NeuroNexus

XDAQ™ USER MANUAL

March 2024

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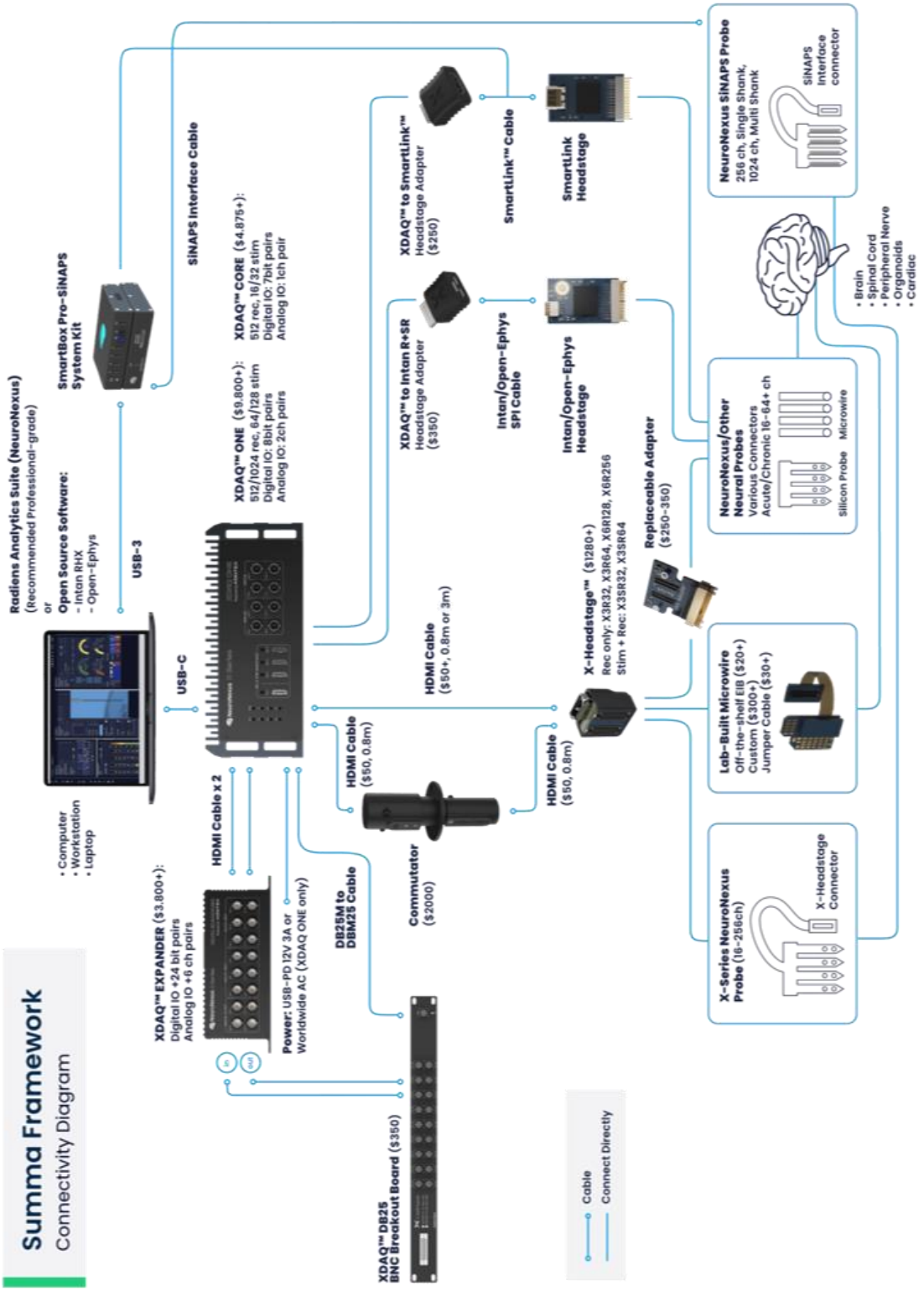

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Congratulations on your new XDAQ system!

Welcome to the forefront of electrophysiology research, where the *NeuroNexus Summa Framework* stands as an innovative and unified ecosystem that not only enhances research productivity but also serves as a catalyst for accelerating scientific discovery. Within this framework, the combination of NEURONEXUS SILICON PROBES, XDAQ SYSTEMS, and the RADIENS ANALYTICS SOFTWARE SUITE provides an integrated, turn-key solution that sets the industry standard for performance, efficiency, and cost-effectiveness. By providing a fully integrated electrophysiology solution, NeuroNexus enables researchers to navigate the complexities of scientific research with more confidence in their experiment data acquisition protocols and quality control. The *Summa Framework* demonstrates NeuroNexus' ongoing work to "make the complex simple" regarding streamlined workflows across diverse research applications. NeuroNexus is committed to delivering value without compromise.

The XDAQ SYSTEMS are the instrumentation core of the *Summa Framework*. XDAQ embodies best-in-class performance and flexibility, providing researchers with a highly performant data acquisition system that lays the foundation for groundbreaking discoveries. Combined with NEURONEXUS SILICON PROBES and RADIENS:ALLEGO SOFTWARE MODULE, this system becomes a one-stop-shop integrated electrophysiology solution, streamlining workflows and maximizing efficiency to meet demanding experiment requirements today and in the future.

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1. Document Overview

This document describes the specifications and features of the XDAQ™ instrumentation systems and associated products. It also provides information on how to set up, test and use your XDAQ™.

2. XDAQ™ Overview

The XDAQ™ is a family of highly integrated, multi-modal data acquisition systems for animal research. It is capable of recording up to 1024 channels of high-quality spike activities simultaneously. In the Stim-Rec (SR) mode, it is capable of driving stimulus pulses and recording from up to 128 channels of electrodes when paired with the XSR headstages.

The XDAQ™ also comes with several onboard digital and analog IO that can be used to interface with common laboratory equipment.

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3. XDAQ™ Models and Accessories

3.1. XDAQ™ Models

3.1.1. XDAQ™ CORE

LED Indicators

SYS	[ON]	Program loaded
	[Flashing]	Hardware Error
S1	[ON]	Acquisition on
S2	[Flashing]	Activities* in DIN1 and DIN2
S3	[Flashing]	Activities* in DOUT1 and DOUT2
P1	[ON]	Headstage Detected on Port 1 (after software initialization)
P2	[ON]	Headstage Detected on Port 2 (after software initialization)
P3	[ON]	Headstage Detected on Port 3 (after software initialization)
P4	[ON]	Headstage Detected on Port 4 (after software initialization)

