RHD2000

Intan 512ch/1024ch Recording Controller

31 October 2016

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Features

- SuperSpeed USB3 interface to Intan Technologies RHD2000-series digital electrophysiology chips.
- Up to 512 or 1024 amplifier channels supported with sampling rates ranging from 1 kS/s to 30 kS/s.
- Open-source, multi-platform C++/Qt GUI software.
- All-digital interface cables with independent ground isolation support robust, noise-free signaling over long distances; cables may be daisy-chained.
- Hardware or software-selectable referencing.
- Amplifier bandwidth settings reconfigurable through software; bandwidth may be changed on the fly.
- Software and hardware supports *in situ* measurement of electrode impedances (both magnitude and phase) at user-selected frequencies.
- Analog output ports can reconstruct waveforms from selected amplifier channels in real time.
- Stereo "line out" jack for real-time audio monitoring of any two selected amplifier signals.
- Low-latency digital threshold comparators for real-time spike detection.
- Analog input ports with ±10V range and 16-bit ADCs for recording auxiliary signals synchronized to all amplifier channels.
- Digital (TTL) input lines supporting 2.0V to 5.5V logic levels synchronized to all amplifier channels.
- Triggered episodic recording allows digital input to start and stop data acquisition to timestamped data files.

Description

The Intan Recording System is a modular family of components that allows users to record biopotential signals from up to 1024 low-noise amplifier channels using the RHD2000 series of digital electrophysiology chips from Intan Technologies. An **Intan RHD recording controller** connects to a host computer via a standard USB cable. Small **headstages** connect to the recording controller via thin, flexible all-digital cables that may be daisy-chained to form robust connections up to ten meters in length. An **open-source, multi-platform GUI** controls the operation of the amplifiers and streams data to the screen and to disk in real time at **user-selected sampling rates from 1 kS/s to 30 kS/s**.

Each headstage includes an Intan RHD2000 amplifier chip with 16, 32, 64, or 128 channels. The amplifier chips have **software-reconfigurable bandwidths** which can be changed on the fly through the GUI. The system also supports **electrode impedance measurement at arbitrary frequencies**.

The recording controller contains a variety of general-purpose digital and analog I/O ports including **analog outputs which can reconstruct waveforms from any amplifier channels with < 0.2 ms latency**. Two of these analog signals are connected to a stereo "line out" jack for **audio monitoring of signals**. The controller also includes **general-purpose analog inputs and digital inputs** that are sampled in synchrony with the amplifiers. The GUI software supports viewing signals from all these channels and streaming the data to disk in binary format. Open-source code is provided for importing the data files into MATLAB.

Contents

Recording Controller Hardware

Figure 1A. RHD recording controller front panel.

The front panel of the RHD recording controller provides connection points for Intan RHD headstages as well as auxiliary digital and analog inputs. From left to right:

- **Intan RHD headstage ports:** These ports, labeled A-D (A-H in the 1024-channel controller), provide connection points for RHD headstages via 12-wire digital SPI (serial peripheral interface) cables. Each cable can stream data from up to two RHD2000 chips. Each headstage port is electrically isolated from the controller and from earth ground. Indicator lights provide information on the status of each port: green and yellow LEDs show that proper voltage supplies are being provided for each headstage. Red LEDs are activated when the software recognizes a headstage plugged into a port.
- **Digital inputs:** Two BNC sockets are provided for recording digital signals in synchrony with the headstage signals. The digital inputs accept TTL-level signals. Any voltage between 0V and +0.8V is read as a digital "low". Any voltage between +2.0V and +5.5V is read as a digital "high". Voltages delivered to these sockets should not exceed the range of 0V to +5.5V. These signals may be used to record discrete events associated with an experiment or to trigger a recording.
- **Analog inputs:** Two BNC sockets are provided for recording general-purpose analog signals. Signals are digitized with 16-bit ADCs over a range of -10.24V to +10.24V. Voltages delivered to these sockets should not exceed this range.
- **Status indicators:** Status indicator A is illuminated when the data acquisition is active. Status indicator B is controlled by DIGITAL IN 1; status indicator C is controlled by DIGITAL IN 2. These LEDs can be used to monitor the status of digital signals that are recorded in synchrony with the RHD headstages.
- **Power indicator:** This red LED is illuminated when the recording controller is powered.

Figure 1B. RHD recording controller rear panel.

The rear panel of the RHD recording controller provides auxiliary output lines as well as other ports and switches. From left to right:

- **Analog outputs:** Two BNC sockets are provided for monitoring waveforms from RHD headstages. The headstages communicate with the controller using purely digital signals, but 16-bit DACs are used to reconstruct analog signals with desired scaling factors. The control software allows users to route selected signals to any analog output ports. These ports have a -10.24V to +10.24V voltage range.
- **Audio line out jack:** This standard 3.5-mm stereo phone jack allows users to connect an audio amplifier to the controller and listen to the signals routed to the two analog output ports. ANALOG OUT 1 is connected to the left channel; ANALOG OUT 2 is connected to the right channel. This port cannot drive speakers directly; an audio amplifier should be used, and the volume should be adjusted carefully to ensure that excessive levels are not delivered to speakers.
- **High-speed port:** This connector is reserved for future use.

