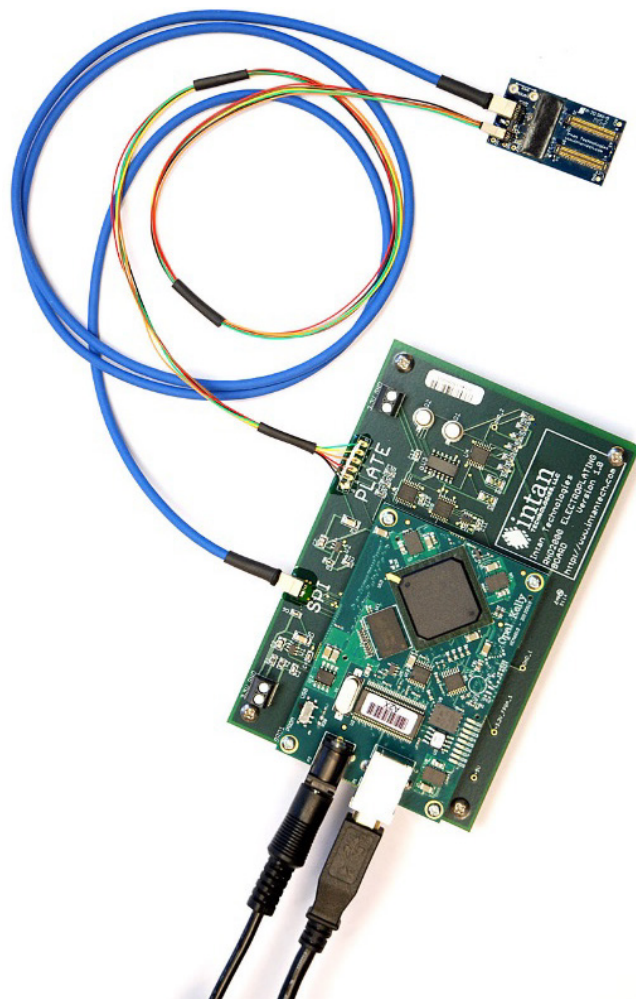# intan
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RHD2000

Electroplating Board and Control GUI

25 February 2015

Description

The RHD2000 electroplating board was built to support the RHD2000 128 Channel Amplifier Board. In combination, these two modules support automated electroplating of dense microelectrode arrays for electrophysiological recording. It is recommended that users also consult the **RHD2000 128 Channel Amplifier Board Datasheet** (available from the Intan Technologies website) along with this document.

The 12 cm x 7.5 cm RHD2000 electroplating board connects to a host computer via a standard USB 2.0 interface, and is powered by a 5 V power supply (included; see the two black wires connecting to the board in the photo to the left). The electroplating board also includes a multicolored plating control cable that connects to the RHD2000 128 Channel Amplifier Board. The amplifier board and an SPI interface cable (e.g., the blue cable shown to the left) are also required and must be purchased separately. An RHD2000 USB interface board is also required for normal data acquisition from the amplifier board after electroplating is complete.

The control GUI (graphical user interface) software that operates the electroplating board was written in MATLAB, so the RHD2000 MATLAB Toolbox is also required for plating.

The electroplating board contains a programmable DC voltage source and a programmable DC current source. Either method may be used for electroplating. The voltage range is ±3.3 V and the current range is ±10 µA. Voltage steps below one millivolt and current steps below one nanoamp are supported for precise control.

The electroplating board applies voltage or current pulses to individual electrodes connected to the amplifier board, then measures the resulting electrode impedance. This permits closed-loop control of electroplating to reach user-specified target impedances.

Features

♦ Easy-to-use USB interface to Intan Technologies RHD2000 128 Channel Amplifier Board to control electroplating of individual electrodes

♦ Electrode impedance measurement and integrated closed-loop control facilitates automated plating to user-specified target impedances

♦ MATLAB-based electroplating control GUI combines ease of use with quickly modifiable, open-source code (requires RHD2000 MATLAB Toolbox)

♦ Constant-voltage or constant-current electroplating capability with a range of ±3.3 V or ±10 µA

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Electroplating Setup

The photo below shows an RHD2000 128 Channel Amplifier Board attached to half of a 256 channel UCLA silicon microprobe. The multi-colored electroplating control cable and the violet SPI interface cable are connected to an RHD2000 electroplating board (not shown). The RHD2000 electroplating board is connected to +5 V power, and to a PC via a USB cable. **Warning: Powering the electroplating board with voltages higher than +5 V (e.g., a +12 V laptop power supply) will permanently damage the board!**

The out-of-focus blue wire is soldered into one of the REF holes on the amplifier board, and is connected to a thin platinum wire that descends into a small plastic well used to hold the electroplating solution (in this case, Sifco 80535500 gold non-cyanide 31 grams/L plating solution). The microprobe is lowered into the solution using a mechanical manipulator.

The probe is now ready for impedance measurement and electroplating using the GUI software.
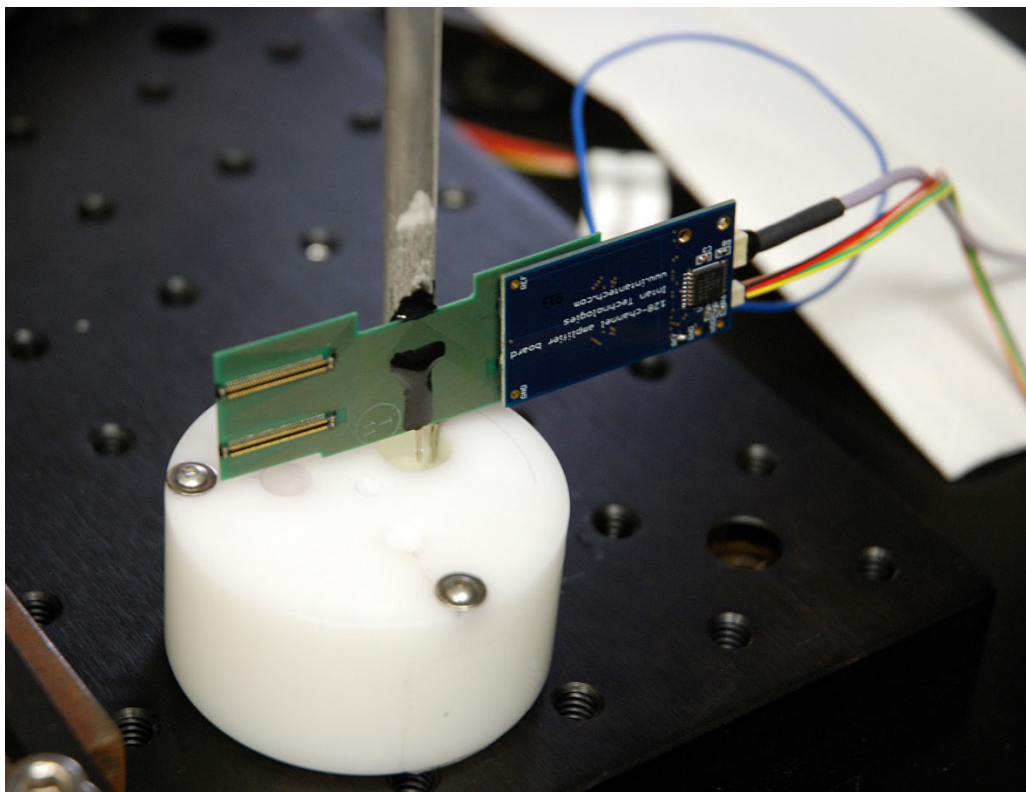
Electroplating Software Interface