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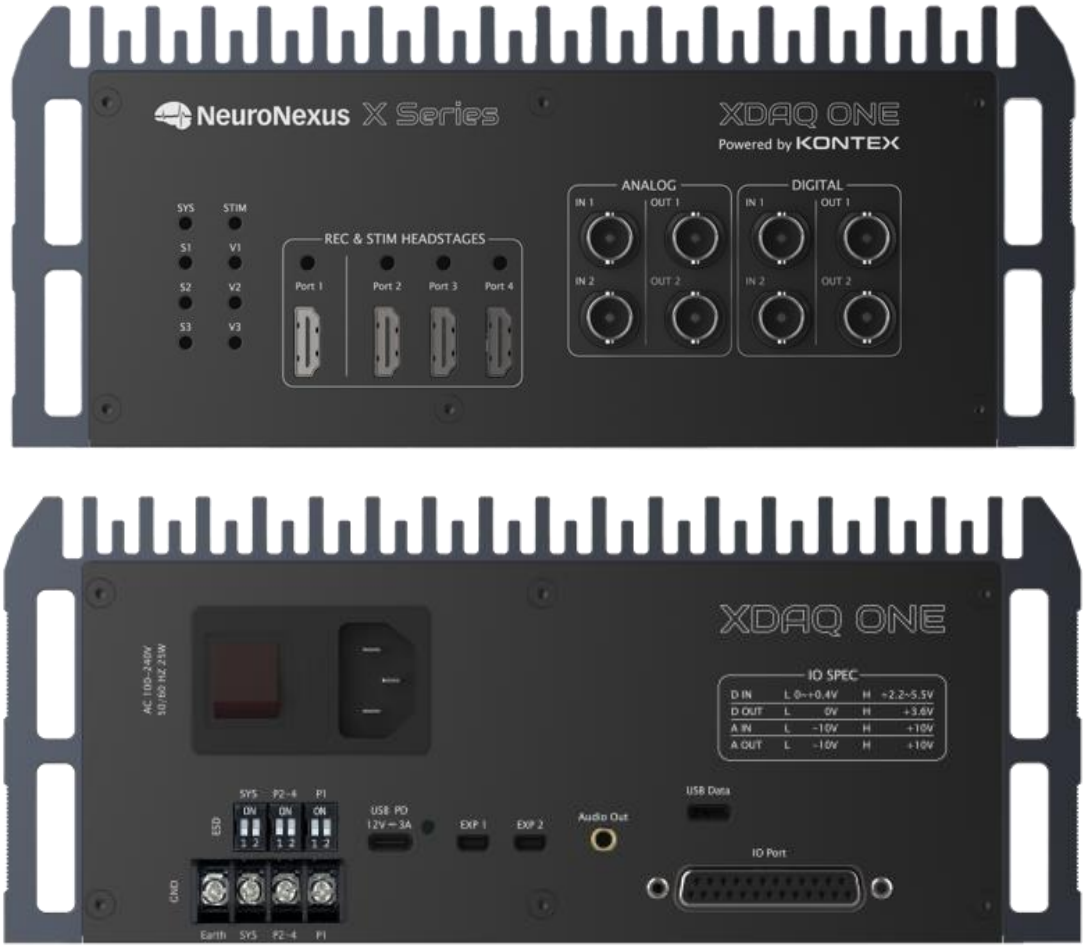
3.1.2. XDAQ™ ONE



LED Indicators

SYS	[ON]	Program loaded
	[Flashing]	Hardware Error
S1	[ON]	Acquisition on
S2	[Flashing]	Activities* in DIN1 and DIN2
S3	[Flashing]	Activities* in DOUT1 and DOUT2
STIM	[ON]	XDAQ™ in StimRecord (SR) Mode
V1	[ON]	VStim level set to +/- 7V
V2	[ON]	VStim level set to +10/-4V
V3	[ON]	VStim level set to +4/-10V
Port1	[ON]	Headstage Detected on Port 1 (after software initialization)
Port2	[ON]	Headstage Detected on Port 2 (after software initialization)
Port3	[ON]	Headstage Detected on Port 3 (after software initialization)
Port4	[ON]	Headstage Detected on Port 4 (after software initialization)

* DIN, DOUT flash rate is deliberately slowed down for visualization purposes.

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3.1.3. DB25 Connector

DB Pin	Signal
1	
2	DI 03
3	DI 05
4	DI 07
5	
6	
7	
8	
9	
10	DO 04
11	DO 06
12	DO 08
13	DAQ_ON
14	SYS GND
15	DI 04
16	DI 06
17	DI 08
18	
19	
20	
21	
22	DO 03
23	DO 05
24	DO 07
25	Sample_CLK

DAQ_ON signal will be high whenever XDAQ™ acquisition is running.

Sample_CLK signal is a pulse train with frequency equals to the headstage sampling rate when the acquisition is running.

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3.1.4. Model Comparison & Specifications

	CORE	ONE
Recording Amplifier (XR) Supported	512ch 128ch per port	512ch or 1024ch 256ch per port
Stim-record Amplifier (XSR) Supported	16ch or 32ch 32ch per port	64ch or 128ch 32ch per port
Recording Sensitivity	16bit ADC, 1k - 30k Hz sampling per channel, 2.4 µVrms input-referred noise	
Stimulation Capability	Constant current source, 10n - 2.55mA per channel, 33µs steps	
Stimulation Compliance Voltage	±7V	Configurable: ±7V, 10 to -4V, 4 to -10V
Signal Isolation	No	Yes
Headstage Power Circuits	1 or 8*	2 or 16*
Max # Experiment /Headstages Supported	8 X3R32* 4 X3R64* 8 XeR64* 4 X6R128 1 X3SR32 or XeSR32 2 XeSR16	16 X3R32* 8 X3R64* 16 XeR64* 8 X6R128* 4 X3SR32 8 XeSR16* 2 X3SR64**
Onboard Synchronized IO	7 Digital IN: 2.2 - 5.5V logic 7 Digital OUT: 3.6V 1 Analog IN: 16bit ±10V 1 Analog OUT: 16bit ±10V	8 Digital IN: 2.2 - 5.5V logic 8 Digital OUT: 3.6V 2 Analog IN: 16bit ±10V 2 Analog OUT: 16bit ±10V
Power Input	USB-PD 12V, 3A	USB-PD 12V, 3A or 100-240VAC
Dimension	72 x 190 x 155 mm	100 x 160 x274 mm
Weight	0.87 KG	3.1 KG

* Requires Port Expander

** Requires SR64 Adapter

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3.2. Headstage

The X3- and X6- Headstage are a family of ultra-small headstages based on Intan Technologies' frontend amplifier/digitizer. NeuroNexus leverages advanced chip packaging technology to pack multiple Intan digitizers inside each NeuroNexus chip, offering the same high-quality recording/stimulating performance at a significantly reduced footprint.

X-Headstage™ or another Intan compatible headstages are required for proper functionality of the XDAQ™.

See X-Headstage™ manual for handling and care information.