- **I/O expansion port:** This connector is used to add an Intan I/O expander. This board is described in the next section. It provides six additional analog inputs and outputs and 14 additional digital inputs and outputs for more complex experiments. Signals on this port are digital and serially encoded, and are not easily accessed without the I/O expander.
- **CONFIG switches:** Configuration switches 1-3 are reserved for future use. Switch 4 (CONFIG4) is used to select the voltage level of the digital output ports (see next item). With CONFIG4 in the down position, 3.3V digital signals are generated. With CONFIG4 in the up position, 5.0V digital signals are generated.
- **Digital outputs:** Two BNC sockets produce either 3.3V or 5.0V digital signals (see previous item) that can be used to implement low-latency threshold comparators that operate on the signals routed to the analog outputs.
- **USB port:** A USB 3.0 port provides a SuperSpeed connection to a host computer running the control software.
- **Sample clock out:** This port generates a digital pulse train at the amplifier sampling rate when the headstages are active. The voltage level of this signal is set by the CONFIG4 switch.
- **Mark out:** This port generates a digital pulse marking the onset and offset of data acquisition. The voltage level of this signal is set by the CONFIG4 switch.
- **I/O GND:** This binding post is connected to the controller system ground used by all analog and digital inputs and outputs. This is the preferred ground to use for Faraday cage and other shielding connections.
- **Chassis GND:** This binding post is connected to the controller chassis and to the grounding conductor of the AC power socket. Either Chassis GND or I/O GND can be connected to **Faraday cage shielding**. It is recommended that any conductive shield used in biopotential recording experiments is tied to one of these terminals for improved rejection of 50/60 Hz interference.
- **Power switch and fuse holder:** The unit uses two standard 1A 250V 5x20mm slow blow fuses that can be replaced by opening the fuse holder to the right of the power switch. The power cord must be removed to access the fuses.
- **AC power socket:** The controller is powered by 90-260V AC power, and is compatible with international voltage levels. A US-style power cord is supplied with the controller. International customers must use an adapter to accommodate non-US power sockets. The center grounding conductor must be connected to earth ground to avoid electric shock hazards.

Mounting

The RHD recording controller can be rack mounted on a standard 19" instrument rack using provided hardware, or it can be used on a bench top by folding out the feet on the bottom of the case:

Intan I/O Expander

Intan Technologies offers an optional I/O expander (sold separately) that provides an additional six analog inputs and outputs and an additional 14 digital inputs and outputs. This unit is shown below:

Front Panel

The front panel of the Intan I/O expander provides auxiliary digital and analog inputs, and analog outputs. From left to right:

- **Analog outputs:** Two analog outputs for monitoring signals from RHD headstages. (Four more analog outputs are provided on the rear panel.) These ports have a -10.24V to +10.24V voltage range.
- **Digital inputs:** Six BNC sockets are provided for recording digital signals in synchrony with the headstage signals. (Eight more digital inputs are provided on the rear panel.)
- **Analog inputs:** Six BNC sockets are provided for recording analog signals. Signals are digitized with 16-bit ADCs over a range of -10.24V to +10.24V.
- **Power indicator:** This red LED is illuminated when the Intan I/O expander is powered. The I/O expander receives low-voltage DC power over an interface cable from the controller.

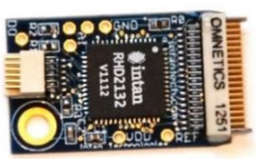
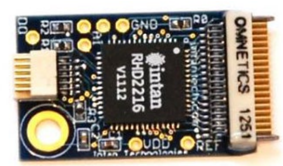
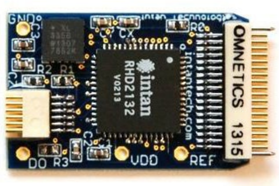
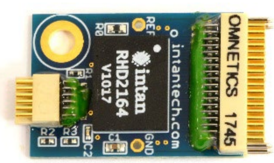
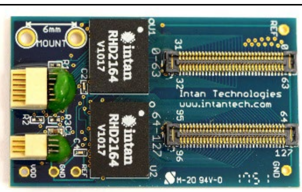
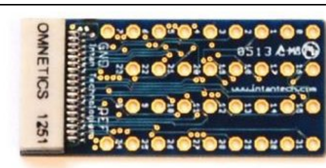
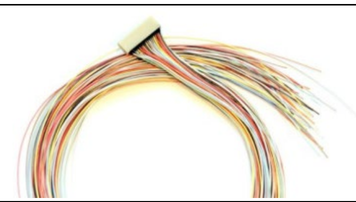
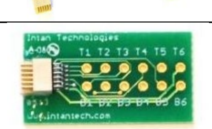
Rear Panel

The rear panel of the Intan I/O expander provides auxiliary input and outputs lines. From left to right:

- **Interface port:** This connector is used to interface with the main controller unit.
- **Analog outputs:** Four analog outputs for monitoring signals from RHD headstages. (Two more analog outputs are provided on the front panel.) These ports have a -10.24V to +10.24V voltage range.
- **Digital outputs:** Six BNC sockets produce either 3.3V or 5.0V digital signals that can be used to implement low-latency threshold comparators that operate on the signals routed to the analog outputs. The CONFIG4 switch on the main Intan controller selects the voltage level used by these ports.
- **Digital inputs 9-16:** Eight additional digital inputs are provided on screw terminal blocks. System ground connections are also provided on the ends of the terminal block.
- **Digital outputs 9-16:** Eight additional digital outputs are provided on screw terminal blocks. System ground connections are also provided on the ends of the terminal block. The CONFIG4 switch on the main Intan controller selects the voltage level used by these ports.

RHD Family Summary

The following table shows hardware components in the RHD family. The minimum required components for a functional electrophysiology recording system are: an **RHD recording controller**, an **SPI interface cable**, and an **RHD headstage**. Prices of all items are listed on the Intan Technologies website. These items are described in detail in the following pages.

