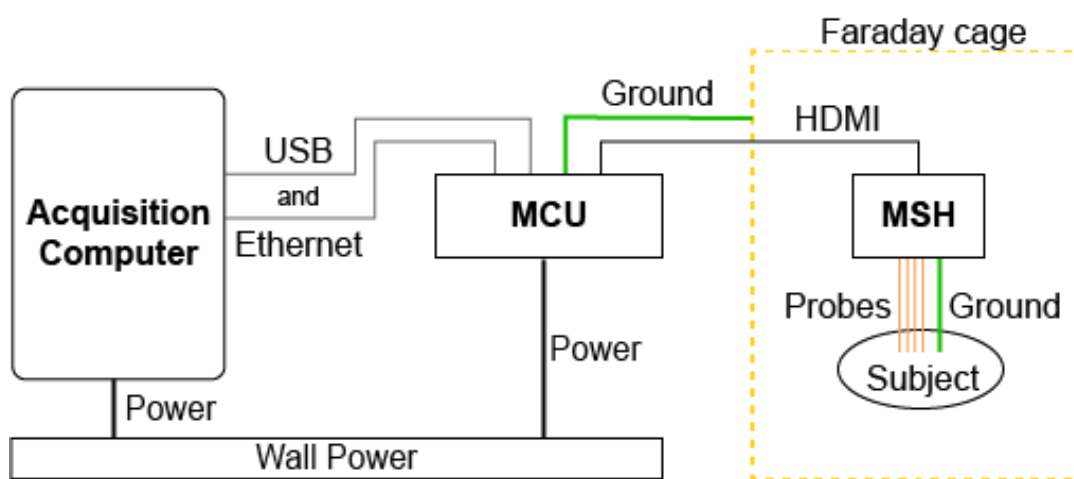
\*While 10000μm is recommended, this spacing can be reduced to a minimum of 9000μm if additional spacing is needed for routing to the ZIF contacts. Reducing this spacing below 9000μm is strongly advised against.

## Referencing and Grounding

The MSH uses a common line to connect all Probe Boards. This line serves as the reference for all channels and is tied to the system ground by default. No grounding or referencing is performed using the recording probes/arrays connected to the Probe Board ZIF connectors. This is true for both the H70 and H80 versions of the MSH, with the H80 using a different underlying circuit configuration to improve the electrical noise profile for high channel count applications.

The MSH supports up to 1024 channels of simultaneously recorded neural data when stacking 8 128-channel Probe Boards. This enables a high degree of flexibility when selecting probes/arrays, as the channel count for any individual probe/array is not restricted to 128 channels.

This is achieved by using a single amplifier reference/ground line for all channels. This avoids ground loops and helps prevent amplifier artifacts that can arise from using multiple reference lines. Importantly, the Probe Board reference/grounding line is routed separately from 71-pin ZIF connectors on the Probe Boards. This ensures that no multi-referencing occurs.



**Figure 6** | Recording setup grounding diagram

When preparing your setup for recording, proper grounding is crucial. This can be achieved using the hardware configuration shown above. In this configuration, a single ground line is connected from the headstage reference board to the experimental subject (often to a implanted skull screw). Importantly, when grounding equipment such as a faraday cage to the MCU, this must be connected to the 2mm ground jack in the rear of the MCU, not the MCU case. NOTE: The MCU and computer should be powered using the same circuit when possible. If this is not possible, connecting with only Ethernet may reduce ground issues.



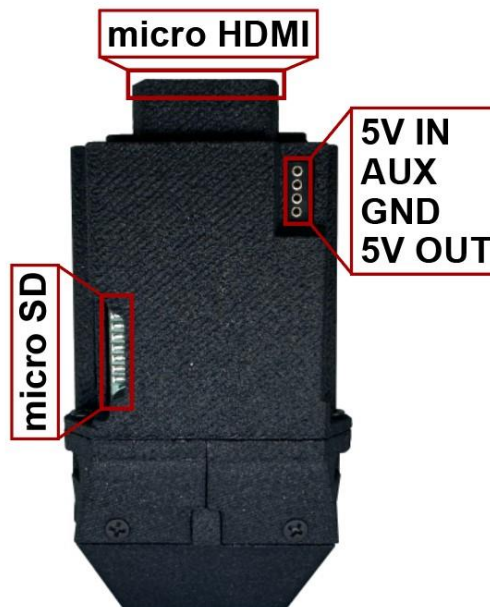
## External Ports

The MSH is equipped with externally accessible ports for both routine and custom applications.