3.2.1. XR Recording X-Headstage™

NeuroNexus currently offers 4 main recording headstage (XR) configurations:

- X3R32: 32-channel recording headstage (based on 1 RHD2132; 1 32-ch data stream will be shown in the compatible software)
- X3R64: 64-channel recording headstage (based on 2 RHD2132; 2 32-ch data streams will be shown in the compatible software)
- X6R128: 128-channel recording headstage (based on 2 RHD2164; 2 64-ch data streams will be shown in the compatible software)
- XeR64: 64-channel recording e-series headstage (based on 1 RHD2164; 1 64-ch data streams will be shown in the compatible software).

Each XR X-Headstage™ can be configured with either a micro-HDMI connector or an optional Omnetics connector. All XR X-Headstage™ is equipped with a 3-axis gyroscope for activity monitoring.

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Each X3R or X6R headstage can be optionally configured with a protective cover that serves as additional protection or anchoring.

N Armor

M Armor

S Armor

IP Armor

3.2.2. SR Stim-Record X-Headstage™

NeuroNexus currently offers 4 main stim-record headstage (XSR) configurations:

- X3SR32: 32-channel stim-record headstage (based on 2 RHS2116; 2 16-ch data stream will be shown in the compatible software)
- X3SR64: 64-channel stim-record headstage (based on 4 RHS2116; 4 16-ch data stream will be shown in the compatible software)
- XeSR16: 16-channel stim-record e-series headstage (based on 1 RHS2116; 1 16-ch data stream will be shown in the compatible software)
- XeSR32: 32-channel stim-record e-series headstage (based on 2 RHS2116; 2 16-ch data stream will be shown in the compatible software)

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The SR Headstage can only be configured with the micro-HDMI connector. If you require the stock Intan style 16pin Omnetics connector for the X-Headstage™, contact NeuroNexus for customization.

Each 3-series SR X-Headstage™ can be optionally configured with a protective cover that serves as additional protection or anchoring.

3.2.3. E-Series X-Headstage™

E-series X-Headstage™ is designed to offer the best value while maintaining the flexibility of the X-Headstage™ that can be used with several off-the-shelf probe adapters. The advantage of adapter-based approach can increase the utilization and longevity of headstage usage. If the probe facing connector breaks due to daily wear, it can be easily and cheaply replaced.

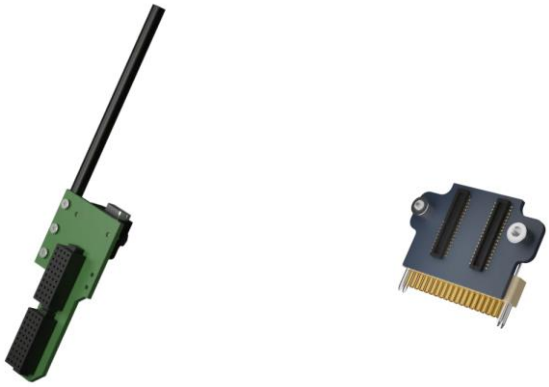
E-series X-Headstage™ is denoted by the Xe- followed by R for recording only headstage and SR for switchable stim-record headstage.

3.2.4. Other Headstages

XDAQ™ can control any Intan compatible headstages with proper signal mapping. Please be aware that even though some other vendors offer headstages with the (micro-)HDMI connector, it may not work when plugged into the XDAQ™ HDMI cables. NeuroNexus provides several off-the-shelf adapters to support stock Intan/Open-Ephys or KONTEX headstages.

3.2.5. X-Headstage™ Probe Adapters

X-Headstage™ have minimally sized onboard connectors that fit within the footprint of the device. NeuroNexus offers several electrode interface boards that mate directly to the X-Headstage™. NeuroNexus offers several off-the-shelf adapters that provide interface to commercial or lab-built electrodes with other connectors. NeuroNexus is experienced with designing custom adapters to interface with electrodes which are not currently accessible. Contact us to get started.



3.3. XHS HDMI Cable

XDAQ™ is designed to leverage the best of the consumer tech products and solutions. However, not all off-the-shelf HDMI cables will work with XDAQ™ as they vary slightly in signal configuration and some cables (longer ones in particular) may even include integrated circuits/amplifiers that are not compatible with the XDAQ™'s communication protocol. It is highly recommended to use KONTEX stock HDMI

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cables for the most reliable connectivity without risking damaging the XDAQ™ system or the X-Headstage™.

Currently NeuroNexus offers 2 cable length options:

- 80cm XHS HDMI Cable
- 3m XHS HDMI Cable

Each cable has a wire diameter of 2.5mm and can be used to drive both XR and XSR X-Headstage

3.4. Recommended Accessories

3.4.1. Commutator

A 360-degree rotary joint supporting up to 256ch of XR X-Headstage™ or 32ch of XSR X-Headstage™ can be used with the XDAQ™. NeuroNexus offers both passive (COM-P256, pictured left below) and assisted (motorized) commutator (COM-A256, pictured right below) designs.

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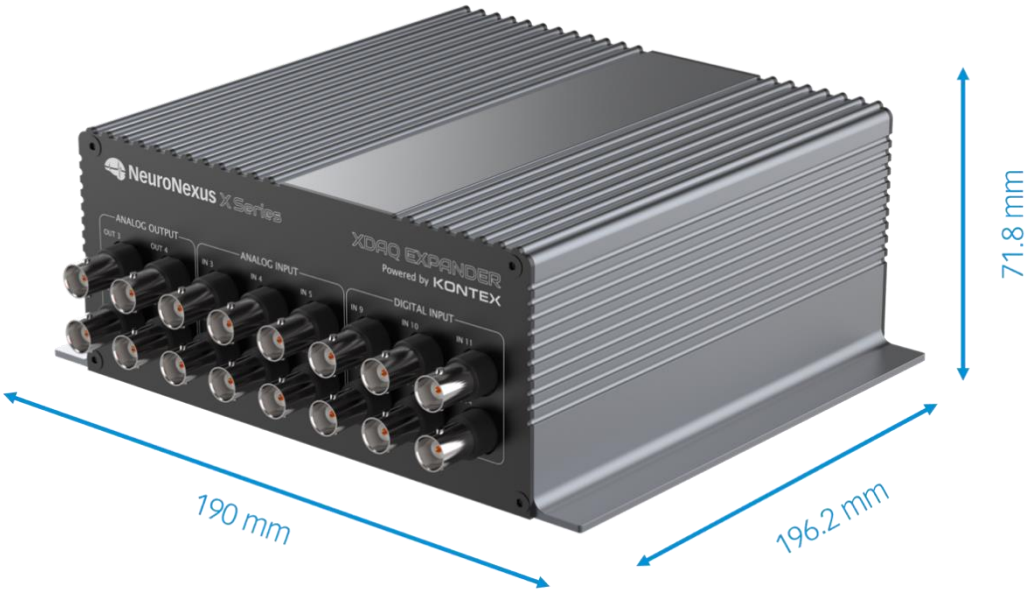
3.4.2. IO Expander

The IO Expander adds additional IO acquisition capability to each XDAQ™.