 **RHD 512ch or 1024ch recording controller** #C3004 or #C3008			Includes USB cable and US-style power cord
	**RHD 32-channel headstage** with 32 unipolar inputs and common reference #C3314		**RHD 16-channel bipolar-input headstage** for EMG #C3313
	**RHD 32-channel headstage with accelerometer** with 32 unipolar inputs and common reference #C3324		**RHD 16-channel bipolar-input headstage with accelerometer** for EMG #C3323
	**RHD 16-channel headstage** with 16 unipolar inputs and common reference #C3334 #C3335 (w/ accelerometer)		**RHD 64-channel headstage** with 64 unipolar inputs and common reference #C3315 #C3325 (w/ accelerometer)
	**RHD 128-channel headstage** with 128 unipolar inputs and common reference #C3316		**36-pin electrode adapter board** #C3410 **18-pin electrode adapter board** #C3418
	**RHD dual headstage adapter** Compatible with 16ch - 64ch RHD headstages #C3442		**18-pin wire adapter** #B7600 **36-pin wire adapter** #C3420
	**RHD SPI cable adapter board** for custom interface development #C3430		**RHD 3-ft (0.9 m) or 6-ft (1.8 m) standard SPI interface cable** #C3203 or #C3206 **RHD 1-ft. (0.3-m), 3-ft (0.9 m) or 6-ft (1.8 m) ultra thin SPI interface cable** #C3211, #C3213, or #C3216

RHD Headstages

The RHD recording controller can communicate with all RHD headstages offered by Intan Technologies. A variety of RHD headstages are available for different applications. Each headstage contains: an RHD2000 amplifier chip, a 12-pin Omnetics polarized nano connector that mates with an SPI interface cable, and a connector to mate with recording electrodes.

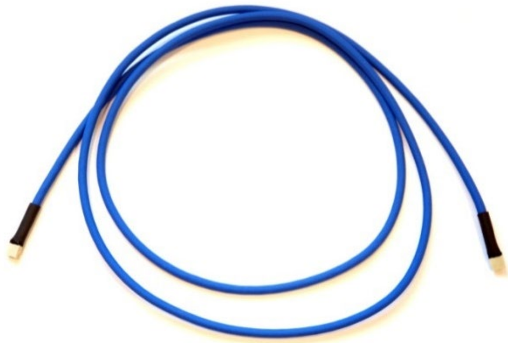


Figure 2. RHD SPI interface cable used to connect headstages to the recording controller.

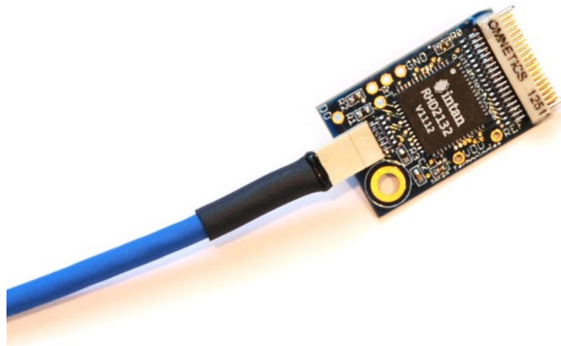


Figure 3. RHD 32-channel headstage plugged in to SPI interface cable.

Figure 2 shows an SPI (Serial Peripheral Interface) cable used to connect headstages to the RHD recording controller. The 12-conductor cable is 2.9 mm in diameter and weighs 8.2 grams/meter. An ultra thin version of the cable with half the weight and a diameter of 1.8 mm is also available. Multiple interface cables may be daisy-chained to create cables of varying lengths up to maximum recommended lengths specified on the Intan website. (The **RHD SPI Cable/Connector Specification** is available on the Intan Technologies website and provides details on this connection.) Figure 3 shows an RHD 32-channel headstage plugged in to an SPI interface cable.

Figure 4 shows a detailed view of a 32-channel RHD headstage with relevant components labeled. The board measures 24 mm × 15 mm with a maximum thickness of 2.6 mm. Three auxiliary analog inputs and one auxiliary digital output are accessible along with power connections and the reference electrode (REF). This allows external sensors or other devices to be connected to the headstage.

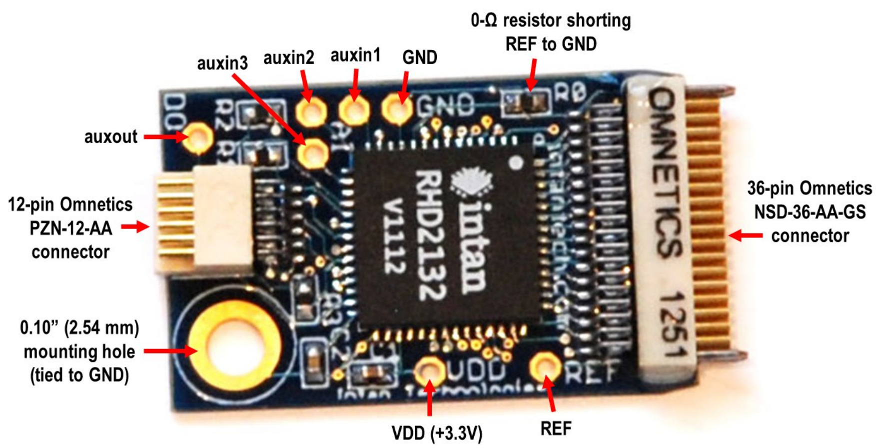


Figure 4. RHD 32-channel headstage with connection ports labeled. The 0-Ω resistor may be removed to disconnect the reference electrode from ground.

Auxiliary analog inputs (**auxin1-3**) and digital output (**auxout**) are accessible, along with power connections.

A 0.10" (2.54 mm) mounting hole is provided for optional mechanical attachment.