The RHD2000 Electroplating Interface requires the Intan RHD2000 MATLAB Toolbox (version 1.1.0 or higher).

Running the Interface

The interface is distributed as a .zip file.

- Unzip this file into a directory of your choice.
- Run MATLAB.
- Within MATLAB, either `cd` to the unzipped directory, or add the path of the unzipped directory to the MATLAB path. (If you do that, then `savepath`, you'll only have to do this once.)
- Run the interface by typing
    ```
    electroplating
    ```
    at the MATLAB command line.

RHD2000 Electroplating Board and Control GUI

Interface Overview

The GUI has two large display areas: the top area displays the most recent impedance measurements for all electrodes, and the bottom displays the history of impedance measurements for a single electrode. Various controls let you read and display impedances, apply manual pulses to a single electrode, and apply automatic pulse protocols to one or more electrodes.
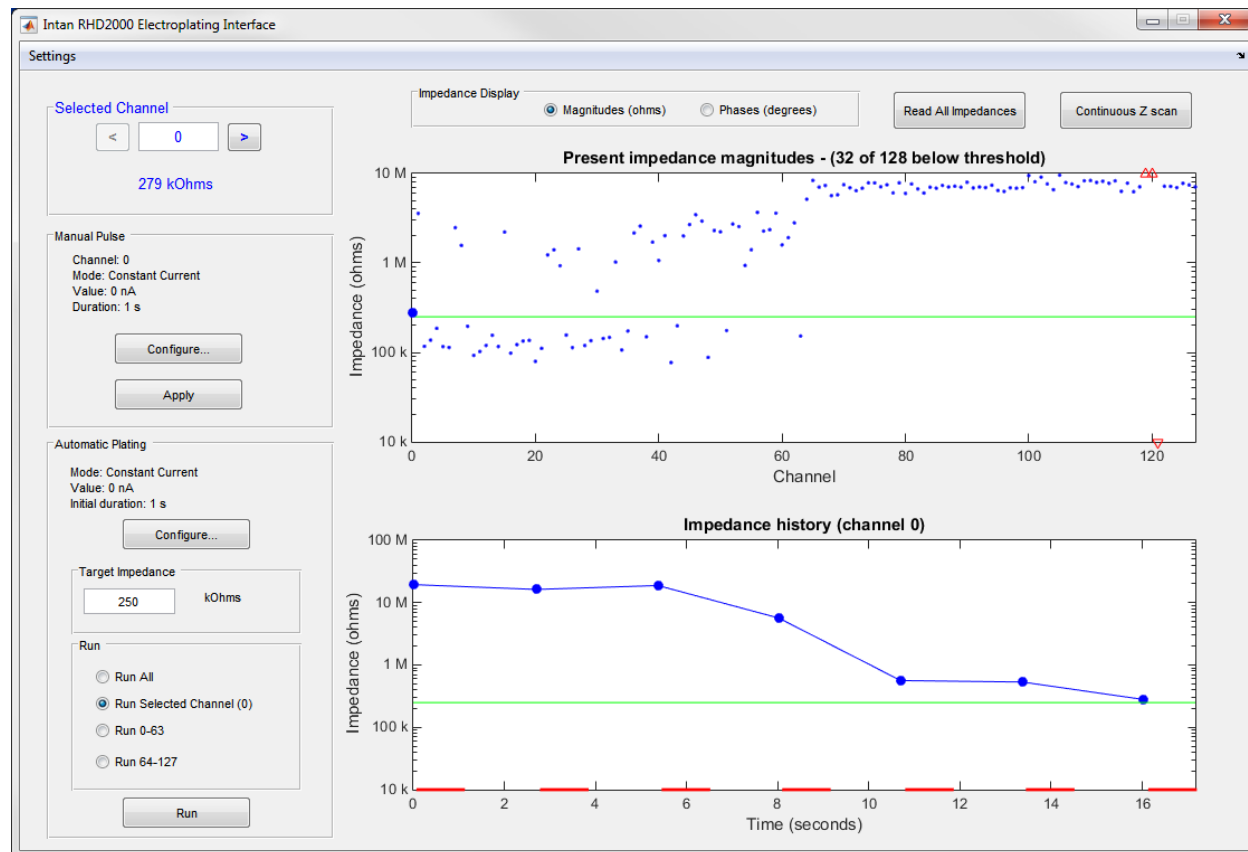
Reading impedances

When you start the GUI, the impedance display will be blank, as you have not yet measured impedances. Clicking the "Read All Impedances" button will cause the software to measure the impedances of all 128 channels and display them as they are read. All impedances are measured at a frequency of 1 kHz.

At any point later in the process, you can click this button again to repeat impedance measurements across all electrodes.