**Micro HDMI:** When using the MSH for tethered recordings, the headstage is connected to the MCU via the micro HDMI port. This allows data to be streamed and saved to the local computer using Trodes.

When recording untethered, the headstage is powered using an external battery connected to the micro HDMI port using the SpikeGadgets battery adaptor.

**Micro SD:** When recording untethered, the micro SD card used to save data is inserted into this slot.



**Figure 7** | MSH external connection ports

**NOTE:** Tethered data streaming in Trodes cannot be initiated while a SD card is mounted in the MCU or connected headstage.

The MSH is also equipped with an externally accessible 4 pin female Mill-max connector (1.27mm pitch) for connecting external devices and components as seen in Fig. 5 above.

**5V input:** The 5V input can be used to power the headstage in situations where the micro HDMI connection is inaccessible or an alternative power source is needed. **NOTE:** connecting a battery to the 5V input while powering the system via HDMI should be avoided.

**AUX:** The auxiliary port is currently inactive but retained for future development.

**GND:** The ground input is connected to the unified headstage ground to ensure a single ground line for any connected devices.

**5V OUT:** The 5V output can be used to power external components of devices such as LED arrays for headtracking applications.

## LED Indications

Color	Pulse	Meaning
<b>Red &amp; yellow</b>	3 blinks	Headstage powered on
	0.25 Hz blinking	Low battery voltage detected*
	4 Hz blinking	Processor bootup error
<b>Red</b>	Solid	Hardware error**
	4 quick blips	Recording Stopped. Initiates when streaming is stopped in Trodes.
	1 quick blip during logging/streaming	Dropped packet
	1 Hz	SD Card mount error (including no card mounted)
	4 Hz	SD card is not enabled
	Breathing	Recording ended***
<b>Yellow</b>	4 quick blips	Start recording
	2 Hz	Mounting SD card
	Breathing	SD card is mounted and ready to record
	Breathing with blips	SD card mounted and receiving RF signal from the control unit (MCU or Logger Dock)

\* This indicates that the battery should be charged before recording. In some cases the recording will automatically be aborted.

\*\* This can indicate a hardware communication issue between either the Probe Boards and headstage or the SD card and the headstage. For chronic implantations where accessing the Probe Boards may be difficult, it is crucial to verify proper headstage function and streaming in Trodes during implantation. Otherwise, the Probe Boards and SD card may need to be disconnected and reconnected to troubleshoot the issue.

\*\*\* This can indicate 2 different conditions: 1) The recording has ended because the headstage received a user-initiated stop command from the control unit. 2) The recording has ended because the SD card reached capacity, automatically ending the recording.

## Standby Mode

When using the MSH for untethered recording, battery life is a key consideration. To maximize recording time, the MSH saves battery life by entering standby mode until a recording is initiated\*. When in standby mode, the headstage can receive radio frequency (RF) commands from control units (MCU or Logger Dock), but most other headstage functions remain dormant.

In standby mode, when the MSH receives a start command from the control unit, the headstage runs a brief boot-up sequence checking all headstage functions before initiating recording. This ensures that all systems are functional before recording begins. The MSH re-enters standby mode when it receives a stop command from the control unit.

**NOTE:** When in standby mode, the 5V OUT is unpowered. This means that any external devices or components powered by this port, such as LED arrays for headtracking, will not receive 5V power until the recording is initiated.

\*Standby mode is present in all headstages running firmware version 4.4.1-1.1.2 or later.