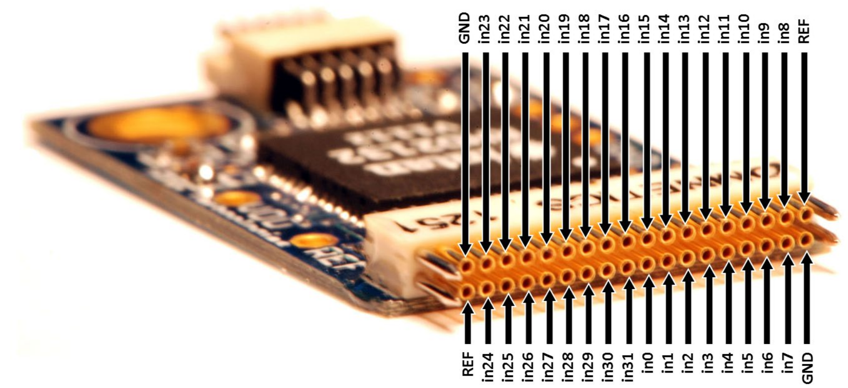


Figure 5. Electrode connector pin diagram for RHD 32-channel headstage.

The two REF pins are connected on the board, so only one pin needs to be connected to the reference electrode. The GND pins are also connected on the board.

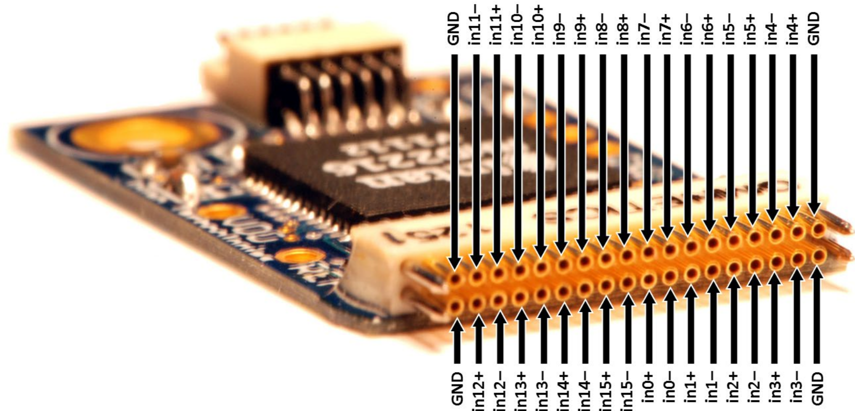


Figure 6. Electrode connector pin diagram for RHD 16-channel bipolar-input headstage for EMG.

Figures 5 and 6 show pin diagrams for the electrode connectors on the RHD 32-channel headstage with unipolar inputs for neural recording and the RHD 16-channel headstage with bipolar inputs (e.g., independent in+ and in- for each channel) for EMG recording. Amplifier inputs 0-31 should be connected to recording electrodes. In the RHD 32-channel headstage, one of the REF pins should be connected to a low-impedance reference electrode (typically a de-insulated electrode or a platinum wire). One of the GND pins should be connected to tissue ground (typically a skull screw in the case of chronic recordings, or a low-impedance electrode located away from active muscles in the case of EMG recordings).

These pin arrangements are compatible with connectors used in a number of commercially-available electrode arrays, including the NeuroNexus CM, OCM, and H32 electrodes, multi-channel arrays from MicroProbes, probes from Atlas Neuroengineering, probes from Cambridge NeuroTech, the Plexon CON/32m-V connector, and the Blackrock CerePlex M connector. The exact order of the 32 amplifier channels may differ from the numbering on a particular electrode array, but amplifier channels may be renamed and reordered in the software GUI to match any configuration.

If electrodes with an appropriate mating connector are not available, Intan Technologies offers an **electrode adapter board** (see Figure 7 below). All 32 amplifier inputs, as well as the REF and GND lines, are routed to solder holes spaced 0.10” (2.54 mm) horizontally and 0.15” (3.81 mm) vertically. Wires may be soldered into these holes, or a standard 16-pin DIP (dual in-line package) socket (included) may be soldered onto this board to connect 16 of the amplifier channels to a NeuroNexus A, OA, or D16 acute electrode connector. The electrode adapter measures 3.0 cm × 1.4 cm.

Intan Technologies also offers a 36-pin wire adapter for these headstages (see Figures 8 and 9 on the following page). This brings out all pins in the electrode connector directly to #34-AWG multi-colored wires.

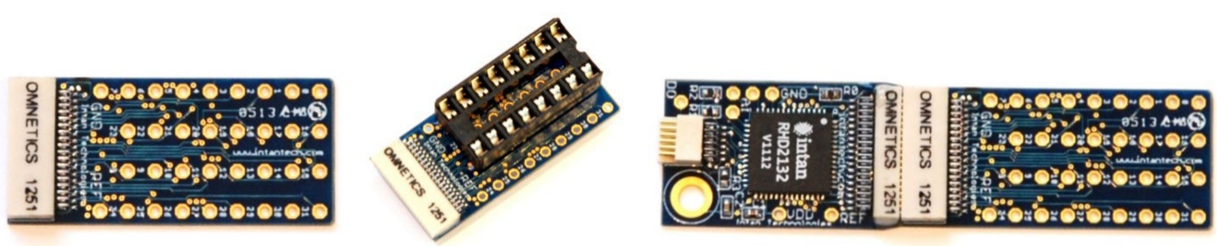


Figure 7. Electrode adapter board (left); with 16-pin DIP socket (center); connected to RHD 32-channel headstage (right).

Figure 8. 36-pin wire adapter for RHD 32-channel headstage. An 18-pin wire adapter is also available for the RHD 16-channel headstage (see below).