- + 24 Digital Inputs: Logic high 2.2 - 5.5V
- + 24 Digital Outputs: Logic high 3.6V
- +6 Analog Inputs: +/- 10.24V
- +6 Analog Outputs: +/- 10.24V

The IO acquisition or update rate will be the same as the sampling rate of the X-Headstage™ controlled by the XDAQ™.

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3.4.3. Port Expander

The Port Expander allows each XDAQ™ to drive up to 4 headstages, or experiments, per port for the recording only XR Headstage or 2 experiments per port for the XSR stim-record X-Headstage™. Each HDMI port in the Port Expander is designed with independent and isolated power sources and ground nodes so the experiments will not interfere with one another. The Port Expander is battery powered to ensure a noise free communication with the X-Headstage™.

3.4.4. Brainwave Simulator

The Brainwave Simulator is a two-channel signal generator designed for system debugging and verifications. It can be configured to deliver sinusoid, triangle, and square waveforms at four preset frequencies and amplitudes as well as neural activity playback. The Brainwave Simulator can also be used to send a digital pulse for XDAQ™ Digital IN acquisition/trigger debugging purposes.

3.4.5. Connector Cycle Extender

Cycle extender adapter is designed as a throw away piece to overcome the limitation of small numbers of rated mating cycle of the ultrasmall connectors used in the X-Headstage™ and prolong the

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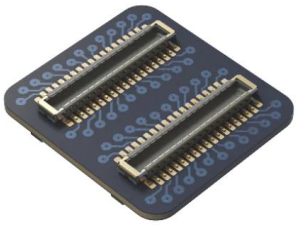
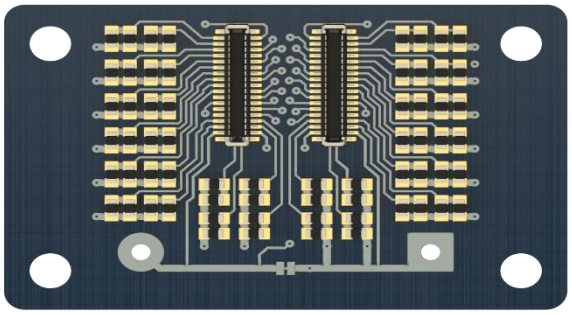
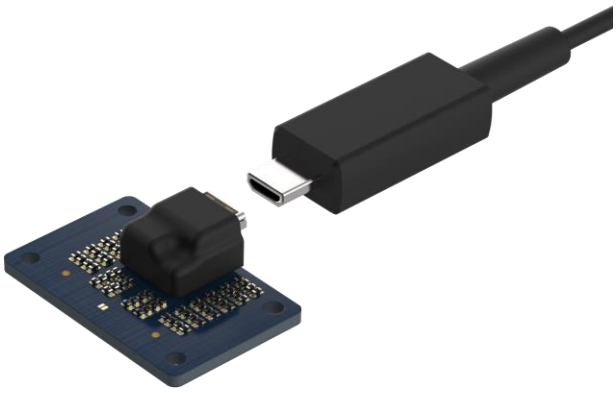
connectivity cycles of the X-Headstage™ onboard connector. The connectors are pin-to-pin mapped and add 1.2mm to the spacing between the EIB and the X-Headstage™.



3.4.6. Impedance Test Board

A series of RC test loads designed to mimic electrodes of various impedance. This allows the XDAQ™ to perform and verify the impedance measurement functionality of the X-Heastage & XDAQ™.





3.4.7. Stimulation Test Board

The stimulation test board pairs each amplifier channel with a 1kOhm resistor (size 0805), mimicking electrodes with 1kOhm impedance. It is possible to swap the 1kOhm resistor to a value that is closer to the impedance of the electrode to be used. By probing the pad next to the resistor and the ground pin

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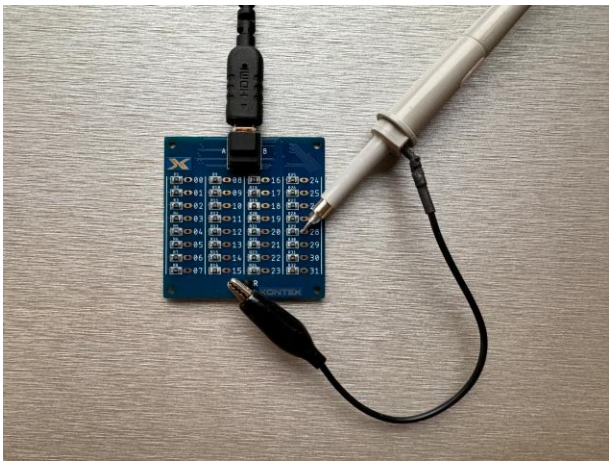
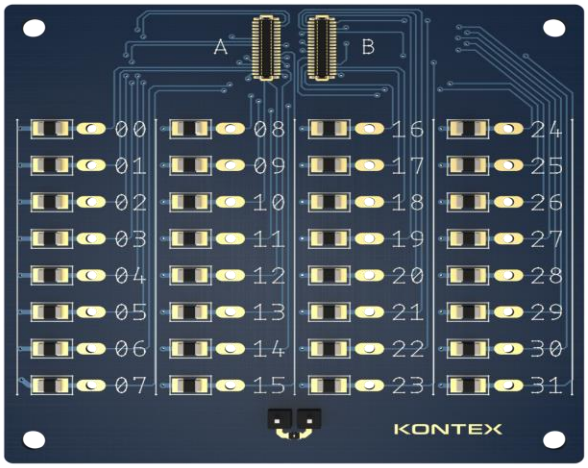
allows users to verify the stimulus pulses delivered by the XDAQ™ and X-Headstage™ on an oscilloscope.





3.4.8. XDAQ™ & IO Expander BNC Breakout Board

Each XDAQ™ and IO Expander includes several IO ports within the DB25 connector. The BNC Breakout Board provides easy access to these IO signals through the BNC connectors.

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3.4.9. XDAQ™-Intan Adapter

XDAQ™ to Intan Stim SPI Cable Adapter

Use this adapter to connect XDAQ™ with standard Intan Stim headstages and the Stim SPI Cable

XDAQ™ to Intan SPI Cable Adapter

Use this adapter to connect XDAQ™ with standard Intan headstages and the SPI Cable. Each adapter can support up to 2 cable-headstage systems.

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4. Setting Up your XDAQ™

4.1. Installing the XDAQ™ driver

Before connecting the XDAQ™ to a PC, it is important to install the driver first.

Follow the instructions on the prompt to install the driver. After the installation, verify the driver is properly installed by running the driver info tool (FrontPanel app).

4.2. Powering the XDAQ™

XDAQ™ CORE

Connect the XDAQ™ with the supplied USB-PD adapter and the USB-C cable. When appropriate power is supplied to the XDAQ™, the white LED power indicator in the back panel will light up. There is no need to turn on the XDAQ™. The front LED indicators will only light up after the software application is loaded.

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XDAQ™ ONE

Connect the XDAQ™ with the built in AC adapter or an external USB-PD adapter. Be sure to use a grounded AC outlet. Turn on the system by pressing the power button next to the AC power connector.