Displaying impedances

By default, the top display will show impedance magnitudes in ohms, but it can be switched to show impedance phases (in degrees) with the radio button at the top of the GUI. Impedances are complex quantities, and their phase, while rarely reported, conveys meaningful information. An ideal resistor has an impedance with a phase angle of zero, while an ideal capacitor has an impedance with a phase angle of -90°. Most microelectrodes have impedance phase angles somewhere between -50° and -90° at 1 kHz.
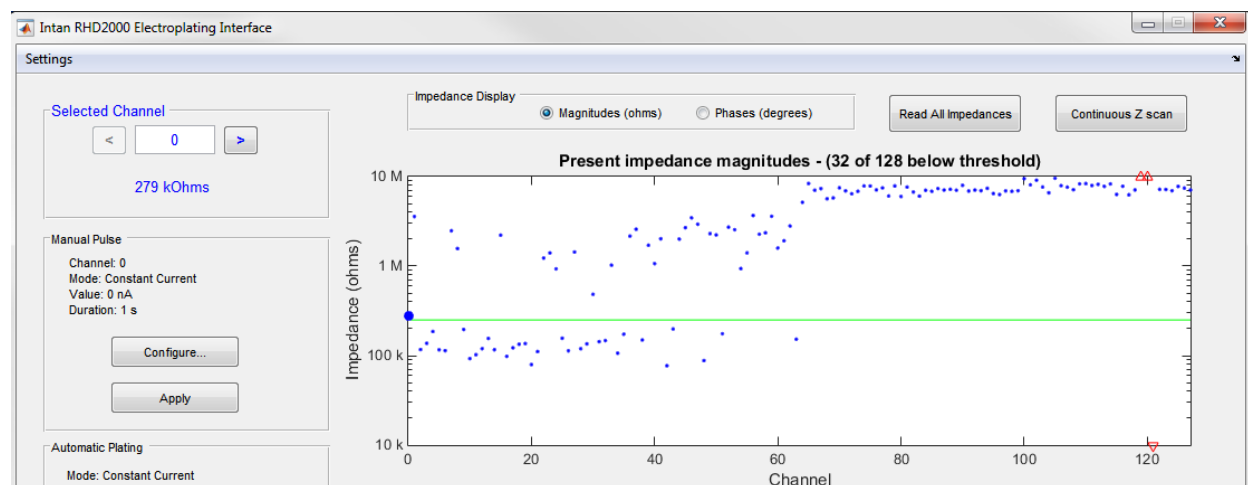
Magnitude mode

In Magnitude mode, the impedances are shown as blue dots. The scale is fixed at 10 kΩ to 10 MΩ; any impedance outside that range is shown as a red triangle. (There are three red triangles in the right side of the figure above; two with impedances higher than 10 MΩ, one with impedance lower than 10 kΩ.) The selected channel is highlighted on the plot, either with a bigger blue dot or with a filled-in red triangle. See "Selecting Channels" for more information. In the figure above, channel 0 is selected.

The green line indicates the Target Impedance for automatic plating, if that option is selected. In the figure above, you can see that 32 of the electrodes are below the target impedance of 250 kΩ, either by counting dots or reading the title of the graph. The channels are indexed 0-127, which matches the numbering scheme used on the board and in the RHD2000 recording software. (If data is saved and loaded into MATLAB, which uses indexes that start with one instead of zero, you may need to adjust electrode indexing accordingly in your analysis software.)

Phase mode
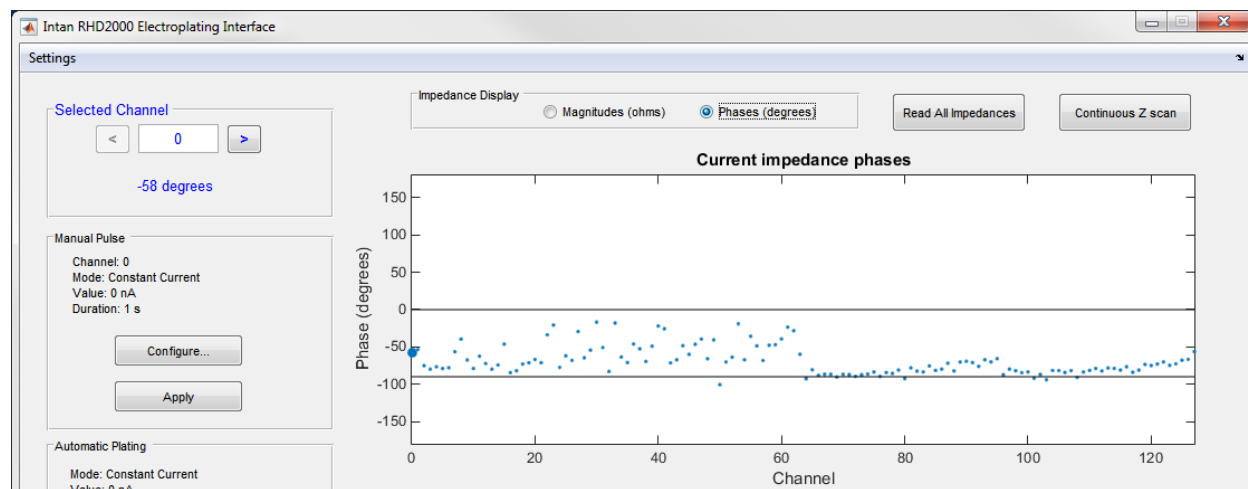
In Phase mode, the phases of the impedances are shown. Again, the selected channel is highlighted. Phases are shown in degrees. Two horizontal black lines indicate phases of 0° (i.e., the impedance is purely resistive) and -90° (i.e., the impedance is purely capacitive).

Selecting channels

You can select a channel in several ways:

- Typing the channel number into the text box in the Selected Channel area
- Clicking the arrow buttons in the Selected Channel area
- Using the left-arrow or right-arrow on your keyboard to move up or down a channel
- Clicking on the dot or arrow corresponding to the channel in the current impedance display
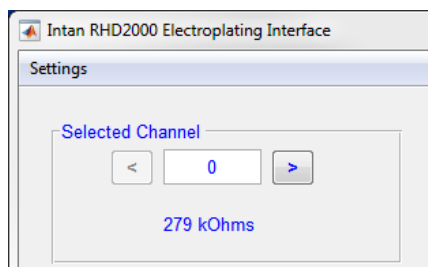
Several things happen with the selected channel:

- Its impedance is displayed in the Selected Channel area (either magnitude or phase, based on which you've chosen to display).
- It is highlighted in the current impedance display
- Its history is shown in the Impedance History area (see below for more information)

One of the options for Automatic Plating is to plate only the selected channel (see below).