Figure 9. Wire adapter plugged into headstage.

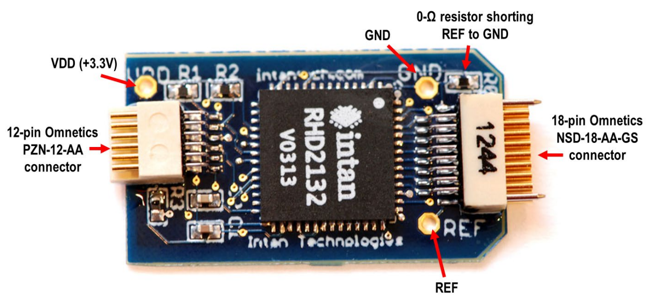


Figure 10. RHD 16-channel headstage with connection ports labeled. The 0-Ω resistor may be removed to disconnect the reference electrode from ground.

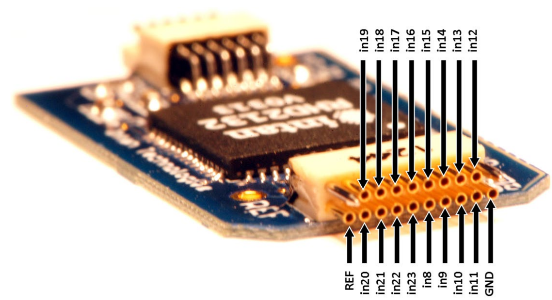


Figure 11. Electrode connector pin diagram for RHD 16-channel headstage.

An RHD 16-channel headstage using half the channels of an RHD2132 chip (see Figure 10 above) is also available. This board uses an 18-pin Omnetics NSD-18-AA-GS nano strip electrode connector, which is compatible with NeuroNexus CM, OCM, and HC16 chronic electrode connectors, multi-channel arrays from MicroProbes, probes from Atlas Neuroengineering, and probes from Cambridge NeuroTech. Figure 11 shows the labeled electrode connector for this board. Note that amplifier channels 0-7 and 24-31 are tied to ground. The board is slightly smaller than the RHD 32-channel headstage, measuring 23 mm × 13 mm. To minimize size, this board does not include a mounting hole or solder holes for auxiliary analog inputs or the auxiliary digital output.

RHD Headstages with Accelerometers

Intan Technologies also offers variants of RHD headstages that include an Analog Devices ADXL335 3-axis accelerometer connected to the three auxiliary analog inputs of the RHD2000 chip (see Figures 12 and 13 on the following page). The accelerometer signals may be used to calculate the orientation of the board relative to gravity and to estimate movement in three dimensions. This board is 24 mm × 15.5 mm in size, but does not include a mounting hole.

The analog signals from the ADXL335 accelerometer have zero-*g* bias levels around 1.7 V, though this can vary by several hundred millivolts between axes and from chip to chip. The sensitivity of the accelerometer is approximately 340 mV/*g* (where 1 *g* = 9.81 m/s^2), but this can vary between 270 mV/*g* and 390 mV/*g*. The accelerometer responds both to movement and to the gravity vector. When the board is resting flat as shown in Figure 13, the accelerometer will return +1 *g* on the Z axis. Each sensor has a minimum full-scale range of ±3 *g*, but this may be limited somewhat by the 2.45V maximum voltage range of the auxiliary inputs to the RHD2000 chip. External 27 nF capacitors on the circuit board are used to set the bandwidth of the accelerometer to 200 Hz.

For tips on calibrating the accelerometer and distinguishing dynamic acceleration from static acceleration due to gravity, see the **RHD Application Note: Accelerometer Calibration** available from the Intan Technologies website. For more detailed information on this sensor, please consult the ADXL335 datasheet from Analog Devices (www.analog.com).

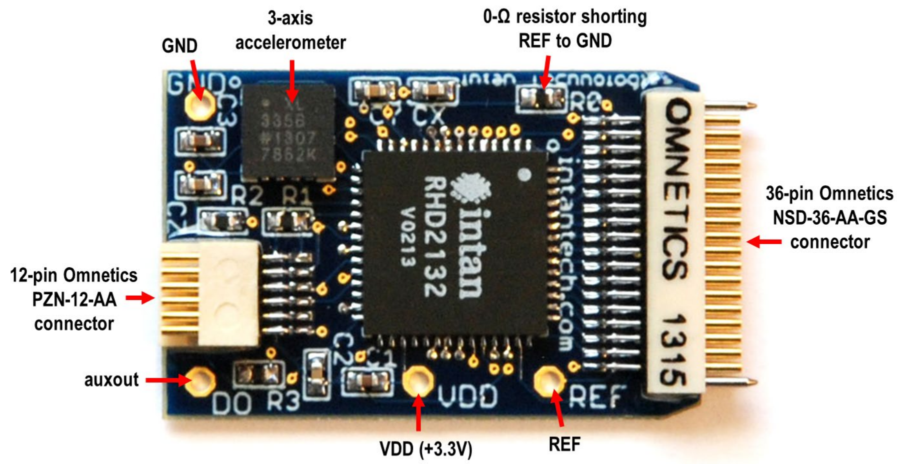


Figure 12. RHD 32-channel headstage with 3-axis accelerometer. The 0-Ω resistor may be removed to disconnect the reference electrode from ground.

Auxiliary analog inputs (**auxin1-3**) and digital output (**auxout)** are accessible, along with power connections.

This board is also available with an RHD2216 chip.