4.3. Grounding the XDAQ™

XDAQ™ CORE

XDAQ™ CORE is powered by a USB-PD adapter thus does not have a path to earth ground for noise or electrostatic discharge (ESD) shielding. The GND pin that protrudes out of the back panel is available for accessing the system ground node.

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XDAQ™ ONE

XDAQ™ ONE can be powered by the built-in power supply or an external USB-PD adapter with 12V 3A output. The Earth (chassis) GND node provides grounding access to the earth ground if powered by the USB-PD adapter, or when the AC plug's ground is not truly grounded.

SYS GND node is the common ground used by the primary electronics circuitry of the XDAQ™ system. This node can be used for Faraday cage or other shielding applications.

Two additional ground nodes are available: P1 and P2-4 nodes, which are the actual animal grounds at the headstages.

Each node in the SYS ground and animal grounds (P1 and P2-4) can be connected to the Earth ground node by activating (flipping the dip switch to ON position) the ESD DIP switches in the back panel of XDAQ™. DIP #1 of each corresponding node (SYS, P1, or P2-4) when turned ON ties a 1nF capacitive discharge path to Earth ground. Similarly, DIP #2 of each ground node adds an additional 1nF in parallel to a 1MOhm resistor to Earth ground. When both DIP1 and DIP2 are activated, the resulting circuit becomes a 2nF capacitive buffer in parallel with 1MOhm resistor for each port.

In theory, having isolated animal grounds should offer the best recording quality. However, due to the potential grounding inconsistency or environment noise interference, it is best for users to experiment

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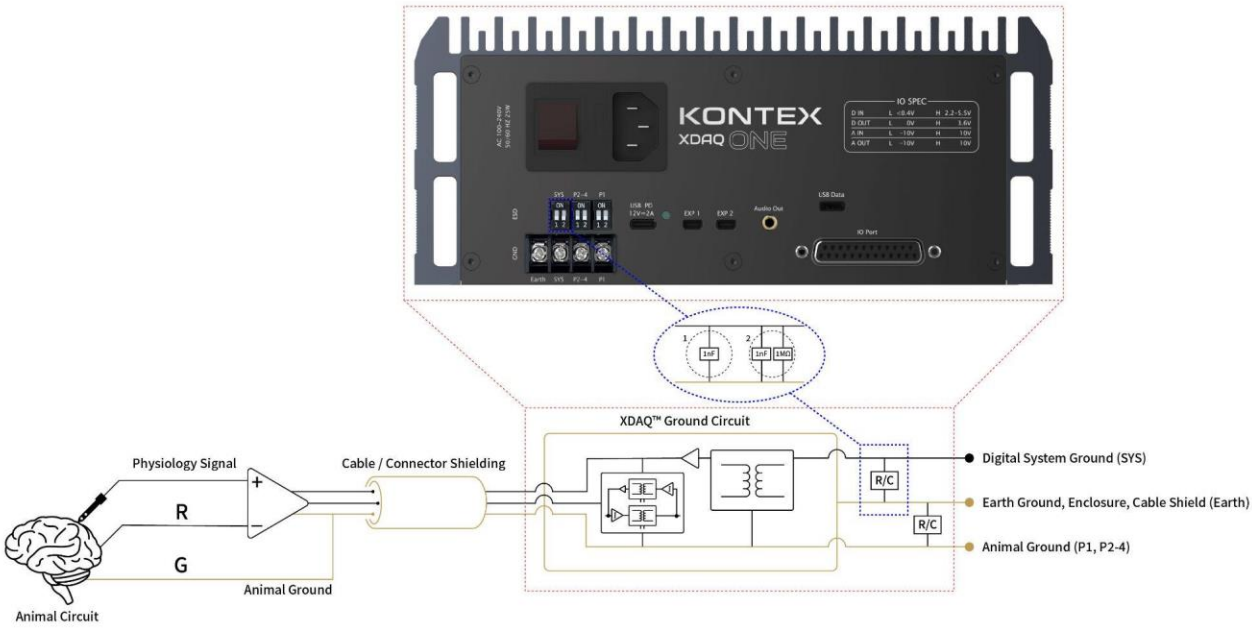

with various ground settings. XDAQ™ ONE offers an extremely flexible grounding configuration to accommodate and support high quality neural acquisition in the most extreme environments.

4.4. Turning ON/OFF the XDAQ™

XDAQ™ CORE does not have to be turned on or turned off. It is ready as soon as the USB-PD is plugged in. The status indicator in the front panel will only be activated when XDAQ™ compatible software is activated.

XDAQ™ ONE has a rocker switch that controls the AC power input to the system. Flip the power switch to ON. To turn off, flip the switch to OFF.

4.5. Connecting to the PC

Use the supplied USB-C to USB-A data cable between the port labeled “USB Data” on the XDAQ™ and a PC’s USB3.0 port.

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4.6. Connecting to the Optional IO Expander

Use the KONETX HDMI cable to connect the EXP1 port in the back of the XDAQ™ to the IO Expander's EXP1 port. Similarly connect the EXP2 port between the XDAQ™ and the IO Expander. The IO Expander will be powered by the XDAQ™ and there is no need to connect additional power sources.

4.7. Connecting to the Optional Port Expander

XDAQ™ is designed to support high channel count electrodes by design. Thus, each headstage port can control up to 128ch or 256ch headstage-electrode depending on the model. Port Expander can be used to increase the number of independent experiments the XDAQ™ can support while maintaining the best electrical performance - signal and power isolation - for each experiment/animal. Use a KONTEX HDMI cable to connect one of the headstage ports (Port 1 to 4) to the "Input" port of the Experiment Expander. The Port Expander can be used solely on the built-in battery or plugged in.

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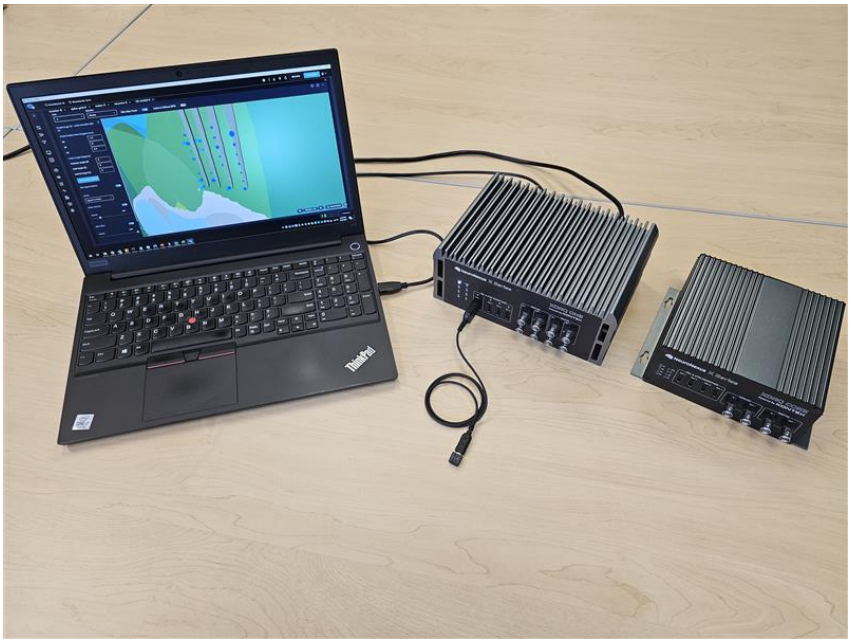
4.8. Connecting to the X-Headstage™

Connect the X-Headstage™ to XDAQ™ using the KONTEX HDMI cable. Always use Port 1 first as other ports might be inactivated depending on the licensing configuration.