Impedance History

The Impedance History plot shows how the impedance of a single electrode changes over time. It always displays the selected channel. See "Selecting channels" for more information.
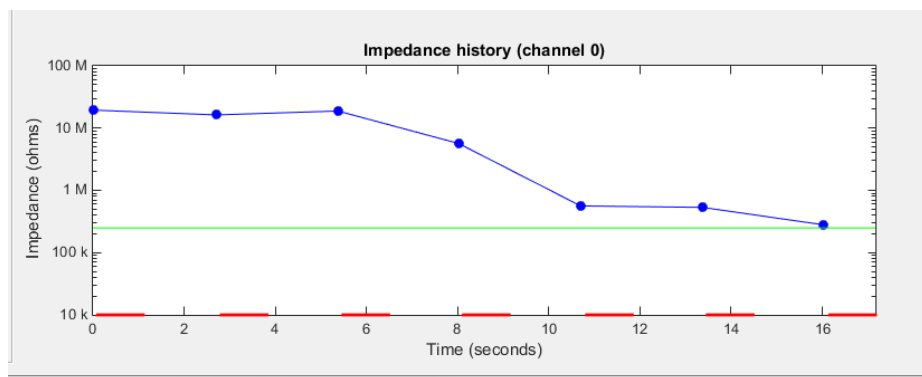
In this display:

- The blue dots indicate impedance measurements. The Y-scale is flexible, so the impedance measurements always show as blue dots, never as red arrows.
- The green line indicates the Target Impedance for automatic plating, if that option is selected.
- The red line segments at the bottom indicate the timing of voltage or current pulses used for electroplating.

Depending on what you're doing, this display will show one of the following:

- A single impedance value (if you've only done "Read All Impedances," and haven't done anything else with the selected electrode).
- Two impedance values, one pulse, and the threshold (if you're doing manual pulses).
- Multiple impedance values and pulses, and the threshold (if you're doing automatic plating).
- Multiple impedance values and the threshold; no pulses (if you're running a continuous impedance scan).

In general, when you switch from one of the operations above to another (for example, if you've been doing a continuous impedance scan and you begin automatic plating), the history is reset, a new impedance measurement is collected on the given channel, and the display begins with that new measurement at time zero. (Note that selecting different channels does not cause new impedance measurements be made. Impedance measurements are only performed in concert with the actions listed above.)

Continuous Impedance Scan

Clicking the "Continuous Z scan" button at the top right of the interface will repeatedly measure the impedance of the selected channel every two seconds. The interface will continue to do this indefinitely, until you cancel the operation. This can be used to verify stability of the impedance of the selected electrode.

Configuring Pulses

Before running a manual or automatic electroplating pulse, you need to configure the plating settings. The two "Configure…" buttons in the UI are used for that.
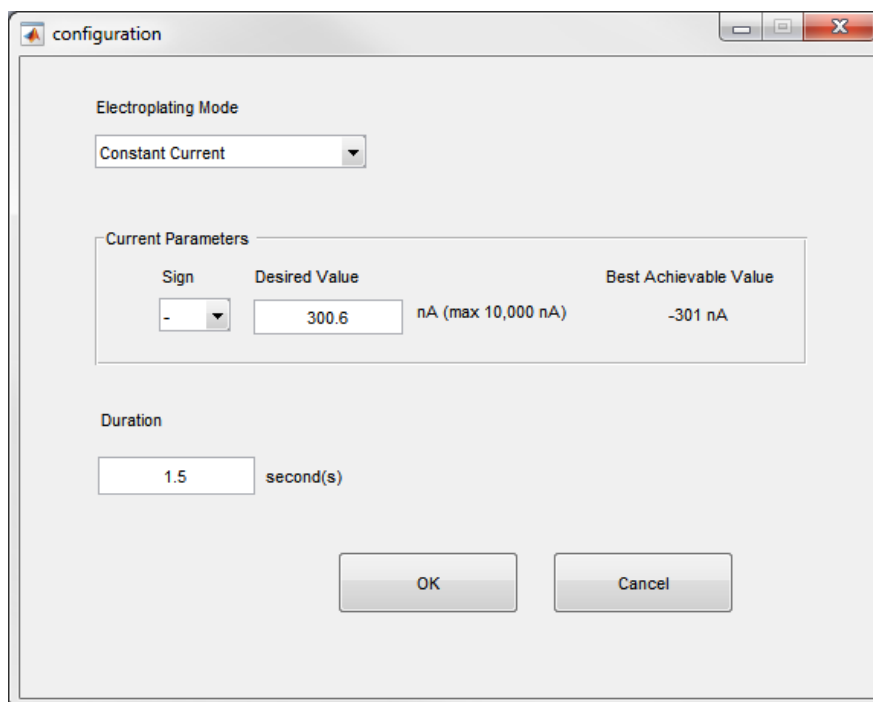
The configuration screen lets you select:

- Constant current or constant voltage electroplating pulses
- The sign and magnitude of the current or voltage
- The pulse duration

The interface also displays the best achievable value (i.e., the closest the system can get to the desired voltage or current value given the hardware constraints).

For constant current mode, positive current means positive charges flowing out of the electrode, into solution. Negative current means positive charges flowing out of the solution, into the electrode. Negative currents in the range of -30 nA to -60 nA , 10 to 30 seconds in duration, are typically used for gold electroplating on the UCLA silicon microprobe, which has recording site dimensions of 10 μm x 10 μm.

For constant voltage mode, positive voltage means an electrode voltage that is more positive than the solution. Negative voltage means an electrode voltage that is more negative than the solution. Negative voltage pulses between -2.0V and -2.6V, and one or two seconds in duration, are typically used for gold electroplating on the UCLA silicon microprobe.

For manual pulses, the pulse duration sets the length of each user-triggered pulse. For automatic plating, the protocol consists of a series of pulses, each of the selected duration. See the appropriate sections for more details. Values configured here are displayed on the main screen, and may be saved to/loaded from settings files (see "Saving/Loading Settings").