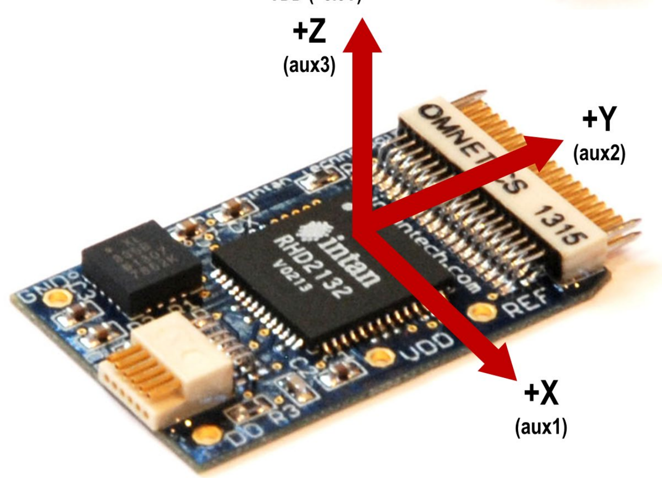


Figure 13. Accelerometer axes labeled as they are connected to the auxiliary inputs of the RHD2132 (or RHD2216) chip.

See text for more information on the relationship between acceleration and voltage levels on these signals.

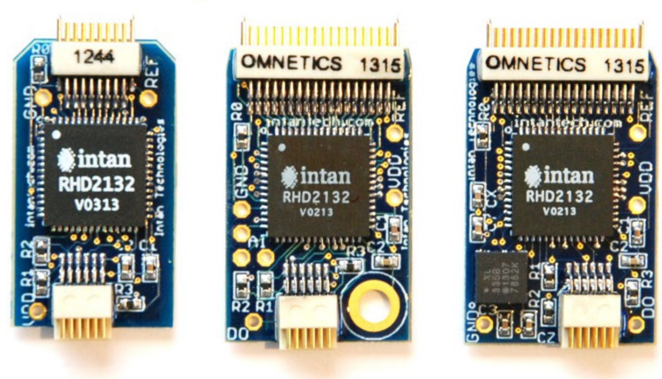


Figure 14. Size comparison of RHD 16-channel headstage (left), RHD 32-channel headstage (center), and RHD 32-channel headstage with 3-axis accelerometer (right).

Sizes are 23 mm × 13 mm, 24 mm × 15 mm, and 24 mm × 15.5 mm, respectively.

Figure 14 shows a size comparison of three types of RHD headstages: the RHD 16-channel headstage, the RHD 32-channel headstage, and the RHD 32-channel headstage with accelerometer. The last two boards are also available with the RHD2216 chip.

RHD 64-Channel Headstage

The RHD 64-channel headstage is shown in the Figures 15-17 below.

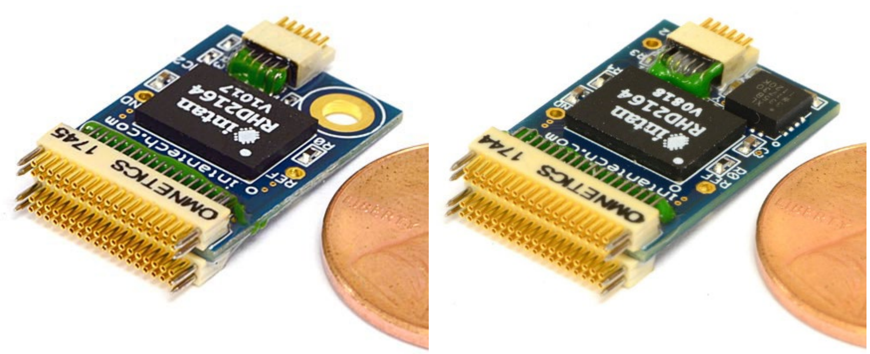


Figure 15. RHD 64-channel headstage (left, 21 × 14 mm, 1.30 g) and RHD 64-channel headstage with 3-axis accelerometer (right, 22 × 14 mm, 1.38 g).

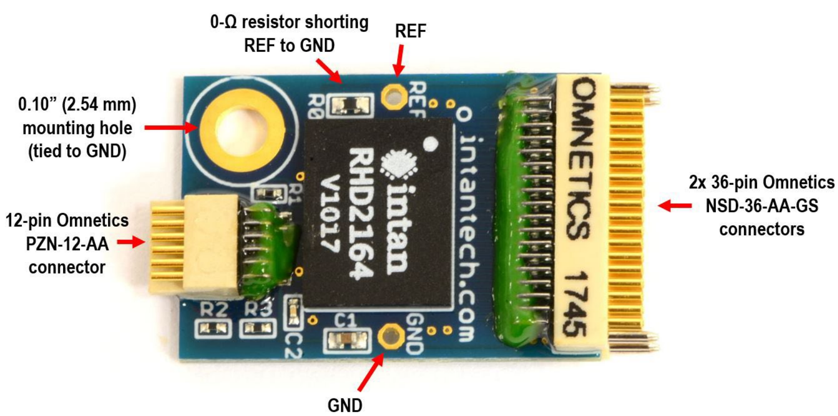


Figure 16. RHD 64-channel headstage with connection ports labeled. The 0-Ω resistor may be removed to disconnect the reference electrode from ground.

A 0.10” (2.54 mm) mounting hole is provided for optional mechanical attachment.