4.9. Starting the acquisition

Start the software of your choice (see XDAQ™ Compatible Software), the LED in the front panel of the XDAQ™ will update to appropriate status. From the software, start previewing the data by enabling the data streaming and/or start the data acquisition.



5. XDAQ™ Compatible Software

Radiens™ is the recommended software solution for controlling XDAQ™ systems, offering unparalleled functionality, user-friendly interface, and robust integration capabilities. Its comprehensive suite of features streamlines the management and operation of XDAQ™ systems, empowering users with advanced control and monitoring capabilities.

By opting for Radiens™ as the recommended software for XDAQ™ systems, users benefit from a seamless and intuitive experience. From configuring system parameters to monitoring data acquisition

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in real-time, Radiens™ provides a sophisticated yet accessible platform for maximizing the performance of XDAQ™ systems.

Users of NeuroNexus XDAQ™ systems are entitled to a **COMPLIMENTARY TRIAL** of the Radiens™ software suite. This trial offer allows users to experience firsthand the enhanced capabilities and efficiency it brings to their research or application. It also allows users to explore the full potential of Radiens™ in optimizing their XDAQ™ workflows.

While Radiens™ is the preferred choice for maximizing the functionality of XDAQ™ systems, the XDAQ™ system also supports integration with Open-Ephys GUI and a modified version of the Intan RHX application. Users opting for open-source solutions should be aware of potential limitations in functionality and performance compared to utilizing Radiens™ as the primary software solution.

6. Additional XDAQ™ Features

6.1. Functionality Upgrade

If you purchased a base configuration XDAQ™ model, it is possible to enable additional features (e.g. enable additional 16 stimulation channels for the XDAQ™ CORE). Please contact us directly with the serial number of the XDAQ™ for upgrade information.

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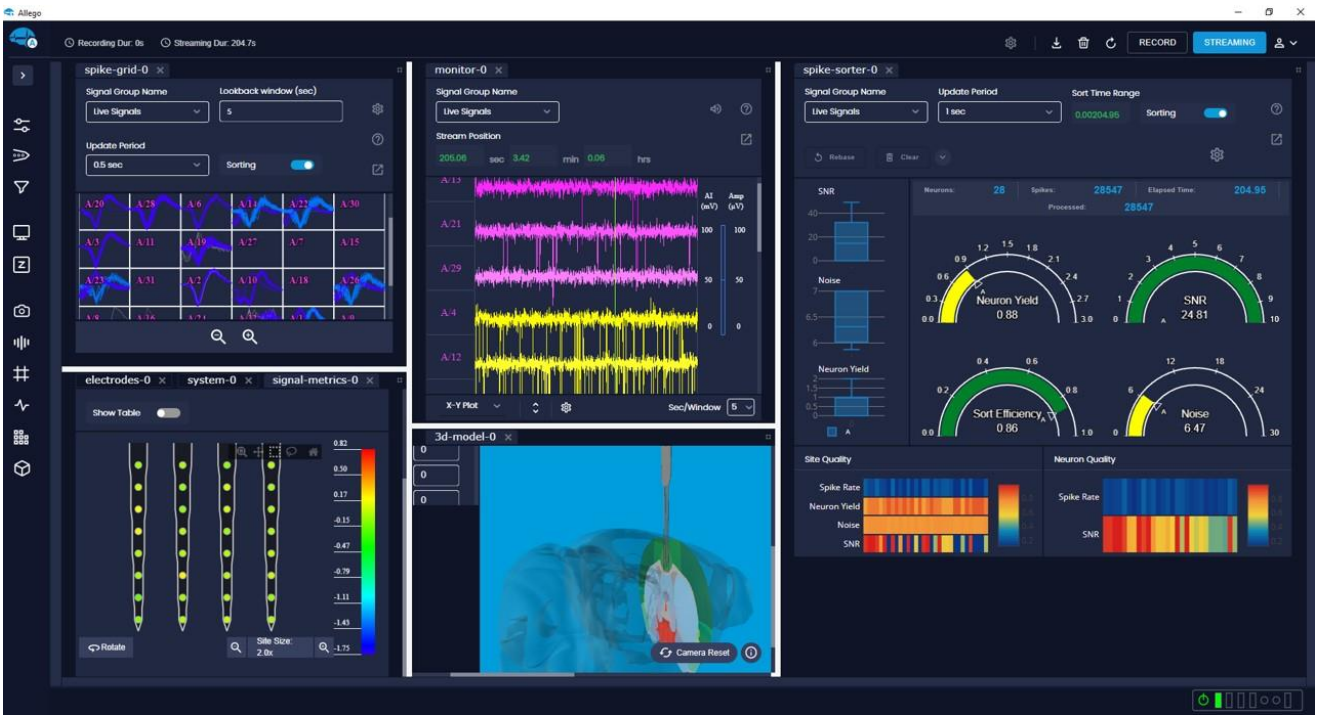
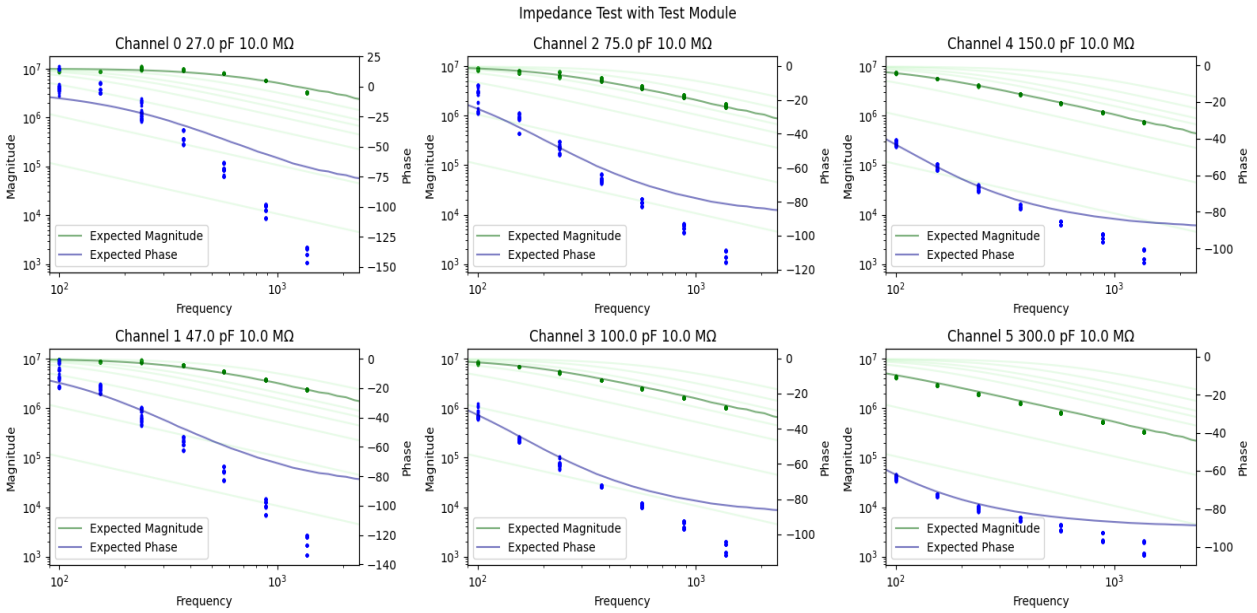