Manual Pulse

To run a manual plating pulse:

- Configure the pulse parameters with the "Configure…" button in the Manual Pulse area.
- Select a channel.
- Click Apply.
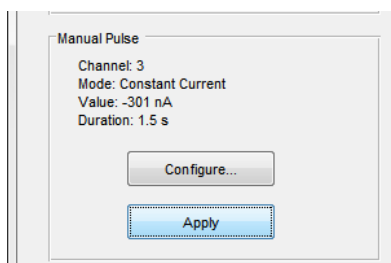
The following will occur:

- The electrode impedance will be measured.
- The specified manual plating pulse will be delivered.
- The electrode impedance will be measured again.
- The Impedance History plot will be updated with the two electrode impedances (blue points) and the pulse timing (red line).
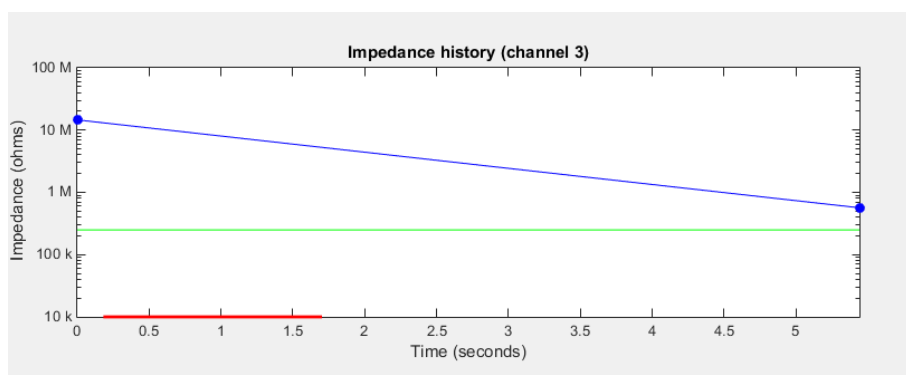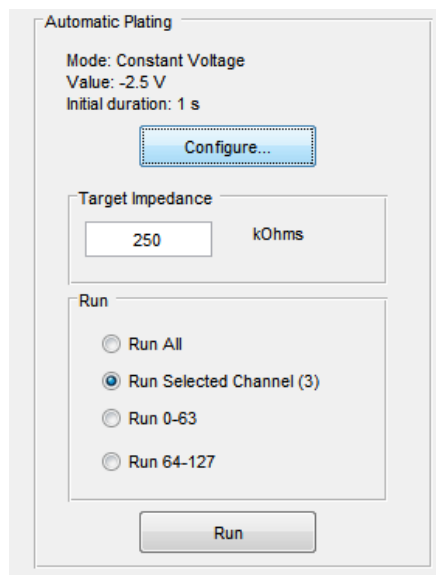
Automatic Plating

Automatic plating lets you run a pulse protocol to plate one or more channels.
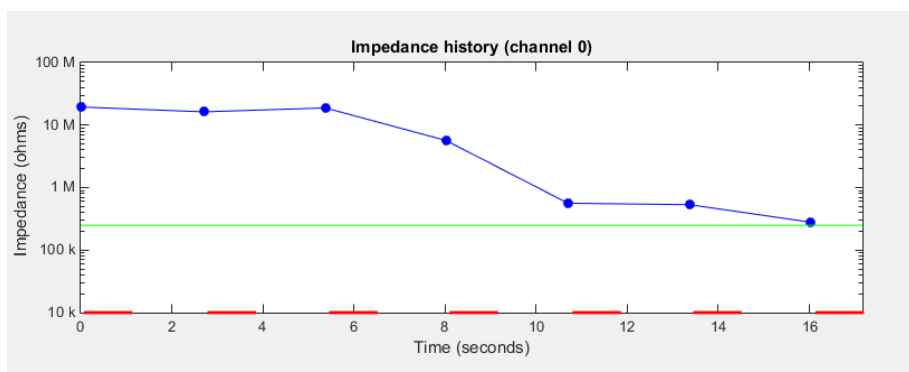
To run automatic plating:

- Configure the pulse parameters with the "Configure…" button in the Automatic Plating area.
- Select a target impedance (it is also possible to run automatic plating without a target impedance; see "Configuration Settings" for details)
- Select which channel(s) to run the automatic plating protocol on.
- Click Run.

The automatic plating protocol runs as follows:

- Measure the electrode impedance.
- Repeat some number of times:
  - Apply a plating pulse.
  - Measure the electrode impedance.

In this plot the plating pulses are shown in red, the measured impedances are shown in blue, and the target impedance is shown in green.

Automatic plating ends when:

- The measured impedance is below the target impedance **or**
- The maximum number of pulses has been applied.

For example, the user could specify a maximum of 10 pulses, and run automatic plating on all electrodes (Run All). The plating protocol would step through electrode by electrode, running until either the electrode hit its target impedance or 10 pulses had been tried. At that point, it would move to the next electrode and continue the process.
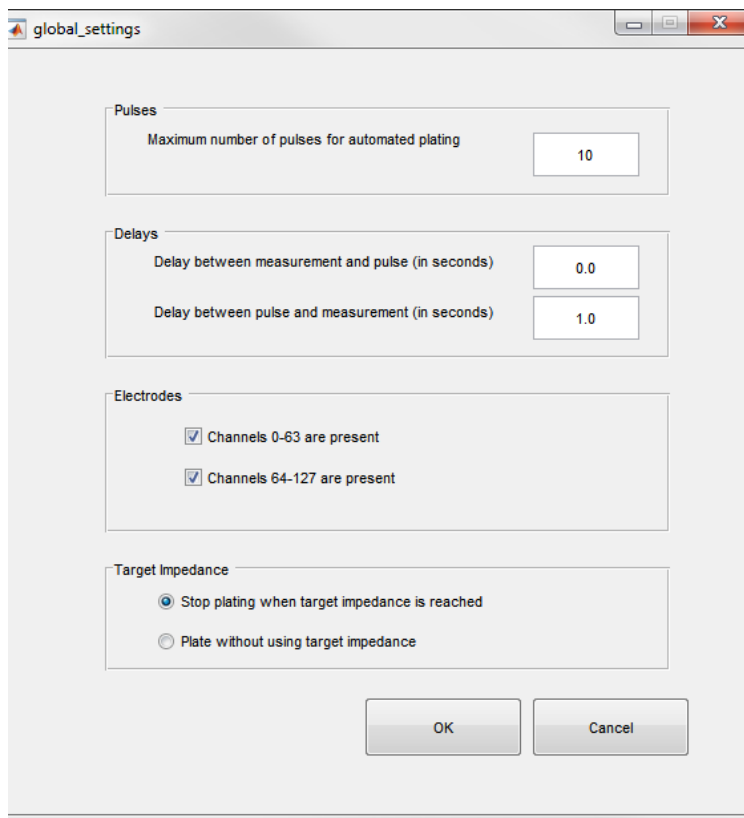
Note that because automatic plating always begins by checking the impedance of the electrode, you could Run All, then Run All again. This would run an additional number of pulses *only on those electrodes that weren't already at or below the target impedance*.