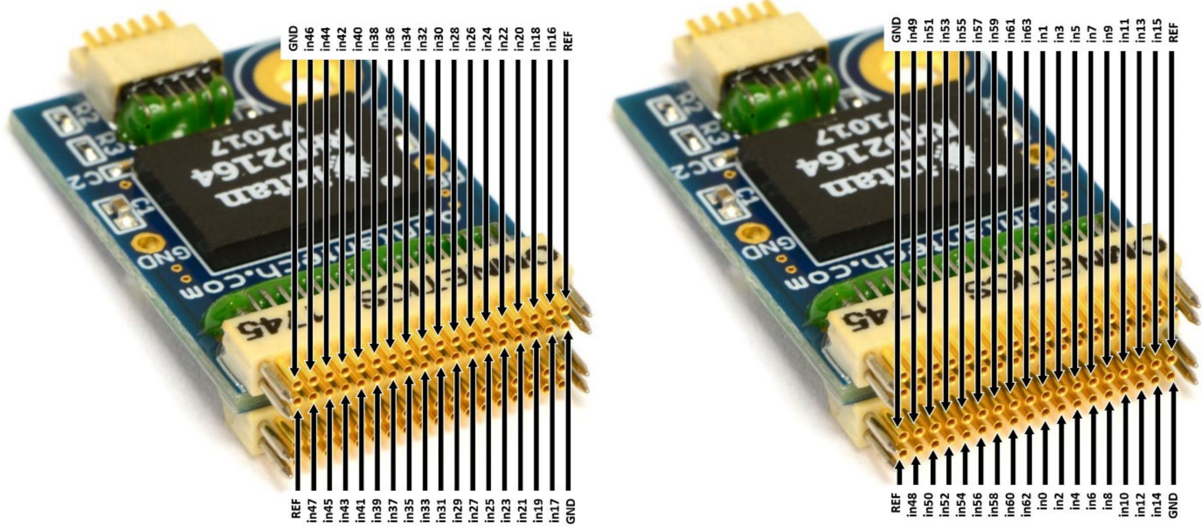


Figure 17. Electrode connector pin diagram for RHD 64-channel headstage. This geometry matches the NeuroNexus H64LP electrode connector. The four REF pins are connected on the board, so only one pin needs to be connected to the reference electrode. The GND pins are also connected on the board.

Figure 17 shows pin diagrams for the electrode connectors on the RHD 64-channel headstages. Amplifier inputs 0-63 should be connected to recording electrodes. One of the REF pins should be connected to a low-impedance reference electrode (typically a de-insulated electrode or a platinum wire). One of the GND pins should be connected to tissue ground (typically a skull screw in the case of chronic recordings, or a low-impedance electrode located away from active muscles in the case of EMG recordings).

This pin arrangement is compatible with the NeuroNexus H64LP electrode connector. NeuroNexus also offers adapters between the H64LP connector and other types of electrode connectors. MicroProbes and Cambridge NeuroTech can also make multi-channel arrays to mate with this headstage. The exact order of the 64 amplifier channels may differ from the numbering on a particular electrode array, but amplifier channels may be renamed and reordered in the software GUI to match any configuration.

The electrode adapter board and 36-pin wire adapters shown earlier may also be connected to the two 36-pin connectors on the RHD 64-channel headstage. A version of this headstage with a 3-axis accelerometer is also available.

RHD 128-Channel Headstage

The RHD 128-channel headstage contains two 64-channel RHD2164 chips. This board is shown in the Figures 18-19 below. This board uses two 64-pin Molex SlimStack connectors to interface with UCLA silicon probes developed by Prof. Sotiris Masmanidis (see http://masmanidislab.neurobio.ucla.edu/technology.html). Since these probes require electroplating prior to recording, an RHD electroplating board was developed to deliver automated constant-voltage or constant-current pulses to selected electrodes (see Figure 20).

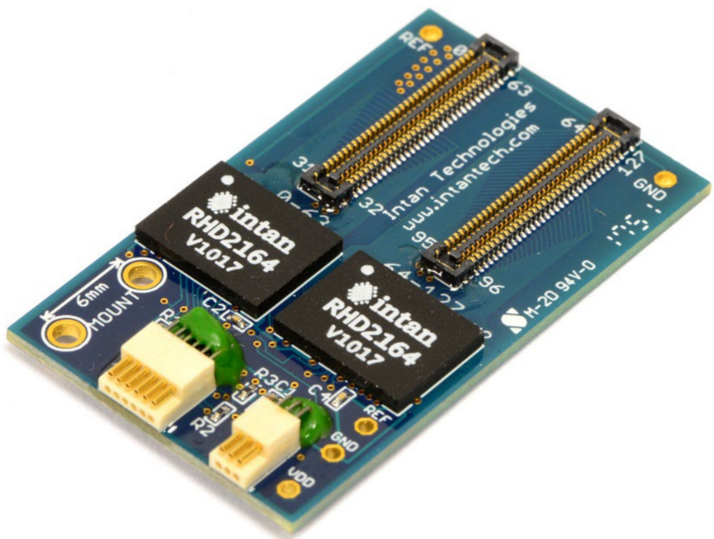


Figure 18. RHD 128-channel headstage.

The circuit board is 35 mm × 21 mm in size and weighs 2.05 g.

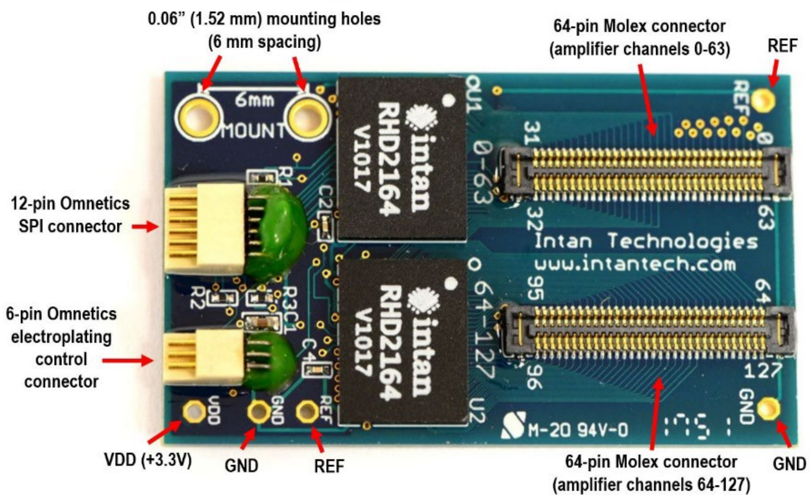


Figure 19. RHD 128-channel headstage with connection ports labeled. A 0-Ω resistor on the back of the board may be removed to disconnect the reference electrode from ground.