6.2. Impedance Measurement

Every XDAQ™ when paired with a X-Headstage™ can measure impedance of attached electrodes. The impedance measurement is intended for rudimentary probe condition diagnostics. Note there may be significant (~20%) variance between repeated measurements and accuracy for *in situ* measurements may be highly dependent on the prep.



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Please refer to the individual software package (5. XDAQ™ Compatible Software) for performing impedance measurements.

Additionally, users wishing to perform impedance spectroscopy might find the PyXDAQ™ (beta) API useful. See script, “Impedance Spectroscopy.py” under the example folder.

6.3. Self Diagnosis

See 7. Testing your XDAQ™

6.4. Electroplating (Experimental)

See additional information page for more details.

6.5. Short Detection (Experimental)

See for additional information page more details.

6.6. TCP Control

Using RHX XDAQ™ application, users can control and stream data over ethernet using TCP protocol.

7. Testing your XDAQ™

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If you believe the XDAQ™ is behaving strangely even after power cycling the XDAQ™, you may run the XDAQ™ diagnostic program to check if XDAQ™ is functioning properly and pinpoint where the problem might be.

Required parts: XDAQ™ debug headstage, XDAQ™ HDMI cable, X-Headstage™, XDAQ™ and its associated data and power cable.

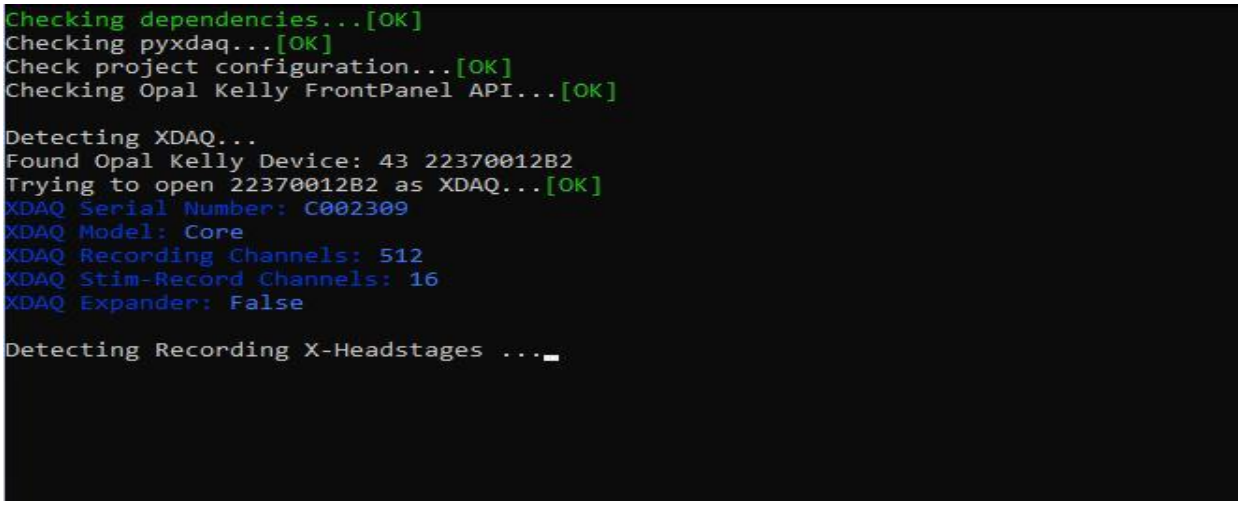
Optional parts: Brainwave simulator and a multimeter.

Download and unzip the XDAQ Windows Self Diagnosis app:

https://drive.google.com/file/d/11umxpPhX2vt4aT5Z7aFgtdLILwnuXTAR/view?usp=sharing

Unzip the diagnostic tool then launch "self_diagnosis.exe"

1. The first thing it does is check the presence of the FPGA and reports it's serial number, then the same for the XDAQ system motherboard. The screen output like below should appear. Note, if you do not have an XDAQ™ Expander installed, the program will state: “XDAQ™ Expander: False” but this does not affect the outcome of further tests.



2. To continue testing the XDAQ™ with recording headstages, connect a X-Headstage™ (type X3R-, X6R-, XeR-) with a NeuroNexus HDMI cable. If you have multiple recording headstages, you may connect them simultaneously to different HDMI ports. If you use a commutator, it is a good idea to perform separate tests and first test only the minimally required accessory.

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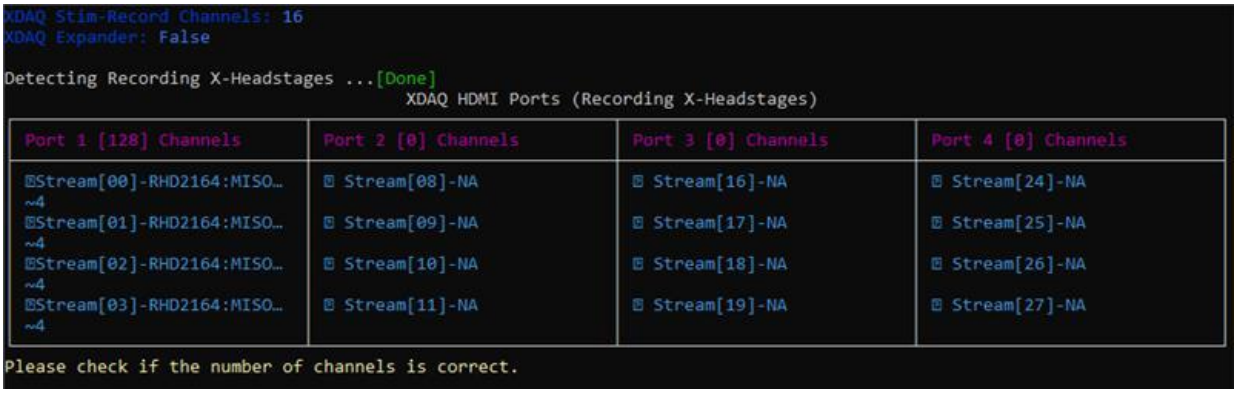
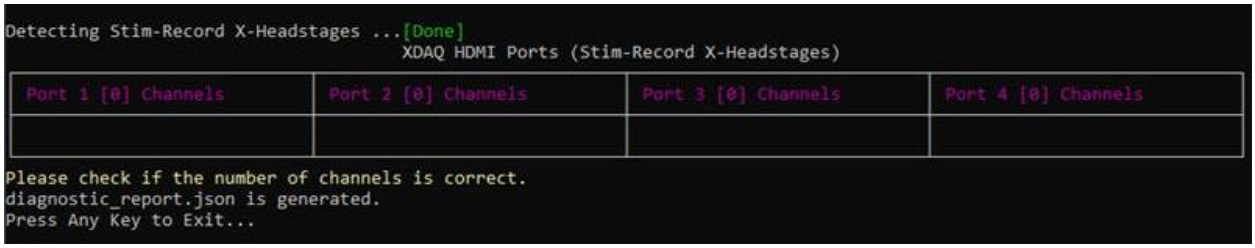
When the devices are properly connected, press any key to continue.