It is possible to change several parameters related to the pulse protocol; see "Configuration settings" below for more information.

Configuration settings

Various global settings can be changed using the Settings/Configure menu, which brings up this dialog box:

Maximum number of pulses for automated plating is described in the automatic plating section. It is often a good idea to set this to a relatively low number (e.g., 2), and run through all electrodes on a new, unplated probe. Any electrodes that can plate quickly will, and any that don't plate will be skipped much more rapidly than if a larger number is used. After the initial quick pass, a larger value may be called for to plate stubborn electrode sites.

Delays. During both manual and automatic plating, the basic flow is:

- Measure electrode impedance.
- Apply plating pulse.
- Measure electrode impedance.

The two delay values set pauses between these steps.

Electrodes. If you only have 64 electrodes plugged in to the 128 channel board, you can deselect one or the other of these values; those channels will be skipped when measuring impedances and electroplating.

Target Impedance. Typically users wish to electroplate to a target impedance. If you want to unconditionally electroplate (for example, if you want to apply a fixed pulse to all electrodes), you can choose "Plate without using target impedance."

Saving/Loading Settings

All electroplating settings (Manual Pulse settings, Automatic Plating settings, and Configuration settings) can be saved via Settings/Save Settings. The resulting settings can be loaded via Settings/Load Settings.

You might use this feature to create one or more "recipes" for plating, and save them into well-named files, rather than having to set the parameters each time you re-run the program.

Saving impedances

The Settings/Save Impedances menu item lets you save a CSV file with the present measured impedance values of all electrodes.
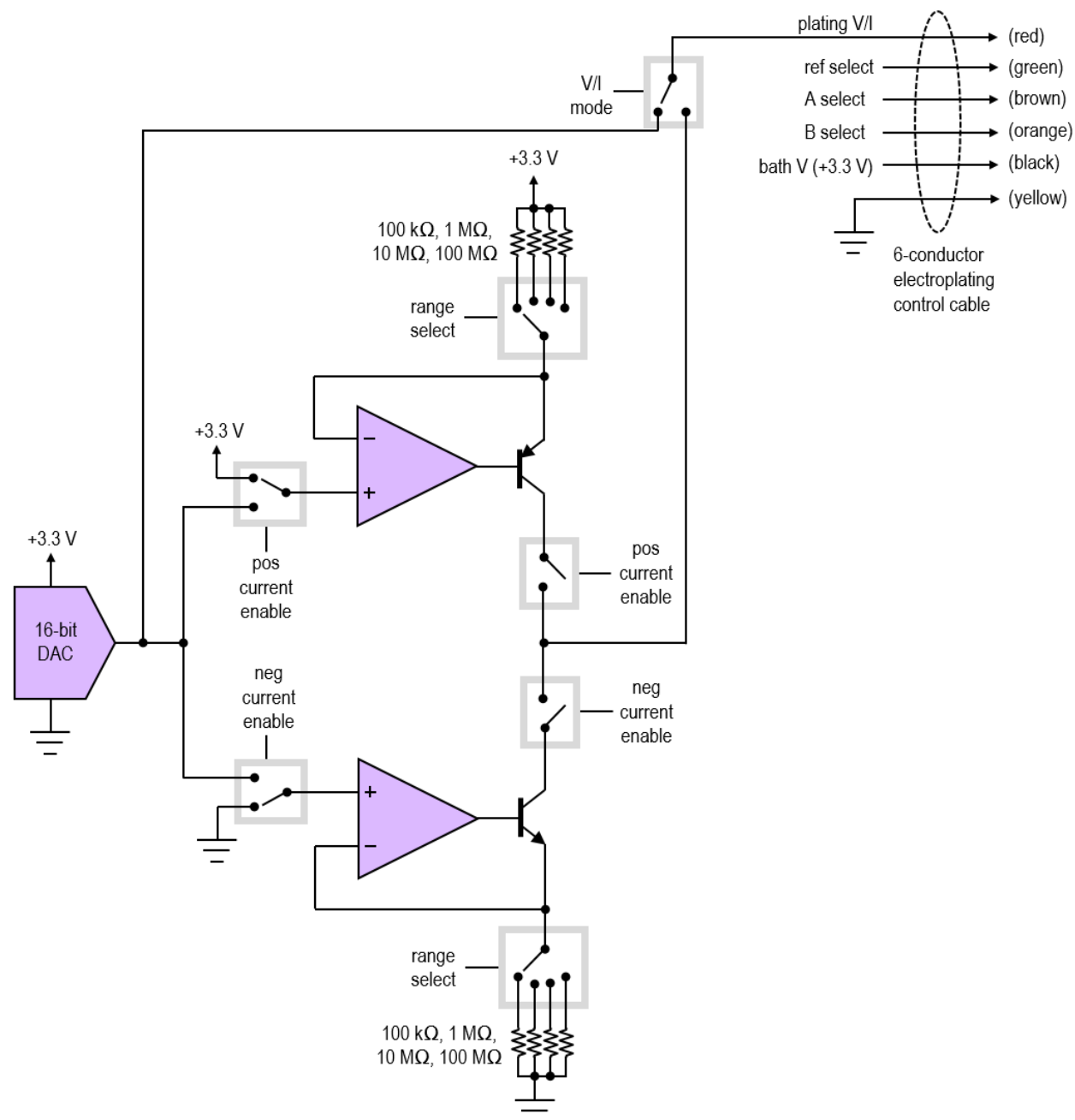
Electroplating Tips