Two 0.06" (1.52 mm) mounting holes are provided for optional mechanical attachment.

The board includes a 6-pin connector for interfacing with the optional RHD electroplating board.

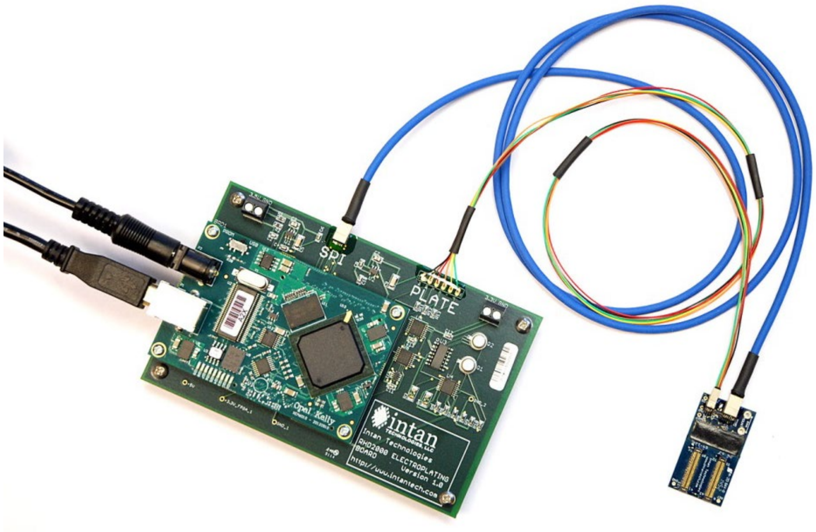


Figure 20. RHD electroplating board with RHD 128-channel headstage attached. The electroplating board delivers constant-voltage or constant-current pulses to selected electrodes connected to the headstage to facilitate electroplating of microelectrodes.

Dual Headstage Adapter

The SPI interface cables from Intan Technologies support signals from up to two RHD2000 chips. The **dual headstage adapter** allows two headstages to be connected to a single interface cable. Using this connector, it is possible to create amplifier modules with up to 128 amplifier channels (e.g., two RHD 64-channel headstages) using a single cable. The RHD recording controller hardware and software already has full built-in support for dual headstages on each headstage port.

A flexible RHD dual headstage adapter (see Figure 21) allows for individual headstages to be physically repositioned to accommodate a wide variety of electrode connector configurations. Headstages of different types may be combined using the dual headstage adapter. Figure 22 shows an example of this flexibility: two RHD 64-channel headstages (one with accelerometer) have been combined to create a 128-channel headstage with a 3-axis accelerometer.

The dual headstage adapter may not be used with the RHD 128-channel headstage.

For more detailed information on this device, see the **RHD Dual Headstage Adapter datasheet** available from the Intan Technologies website.

Figure 21. RHD dual headstage adapter.

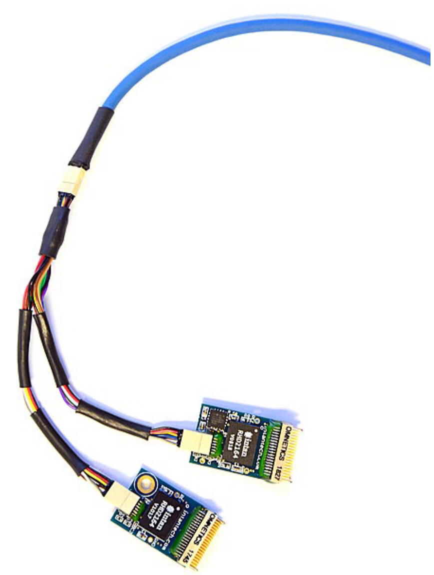


Figure 22. Two RHD 64-channel headstages (one with accelerometer) combined to create a 128-channel headstage.

Data Acquisition Software

The Intan Recording System uses the free, open-source **RHX data acquisition software** developed by Intan Technologies. This software is available for Windows, Mac, and Linux. Easy-to-use installers and a complete user manual are available at:

https://www.intantech.com/RHX_software.html

Related RHD Documentation

The following supporting datasheets may be found at **http://www.intantech.com/downloads**:

- **RHD2000 Series Digital Electrophysiology Interface Chips**
- **RHD2164 Digital Electrophysiology Interface Chip**
- **RHD USB3/FPGA Interface: Rhythm USB3**
- **RHD SPI Cable/Connector Specification**
- **RHD Dual Headstage Adapter**

Application Notes:

- **RHD Application Note: Data File Formats**
- **RHD Application Note: Adapting SPI Cables to a Commutator**
- **RHD Application Note: Accelerometer Calibration**
- **RHD Application Note: Interfacing a Microphone to Headstages**
- **RHD Application Note: Adding an LED to Headstages**

Contact Information

This datasheet is meant to acquaint engineers and scientists with the RHD recording controller developed at Intan Technologies. We value feedback from potential end users. We can discuss your specific needs and suggest a solution tailored to your applications.

For more information, contact Intan Technologies.

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