## Headstage Configuration and Recording

### Headstage Configurations

In tethered mode, an HDMI to micro HDMI cable is used to power the headstage and stream data to the MCU. Once connected via micro HDMI, if the headstage is properly detected by the MCU, the MCU's power indicator LED will change from blinking amber to solid green. Data streaming is controlled by the Trodes application via the MCU. More information about this can be found in the [Trodes wiki](#).

For both tethered and untethered recording modes, headstage settings are modified using Trodes and saved to the headstage's onboard flash memory. The MSH must be configured in Trodes while connected to the MCU via HDMI before recording in untethered mode. To modify settings, the MCU connection to your computer must be enabled in Trodes, but streaming should not be initiated. Settings cannot be saved to the headstage while streaming data. Headstage setting specific to untethered recording will be discussed [below](#).

Connecting your MCU to your computer via Trodes is done under the Connection dropdown in your Trodes Workspace:

Connection > Source > SpikeGadgets > USB **OR** Ethernet

The following MSH settings can be modified under t Settings in your Trodes Workspace:

- **Auto Settle** – Large transient electrical events (caused by electrical stimulation, physical bumping, etc.) can cause extended amplifier ringing. The Auto settle function resets the amplifiers when this occurs and allows you to set a voltage and channel count threshold for triggering the reset.

**IMPORTANT NOTE:** Auto settle channel threshold should always be set to a value greater than zero. Failure to do this can result in high amplitude noise “ticks” occurring at a 500ms interval across all neural data channels.

- **Sampling Sequence Correction (on/off)** – Eliminates temporal referencing error associated with the sequential nature of how Intan channels are sampled. It is highly recommended to turn this on when using digital reference.
- **3-axis accelerometer (on/off)** – The accelerometer range is +/- 2g, encoded in signed 16-bit integers. This means each step is  $2/32767g$  or  $0.000061g$ .
- **3-axis gyro (on/off)** – The gyro range is +/- 2000 degrees/second at 16 bits, or  $0.061deg/sec$  per step.

The accelerometer and gyro sensors both refresh at 104 Hz. When both sensors are enabled, each sensor is sampled at 500 Hz. When only one sensor is enabled, it is sampled at 1kHz.

### Initiating a Tethered Recording

1. Open Trodes and create a new Workspace “From Scratch” under the Create/Edit Workspace menu or open the Workspace you have already created.
2. Once you have opened your Workspace, connect your headstage to the MCU via HDMI, and link your MCU to Trodes using the "Connection" dropdown menu by selecting: Source > SpikeGadgets > USB OR Ethernet
3. Begin streaming by clicking "Stream from source" under the Connections dropdown menu.
4. Create a new recording file by selecting "New recording" under the File dropdown menu.
5. Set your recording directory using the file explorer pop-up window.
6. Begin recording by hitting the record button.

7. To end your recording, hit the pause button, and disconnect your stream.

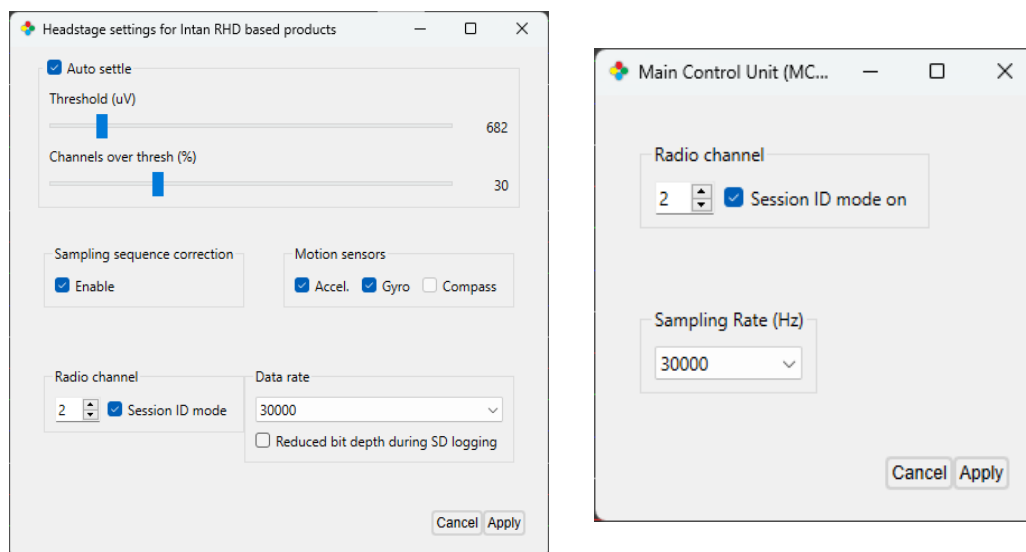
For more information about using Trodes and tethered recording, see the [Trodes Wiki](#).