- Microelectrodes are often plated to target impedances somewhere in the range of 100 kΩ to 500 kΩ. Some researchers prefer to use constant voltage electroplating, while others prefer constant current electroplating.
- The voltage required for electroplating will depend on the type of metal used for plating and the material of the reference wire.
- If long pulses are used for plating, a site may become overplated and short to adjacent sites. Use shorter pulse durations if electrode impedances routinely drop far below the target impedance.
- When plating the UCLA silicon microprobes using gold, voltage pulses of 1-2 seconds at voltages between -2.0 V and -2.6 V seem to work well. Alternatively, try 10-second current pulses between -30 nA and -60 nA.
- During electroplating, it is common to encounter "stubborn" electrode sites that do not respond to plating pulses and instead maintain a high impedance. Some researchers have found that raising the electrode out of the plating solution and then lowering it back in sometimes helps with these troublesome sites.
- Most electroplating solutions must be stored in refrigerators at specific temperatures (e.g., 4°C) and expire after a certain amount of time (e.g., one year). Old plating solution should be replaced for best results.
- Plated electrodes may be examined under microscopes. An example of a semi-plated UCLA silicon microprobe is shown below. Unplated sites are flat and shiny, while plated sites are black. The gold deposited during electroplating has a high surface roughness which causes the black color and also the reduced electrode impedance.
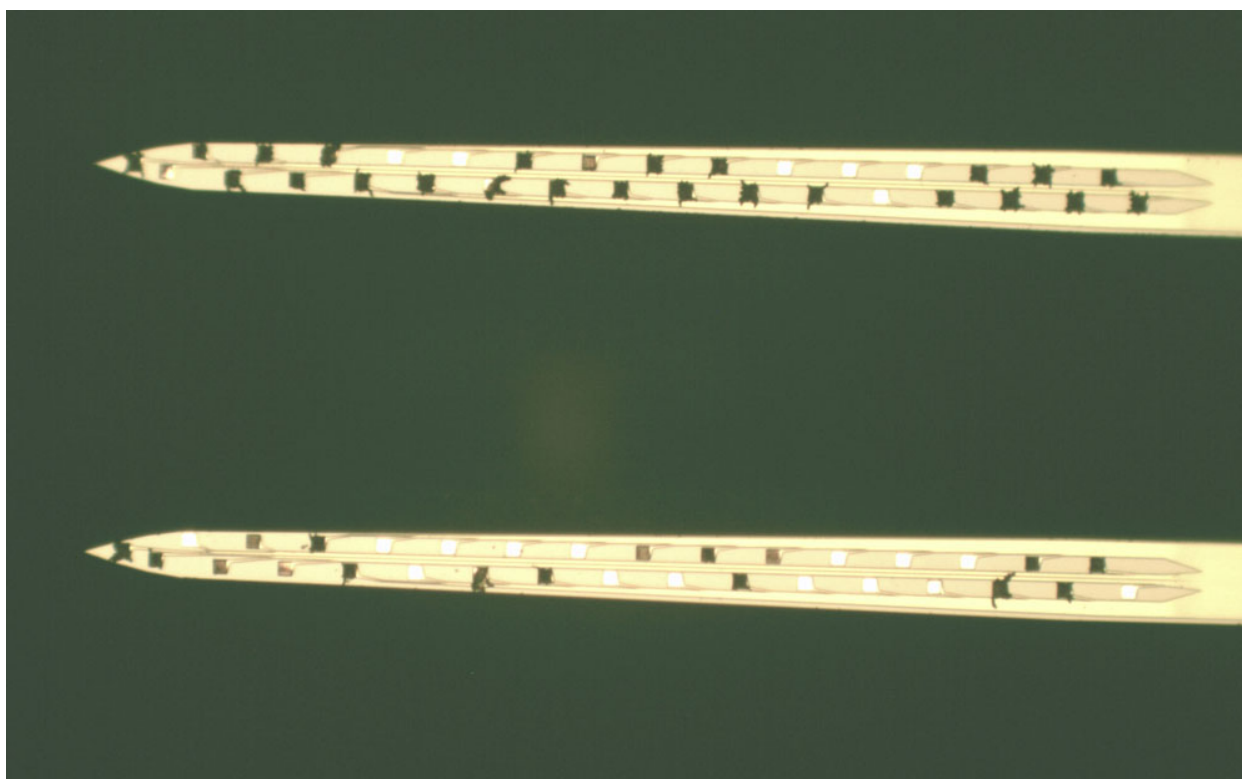
Circuit Design and Operation

This section describes the hardware on the RHD2000 electroplating board that generates plating voltages and currents. It is not necessary to understand this material in order to use the system with the MATLAB GUI software provided. This information is provided for advanced users who wish to modify the software or develop similar hardware.

The schematic diagram below shows a simplified circuit schematic of the hardware on the electroplating board. Switches surrounded by grey boxes are digitally controlled CMOS switches (74HC4052 and 74HC4053 integrated circuits). The amplifiers are OPA4170 rail-to-rail operational amplifiers well-suited for operating from the relatively low (3.3 V) voltage supply. The NPN bipolar transistor is a BC107 and the PNP bipolar transistor is a 2N3964; both of these are general-purpose devices. The DAC is an Analog Devices AD5662 – the same DAC used in the RHD2000 USB interface board. This DAC can produce an output voltage between 0 and +3.3 V.

TTL output	signal	notes
0	**neg current enable**	0: disable negative current 1: enable negative current
1	**pos current enable**	0: disable positive current 1: enable positive current
2	**V/I mode**	0: constant voltage mode 1: constant current mode
3	**range select[0]**	range select[1:0] = 00: R = 100 MΩ range select[1:0] = 01: R = 10 MΩ
4	**range select[1]**	range select[1:0] = 10: R = 1 MΩ range select[1:0] = 11: R = 100 kΩ
5	**A select**	0: operate amplifier board chip A in normal recording/impedance measure mode 1: connect amplifier board chip A (channels 0-63) to **plating V/I**
6	**B select**	0: operate amplifier board chip B in normal recording/impedance measure mode 1: connect amplifier board chip B (channels 64-127) to **plating V/I**
7	**ref select**	0: amplifier board REF = ground (for positive plating voltages/currents) 1: amplifier board REF = **bath V** = +3.3V (for negative plating voltages/currents)

Notes:
- **neg current enable** and **pos current enable** should never both be set to 1.
- If either **neg current enable** or **pos current enable** is set to 1, **V/I mode** should also be set to 1.
- **A select** and **B select** should never both be set to 1.
- If **neg current enable** is set to 1, **ref select** should be set to 1.
- If **pos current enable** is set to 1, **ref select** should be set to 0.
- **ref select** should be set to 0 when measuring electrode impedances.

The RHD2000 electroplating board uses the same Rhythm USB/FPGA interface that is used by the RHD2000 USB interface board. The FPGA on the electroplating board controls electroplating through the use of one 16-bit digital-to-analog converter ("DAC 1" defined in the Rhythm specification) and eight digital outputs ("TTL outputs" defined in the Rhythm specification). The DAC is controlled using the "DAC Manual Input" data stream described in the **RHD2000 USB/FPGA Interface: Rhythm** datasheet available on the Intan Technologies website on the Downloads page. (Technical note: The DACs on the RHD2000 USB interface board are configured to produce voltages in the range of -3.3 V to +3.3 V. The DAC on the RHD2000 electroplating board is configured to produce a voltage in the range of 0 V to +3.3 V, so the conversion factor from true voltage to "DAC Manual Input" value differs between these two boards.)