3. To continue testing the XDAQ™ with stim-record headstages, connect a X-Headstage™ (X3SR-, XeSR-) with a NeuroNexus HDMI cable. If you have multiple recording headstages, you may connect them simultaneously to different HDMI ports. If you use a commutator, it is a good idea to perform separate tests.

   When the devices are properly connected, press any key to continue.



4. If no headstages can be properly detected from step 2 and step 3, proceed to swap the X-Headstage™ with the Headstage Debugger. The software will determine if the data lines for communication are working properly. The Debugger provides a loop back between command line and data line.

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5. Optionally, while the Debugger is attached check the voltage level powering the X-Headstage™ using a multimeter.

   VCC, measured between Tp3 and Tp5, should be 3.5V

   VStim+, measured between Tp2 and Tp5, should be 7V (or 10 or 4V per setting)

   VStim-, measured between Tp1 and Tp5, should be -7V (or -4 or -10V per setting)

   LVDS_EN, measured between TP4 and TP5, should be 3.5V

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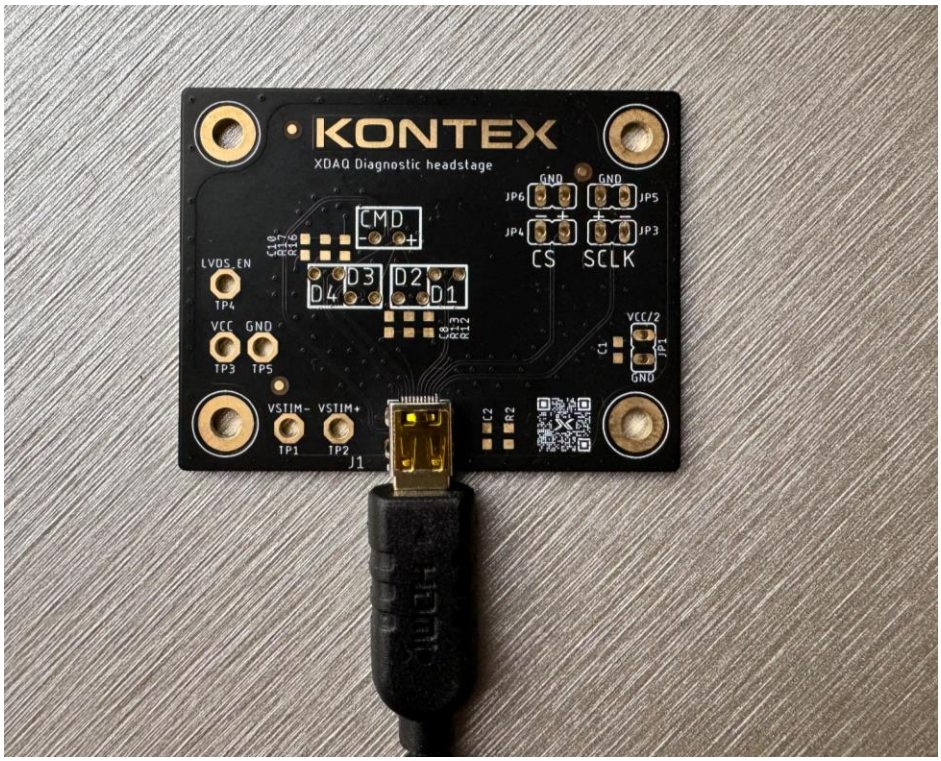

6. Attach the X-Headstage™ to the Brainwave Simulator, test the data acquisition accuracy by varying the input amplitude, frequency and observe and confirm the appropriate signal quality.

8. Additional Information

Electroplating (experimental)

XDAQ™ when paired with a SR X-Headstage™ can be used to perform basic electrode plating since SR X-Headstage™ can deliver constant current down to 10nA.

Please be aware that the XDAQ™ is not developed for EIS use and so realistic expectations should be set, knowing there might be limitations.

To perform electroplating, see “plating.py” under the examples folder in PyXDAQ™. Below shows a screen capture of a part of the script.

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```
21  def create_monophasic_pulse(mA: float, frequency: float):
22      """
23      Create a basic pulse with duty cycle 50%, current can be positive or negative.
24           |-----|     |-----|
25           |     |     |     |
26      -----|     |-----|     |-----
27
28      |--period--| = 1/frequency
29      """
30      half_period_ms = 1e3 / frequency / 2
31      return (lambda **kwargs: kwargs)(
32          # Polarity of the first phase
33          polarity=StartPolarity.cathodic if mA < 0 else StartPolarity.anodic,
34          # Shape of the pulse
35          shape=StimShape.Monophasic,

146 target_stream = 0
147 target_channel = 0
148 for i in range(3):
149     print(f'Run {i+1}: Checking impedance at 1000 Hz')
150     magnitude1000, phase1000 = xdaq.measure_impedance(
151         frequency=Frequency(1000), channels=[target_channel], progress=False
152     )
153     print(f'Impedance at 1000 Hz: {magnitude1000[target_stream,0]:.2f} Ohm')
154     print(f'Sending 50Hz 1mA pulses for 1 second (dutycycle 50%)')
155     run_steps = send_pulses(
156         xdaq,
157         stream=target_stream,
158         channel=target_channel,
159         duration_ms=1000,
160         pulse_current_mA=2,
161         pulse_frequency=50
162     )
```

Short Detection (experimental)

KONTEX offers a standalone product for high channel count (up to 256ch), any combination short circuit detection. This is the recommended method.

KONTEX is currently testing an out of box method to check for shorts using XDAQ™ and X-Headstage™. It is still under development. Please contact us if you are interested in this and would like to stay informed.

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