## Untethered Configuration and Recording

In untethered data-logging mode, the MSH records neural data directly to an onboard microSD card without the need of a cable tether. It does this under battery power by receiving wireless communication from the control unit (MCU or Logger Dock). The MCU or Logger Dock sends start/stop and synchronization commands to the headstage via radio frequency (RF) wireless link.

This guide will primarily cover untethered recording using the MCU for RF control. The Logger Dock can also be used for RF control, but the MCU is still needed for updating headstage settings via HDMI.

When taking an untethered data-logger recording, the headstage and control unit must be set to the same Radio Frequency (RF) channel and sampling rate, with RF session ID mode turned on (as shown below).



**Figure 8** | Headstage and MCU RF channel, sampling rate and session ID mode

**Logger Dock Usage:** When using the Logger Dock to control untethered recording, the RF channel and Session ID settings can be changed using the DataLoggerGUI application packaged with Trodes. These settings can be updated by selecting your connected Logger Dock from the Detected Storage Devices menu, then clicking the Edit Device Settings button to the upper right.

## Preparing your Headstage for Untethered Recording

1. Open Trodes and create a new Workspace "From Scratch" under the Create/Edit Workspace menu or open the Workspace you have already created.
2. Connect your headstage to the MCU via HDMI and link your MCU to Trodes using the "Connection" dropdown menu by selecting:

Source > SpikeGadgets > USB **OR** Ethernet.

- Your SD card should not be inserted into your headstage yet.
3. Under the "Settings" dropdown menus, set the MCU and headstage RF channel and sampling rate to the same values and select the session ID mode checkbox for both (Fig. 8):

**MCU:** Settings > MCU Settings...

**Headstage:** Settings > Headstage Settings...

4. Apply your settings above, then save your Workspace. This Workspace can be used later as the basis for the Workspace used to merge your neural and environmental data.

## Initiating an Untethered Recording

1. Connect your RF transceiver to the Aux 1 port on the front of the MCU.
  - When using the Logger Dock, the RF transceiver connects to the rightmost SPI connector on the front of the unit.
2. Disconnect your headstage from the MCU, connect the headstage to battery power, insert your SD card into the headstage and power the headstage on.
  - For more information about preparing your SD card, see [SD Card Setup](#) above.
2. Open Trodes and create a new Workspace with channel count set to zero. This Workspace will be used to acquire the environmental record.
3. If you are using an Environmental Control Unit (ECU), make sure this is connected to your control unit via HDMI. Your ECU must also be added to your Workspace by selecting "ECU" from the Hardware Devices dropdown menu, then clicking "+Add Device."

4. Open your Workspace, connect to your MCU, and set your MCU RF channel and sampling rate to match the settings you previously applied to your headstage, also making sure Session ID mode is checked.
5. When you are ready to begin recording, select "Stream from source" from the Connections menu. This will trigger the headstage to begin recording.
6. To initiate recording with the MCU, select "New Recording..." from the File dropdown menu and select your recording directory.
7. Hit the red "record" button to begin recording your environmental record with the MCU.
8. To end your recording, hit the pause button, and disconnect your stream.