The functions of the TTL output lines are described in the table above, and shown in the schematic on the previous page.

The switch controlled by **V/I mode** can be used to route the DAC output directly to the **plating V/I** wire which goes directly to the amplifier board. (A simplified schematic of the amplifier board is shown in the **RHD2000 128 Channel Amplifier Board datasheet**. This document should be studied along with this section.) If a positive plating voltage is to be applied to electrodes, the **ref select** line should be set low; this will tie REF on the amplifier board to ground. (The REF terminal will be connected to a low-impedance wire placed in the plating solution.) In this case, the plating solution will be at ground potential (0 V), and the voltage on the electrode will be the voltage produced by the DAC.

If a negative plating voltage is to be applied to electrodes, the **ref select** line should be set high; this will tie REF on the amplifier board to the **bath V** wire, which is connected to +3.3 V on the electroplating board. This will set the plating solution to a potential of +3.3 V, so the voltage across the electrode will be the DAC voltage minus 3.3 V. For example, if you want to plate with a voltage of -1.0 V, set **ref select** high and set the DAC to 2.3 V. The DAC is typically accurate to ±15 mV of the specified value.

To plate with constant currents instead of constant voltages, **V/I mode** must be set high, and either **pos current enable** or **neg current enable** should be set high. Positive and negative current sources are built using an op amp, a bipolar transistor, and a selectable resistor that has a value of 100 kΩ, 1 MΩ, 10 MΩ, or 100 MΩ (set by **range select**). The positive input of the op amp is tied to the DAC, which sets this voltage. The feedback of the op amp through the bipolar transistor forces its negative input to the same voltage as its positive input (i.e., the DAC voltage). This voltage is forced across the selected resistor. The voltage across the resistor sets up a current. No current flows into the negative input of the op amp, so all of the current flows through the

bipolar transistor and hence through the **plating V/I** wire. (The transistor draws off a small amount of base current, but the output current is typically within ±10% of the specified value.)

When generating negative currents, **ref select** should be set high (so that the plating solution is at +3.3 V) and the DAC voltage should be set within the range of 0 V to 1 V. Currents as high as 10 μA can be generated by using the smallest resistor (i.e., 100 kΩ), while larger resistors can be used to accurately generate currents in the nanoamp range. (The rationale for keeping the DAC voltage below 1 V is to allow enough voltage headroom for a voltage drop across the electrode of at least 2 V: the 3.3 V power supply drops across the electrode, then the bipolar transistor, then the resistor. Bipolar transistors need at least 0.3 V from their collector to emitter to function properly.)

When generating positive currents, ref select should be set low (so that the plating solution is at 0 V) and the DAC voltage should be set within the range of 2.3 V to 3.3 V. The current generated will be (3.3 V – DAC voltage)/R, where R is the selected resistor value.

The **A select** and **B select** lines route the signal on the **plating V/I** wire to either of the two RHD2164 chips on the 128 channel amplifier board. Each RHD2164 chip has internal CMOS switches that route the plating voltage or current to one selected electrode. For more information on this functionality, refer to the **RHD2000 Series datasheet** and the **RHD2164 datasheet**.

Both **A select** and **B select** should be held low during electrode impedance measurements. Also, the **ref select** signal must be held low during impedance measurements.

Related RHD2000 Documentation

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

♦ **RHD2000 128 Channel Amplifier Board**

♦ **RHD2000 Series Digital Electrophysiology Interface Chips**

♦ **RHD2164 Digital Electrophysiology Interface Chip**

♦ **RHD2000 Evaluation System**

♦ **RHD2000 USB/FPGA Interface: Rhythm**

♦ **RHD2000 SPI Cable/Connector Specification**

♦ **RHD2000 USB Evaluation System Catalog**

Application Notes:

♦ **RHD2000 Application Note: Data File Formats**

♦ **RHD2000 Application Note: I/O Voltage Level Shifting**

♦ **RHD2000 Application Note: Adapting SPI Cables to a Commutator**

♦ **RHD2000 Application Note: Accelerometer Calibration**

♦ **RHD2000 Application Note: Interfacing a Microphone to Intan Amplifier Chips**

♦ **RHD2000 Application Note: Adding an LED to Amplifier Boards**

Schematics of all circuit boards are available from Intan Technologies.

Contact Information

This datasheet is meant to acquaint engineers and scientists with the RHD2000 Electroplating Board and associated control software 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.
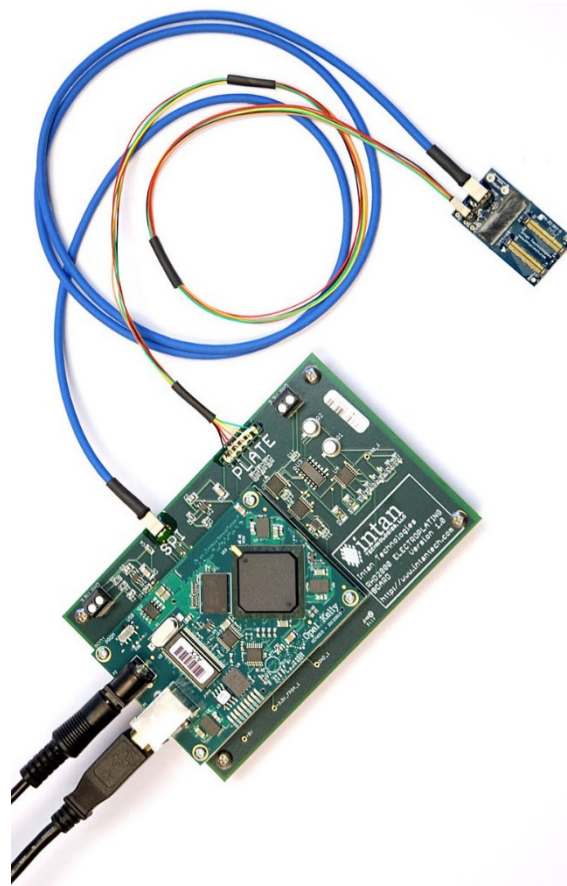
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