**IMPORTANT NOTE:** When recording untethered, the headstage starts recording when you begin streaming with the MCU, but the MCU will **NOT** start recording until you create a new recording file and hit the record button in Trodes. The same holds true for ending your recording; the MCU recording can be ended or paused using the interface buttons, but the headstage recording is ended by disconnecting your stream.

## Batteries and Charging for Untethered Recording

When recording untethered, the Modular Stacking Headstage is powered using rechargeable 3.7V Lithium-ion batteries. Attempting to power the headstage using a different battery type is not recommended and can result in damage to the headstage or connected boards or probes. For most applications a capacity of 400 mAh is recommended.

Batteries can be charged using either the [SpikeGadgets Battery Charger](#), or a 3<sup>rd</sup> 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.

## SD Card Setup

Before an SD card can be used for untethered recording, it must be enabled. This can be done using the MCU or Logger Dock, or using [Direct Access](#) (Trodes 2.5.0 or later).

**MCU:** Place the micro SD card in an SD adaptor, mount to MCU and press and hold the left MCU button. The LED will flash red rapidly then turn solid green. The button can be released when the LED turns green, indicating the card has been enabled.

**IMPORTANT NOTE:** SD cards should only be mounted to the MCU when being read or enabled and should be removed following the action. The MCU cannot read or enable the SD card while streaming, and streaming cannot be initiated while an SD card is mounted.

## Enabling SD via the Logger dock using the DataLoggerGUI

1. Once your SD card has been inserted into the Logger Dock or MCU, open the DataLoggerGUI application from the Trodes application directory.
2. Your SD card should be listed under "Detected Storage Devices." If you do not see your device listed, hit the refresh button.
3. Select the relevant device and hit the "Enable for recording" button to enable your SD card.

## Synchronization

Synchronization between the environmental record recorded by Trodes on your local computer and the neural data recorded to SD on the headstage is done via a radio signal sent at regular intervals (10-second intervals for most setups). This signal is transmitted from the SpikeGadgets control unit that acquires your environmental data and connects to your computer. Trodes connects to this control unit to display and save the environmental data during the recording session. Any video recordings taken using the Camera Module in Trodes are set up the same way they would be for tethered recording.

Importantly, the neural data being recorded to SD cannot be accessed during recording. Once the recording session is done, there will be 2 data files that need to be merged. One data file contains the neural data and is saved to the headstage SD card, the other contains the environmental data saved to your computer. These two files will be aligned using the synchronization signals saved to both files and will be merged using the DataLoggerGUI.

## Transferring and Merging Data

In order to merge your data files into a single .rec file you will need the following:

1. The file containing the recorded neural data from the headstage SD card.
2. The file containing the environmental data recorded to your local computer by Trodes.



3. A Trodes workspace file to append to the merged file containing both environmental record settings as well as probe and channel setting as if the recording were taken in tethered mode. A step-by-step workspace creation tutorial video can be found [here](#).

### Merging Data using the DataLoggerGUI:

1. Power down the headstage, remove the SD card and insert it into the Logger Dock or MCU. **NOTE:** MCU must be running firmware 3.19 or later.
2. Open the DataLoggerGUI application found in the Trodes application folder.
3. The Logger Dock will be listed under the Detected Storage Devices with storage size, type and SD card status listed.
4. Under Extract, select your .rec file and corresponding Workspace .trodesconf file, and set your extracted data directory.
5. Hit START.

More information about workspace creation, the DataLoggerGUI and data merging can be found under the [Workspaces](#) and [DataLoggerGUI](#) subsections of the Trodes Wiki.

## Additional Resources

For information about getting started with your SpikeGadgets recording system, please visit the [Trodes Wiki](#), which contains additional information and resources covering many basic and advanced topics about using SpikeGadgets recording systems. For new users, a good place to start is the [Quickstart Guide](#).

Additional information and [documentation](#) about all our [products](#) and [software](#) can be found on our [website](#).

### 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](mailto:support@spikegadgets.com).